Smart Snow Meter

A Major Qualifying Project Report

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Abstract

This project explores the design of a device capable of accurately measuring snowfall height and relaying that information wirelessly to a central location in order to map a given area with real-time data. The project focused on creating a product that is inexpensive, self-sustaining, capable of being spread anywhere necessary and working autonomously.

Current methods of measuring snowfall are ineffective, archaic and require personnel to gather that information visually. The device in mind would improve the efficiency of plow deployment and usage during snowstorms, hence decreasing the high cost of plowing budgets when used in a city-wide approach.

Acknowledgements

Our deepest gratitude to our advisor, Professor Stephen J. Bitar for his advice, guidance and motivation throughout this project. Without his encouraging words during our weekly meetings, this project would not have been able to be brought to life.

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Without their assistance, this project would not have been successful. Thank you!

Executive Summary

The world we live in is becoming increasingly interconnected. Our gadgets, our phones and even our homes are able to communicate with each other; so why not our cities? Smart cities are a concept that have been gaining much support this decade. It is an urban development vision with the purpose of integrating information and communication technology (ICT) and Internet of things (IoT) technology in a secure approach to manage a city's resources, such as transportation systems, community services, schools, information systems, among other services.

Snowstorms have increasingly become a major problem in the Northeast of the United States. An average of 800 people die every year in the US from winter driving crashes according to the NOAA. Snowstorms can cause dangerous driving conditions, and block roads and hospital entries. Cities in states like Massachusetts spend large sums of money in plowing services. Plow deployment effectivity could be improved if cities were able to identify which areas were affected the most on a reliable basis.

Plowing services can be greatly benefitted with a system capable of transmitting snowfall information for a given area reliably and almost instantaneously. Plowing services response time can be minimized, and it becomes possible to identify areas with the most snowfall accumulations. This could potentially decrease accidents that are caused due to lack of a reliable and precise system to estimate snowfall accumulation.

In order to solve this current problem, our team designed and developed the Smart Snow Meter which is capable of measuring snow height through an array of sensors. The device is also capable of sending this measured height of snow and its GPS location wirelessly.

To achieve this functionality of the system, the wireless snowfall detector (Smart Snow Meter) design was broken down into three major modules, namely;

-The Sensor Module

-The Wireless Module

-The Power Circuit

In order to make the device the most efficient and cost effective, background research was conducted in order to design the device taking certain factors in consideration and minimizing the cost of the device while achieving the project goals.

Infrared sensors were used to create the Sensor Module. The Teensy 2.0 microcontroller would process the data from an array of these sensors, and transmit these through a wired I2C connection to the Wireless Module so that it could be sent wirelessly away from the device.

Initial research on the available forms of communication showed that the most reliable and efficient way of sending data is through GSM communications. GSM works through 2-G band, and the coverage is highly reliable in remote areas compared to other options. Our team decided it would be best to implement the most readily available and the lowest cost GSM module, hence the SIM800 was chosen to be the most suitable for this functionality. The SIM800 was enabled by an Arduino Uno which provides the code and input voltage for the board to run. This module was successfully implemented in the device and was able to send the desired data wirelessly to the user.

Power for the device was chosen to be a NiMH battery so as to be able to charge via a solar cell despite cold winter temperatures. A regulatory circuit was setup to allow the voltage of the cell to reach the proper charging voltage for the 3.6 V battery pack. This battery pack is then boosted with a DC-DC converter to raise to the necessary 7V that the Arduino Uno requires.

Finally, the functionality of the entire system was tested and future considerations were made for the implementation of the device. It was concluded that the prototype was able to operate as expected and the system was functional and ran smoothly.

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1.0 Introduction

Snow remains a costly problem to deal with for many cities in the Northeast when Winter arrives. A calm night can turn to sudden feet of snow that can cause panic, dangerous driving conditions and worse. Cities in Massachusetts alone spend upwards of $6.5 million (Egan, 2015) to as high as $35 million for plows to deal with these sudden snowfalls that can occur (Levenson, 2015). The goals of the project were to create a device that is: self-sustained, accurate to the nearest inch, modular, and able to wirelessly relay it's GPS locations along with the height of snowfall at that area. A device such as this would allow the improvement of the efficiency of plow usage during snowstorms, thus lowering the high cost of a plowing budget and increasing its efficiency. To fulfill this goal, the team had set out to create a product that would be inexpensive to manufacture so that it could be spread out around a city, and had the ability to relay the height of the snow to a centralized location that can use that city-wide information to locate where the plows would be most effective in clearing snow first.

This report covers the whole process that the team underwent from start to finish. It first details background information on snow, prior art in the field, and the technologies that were necessary to research in order to bring this device to reality. This report also details the methodology and the system design of the product as the team went through the process of prototyping, testing different parts and creating an optimal system. Lastly the report contains the findings of the project, and the conclusion and further considerations that the team recommends be used to improve the device in future implementations.

2.0 Background

There was information that the team needed to obtain before prototyping of the device could start. In every process of solving a problem there are many questions that have to be answered. For our purpose, this includes questions such as: What is the purpose of this device, how would the device function and who would the market be? Through research, all these questions were answered. For the scope of our research relating to snow data, New England will be the main focus.

2.1 Snowfall Information

It is very important to understand the weather and how it behaves in order to design a product that is able to work uninterruptedly in such harsh conditions. The team had researched several aspects of the weather conditions in the New England region which are detailed in this section. These include: Physical properties of snow, average snowfall, average snow accumulation, average winter temperatures, the length of winter season and lastly the team needed to understand how many months in a year the device would be utilized.

2.1.1 Physical Properties of Snow

The physical characteristics of snow were researched as to see if this would cause any concern further down the road regarding error involved in calculating the height of snow. Snow is an insulator, an energy bank, radiation field, reservoir and a transport medium (Jones, Pomeroy, Walker, & Hoham, 2001). These characteristics of snow needed to be taken into account when building the device, as they present factors crucial to the design. The readings will be determined by the snow present around the device, therefore it is essential to understand snow's physical properties.

Snow is an energy bank as it stores and releases energy (Jones, Pomeroy, Walker, & Hoham, 2001). Snow is affected by changes in the environment such as rising temperatures and the surrounding that it lands in. Due to this constant change in the environment, snow absorbs and releases energy during the year. (Jones, Pomeroy, Walker, & Hoham, 2001).

Some of snow's properties that will be taken into consideration include radiation. "Cold snow reflects most shortwave radiation and absorbs and re-emits most long-wave radiation (Male, 1980)". This property can be best exemplified during light storms, in which the reflectivity of snow is much less because of the change of physical properties of snow. (Jones, Pomeroy, Walker, & Hoham, 2001). The change in reflection could potentially impact the results obtained using the sensor reading.

Another property of snow is insulation (Jones, Pomeroy, Walker, & Hoham, 2001). his property affects snow's composition because it can lead to substantial gradients in terms of temperature (Jones, Pomeroy, Walker, & Hoham, 2001) Additionally, when snow sits on the ground for a long period of time, it gives the opportunity for different organisms to emerge and live in the top layer of the snow. The measurements of snow that are currently obtained for snow depth take in consideration these two aspects of snow.

Additionally, snow is essentially water. Water is the main provider of food sources for living things. This increases the influence of organisms on the sensor readings also.

The last of the characteristics that need to be taken into account is that snow acts as a transport medium (Jones, Pomeroy, Walker, & Hoham, 2001). In other words, when snow falls into the ground, different mediums of transportation and road-cleanup might shift the snow to piles in one location. A technical perspective on this aspect is that the flux of the snow is in continuous change.

Finally, snow is greatly affected by external factors from the environment. Because of its physical properties, and the lack of consistency in the essence of snow, errors in snow depth readings are likely to occur.

2.1.2 Average Snowfall

In finding how useful such a device will be, the team needed to identity the number of days on average it snows per year and how much snowfall accumulates during those times. Using the table in Figure 1, you can see that it rarely snows even five inches most days that it will snow. Having a resolution of one inch on our device will be best as that is what most weather reporting agencies use when discussing snow. What the team gains from this chart is an understanding that the region from one inch to three inches will be the most important as opposed to the region that is five inches and up.

1 inch 2.5 cm	3 inches 7.6 cm		5 inches 12.7 cm	10 inches 25.4 cm
4.6	1.6	January	1.0	0.1
3.7	1.6	February	0.7	0.2
2.7	1.2	March	0.7	0.2
0.7	0.2	April	0.1	0.1
0.1	0.0	October	0.0	0.0
0.7	0.4	November	0.1	0.0
3.2	1.6	December	1.0	0.2
15.7	6.6	Year	3.6	0.8

Figure 1: Table of Number of days per month and year on average in Worcester with a total snowfall of at least 1, 3, 5 or 10 inches (Worcester Snowfall Totals & Accumulation Averages, n.d.)

2.1.3 Snow Accumulation

In order to decide how the device needs to operate, snow accumulation was researched. The team initially considered using the device to subtract the previous amount of snow (the accumulation) from the total height and find the amount of snow that fell. It was concluded that this would not be an accurate way to measure snowfall, mainly because the snow accumulated gets compressed by the weight of the newly-fallen snow, not providing an accurate measurement. This became even more relevant once the team looked over the data showing the average monthly snow accumulation in Worcester as seen in Figure 2. The greater snowfall accumulation averages provide for greater error if the newly-fallen snow is measured directly on top of the accumulated snow. In order to prevent that from happening, the team suggested that the snowfall measurement be collected after the accumulated snow is cleaned. The figure below shows the average monthly snowfall accumulations during the winter months.

1 inch 2.5 cm	3 inches 7.6 cm		5 inches 12.7 cm	10 inches 25.4 cm
16.7	10.6	January	7.6	2.5
16.0	11.4	February	7.6	2.7
9.4	5.5	March	3.5	1.5
1.4	0.9	April	0.5	0.3
1.8	0.9	November	0.4	0.0
11.3	5.9	December	1.9	0.4
56.6	35.2	Year	21.5	7.4

Figure 2: Table showing Average total days per month and year in Worcester with snow depth of at least 1, 3, 5 or 10 inches on the ground (Worcester Snowfall Totals & Accumulation Averages, n.d.)

2.1.4 Average Winter Temperatures

In order for the device to be fully functional, winter temperatures had to be taken into consideration. Temperatures in Massachusetts go down to an average of 17°F in January (Climate Worcester- Massachusetts, n.d.). However, accounting for wind chill, they can reach low temperatures of -44°F which occurred on a day that was already at -16°F (Bombard, 2016). To account for this low temperature, the team had to keep in mind to keep the battery at higher temperature ranges so that it was able to discharge and for a charging circuit we had to keep the device at an even higher temperature (usually 4°F) so that it can recharge the batteries.

2.1.5 Winter Season Lengths

In terms of the calendar, the season of winter is 3 months. However, as seen in Figure 3, for many parts of the USA snowfall start to fall as soon as September (Erdman, 2016).

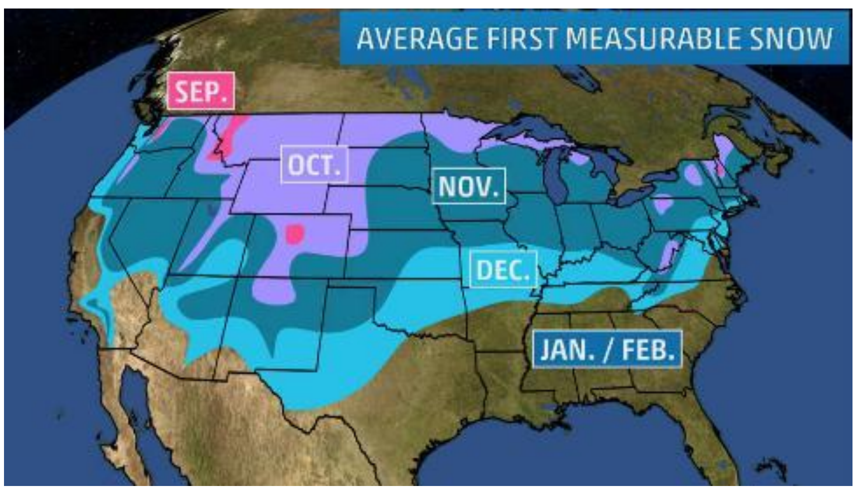


Figure 3: Map of USA Average First Measurable Snow (Erdman, 2016)

Research into the average first-snow to last-snow was important to gauge how long a device like ours would have to be powered in a worst-case scenario. In our research, we found that the snow season can vary widely with the extremes being a start as early as November (Erdman, 2016) to as late as April as seen in Figure 4. This was important to take into account for battery longevity as for the device, one set of batteries were chosen for an entire winter along with a solar charging circuit. Since the project is in respect to the New England, the group can determine that winter will last approximately four months here.

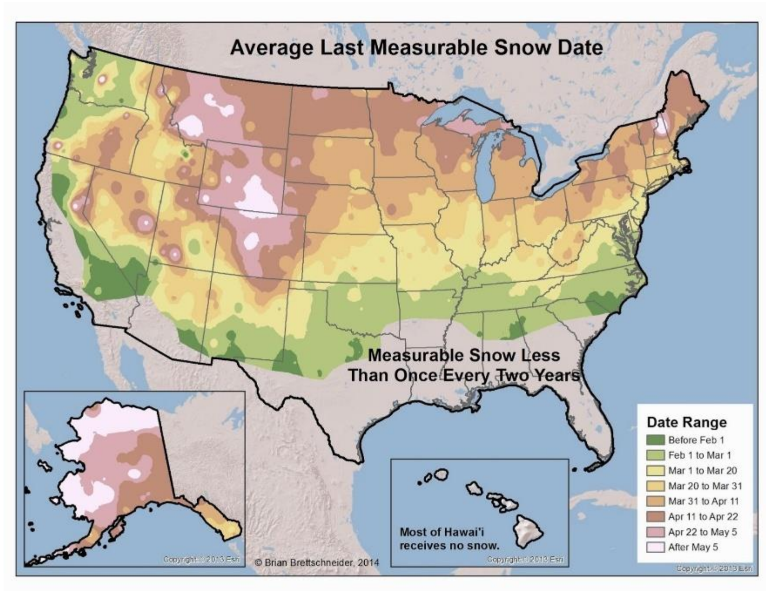


Figure 4: Map of USA Average Last Measurable Snow Data (Burt, 2014)

2.2 Snow Height Detection Methods

The major part of this device is how it measured snow height. There are three differing procedures that the group focused on for this application: physically checking, capacitive sensing, and optical sensing. Physical related to the current way snow is commonly measured to get an accurate reading by manually examining the snow. Capacitive sensing referred to using the capacitance of copper altering when snow was sensed to be in proximity. The last was a more optical approach, whether it be infrared sensors or photoresistors.

2.2.1 Physical

The current way sensing is done for weather services is usually by hand with a ruler (DeRusha, 2009). In special cases, they also use a rain gauge, and melt down the snow to get an equivalent height (DeRusha, 2009). The ruler method is accurate as long as the snow doesn't have much wind to cause drifts and discrepancies to the measuring local area (DeRusha, 2009).

A rain gauge, as seen in Figure 5, is much more precise in that case, however it has the same issue as the ruler, in which you have to physically be at the location to take a reading. It also has the issue of needing to expend time and energy to melt down the snow and convert the volume of the liquid water to a height reading of snowfall.

Figure 5: A rain gauge shown in use (Finn Valley College, 2011)

Some of the current most prevalent precipitation measurement errors are divided into systematic and unsystematic (Jones, Pomeroy, Walker, & Hoham, 2001). Unsystematic errors in snowfall measurement can be induced by human error. The current methods lack computational precision for the measurements made. Systematic errors include site and location type of errors. These are the errors previously described that are caused by wind drafts and which therefore may generate inaccurate measurements. “The current methods of snowfall measurement, such as gauge-measured precipitation, can have an error larger than 10% for solid precipitation” (Legates & DeLiberty, 1993).

Currently, gage-measured precipitation accounts for the fact of the losses involved with snowfall. These losses include: wetting loss, evaporative loss, and for trace precipitation. There are specific gage equations used to estimate these losses such as following that is most commonly used:

$$P_c=K(P_g+\Delta P_w+\Delta P_e)+\Delta P_t$$

Pc is the bias adjusted precipitation estimate. K is the adjustment coefficient for wind-induced gage under catch ($K\geq 1$). P_g is the gage-measured precipitation; ΔP_w is the adjustment for wetting loss due to water adhering to the sides of the gage. ΔP_e is the adjustment for evaporation and ΔP_t is the adjustment for trace precipitation.

The study "Bias Adjustments to Arctic Precipitation" showed that the relationship between wind speed at gage height and solid precipitation adjustment factor scales up at an almost exponential level, as seen in Figure 6.

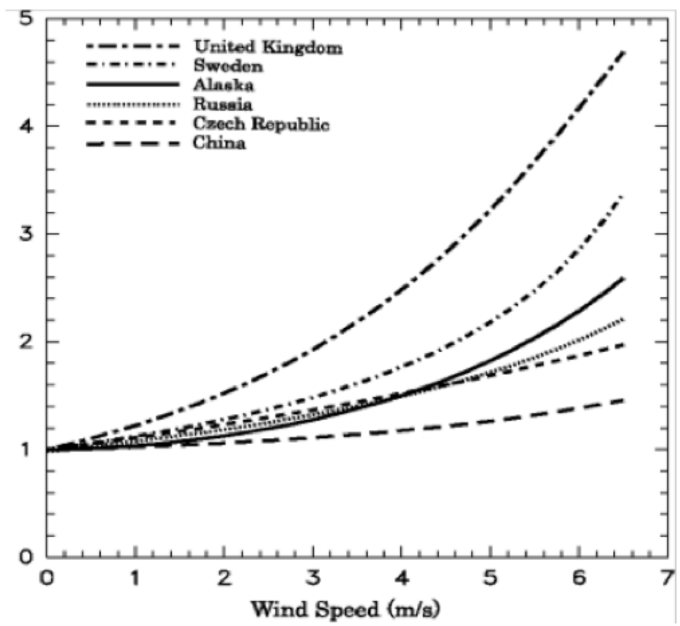


Figure 6: Relationship between solid precipitation adjustment factor (K) and wind speed at gage height (m/s) (Legates & DeLiberty, 1993)

2.2.2 Capacitive Sensing

This method of sensing relies upon the value of capacitance changing based on the dielectric separating two copper plates being used (Texas Instruments Incorporated, 2014). In practice, there are two copper plates used in a parallel finger position as seen in Figure 7, and those will normally have air as the dielectric separating the excitation and the sensor (Texas Instruments Incorporated, 2014). When an object comes in proximity to these plates, the charge changes and this is analyzed and interpreted to height of the object.

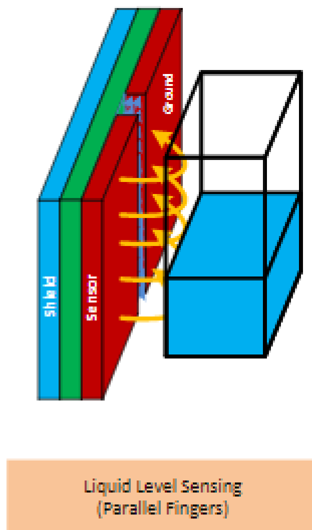


Figure 7: Parallel Finger configuration for capacitive sensors (Texas Instruments Incorporated, 2014)

2.2.3 Optical

Optical sensors were considered for the design. Photoresistors, as seen in Figure 8, are often used as sensors due to their property of their resistance changing when covered from light or exposed to higher levels of light of certain wavelengths (Resistor Guide, 2016).

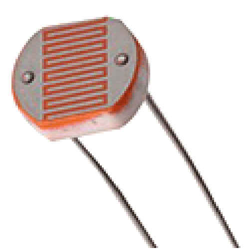


Figure 8: Photoresistor (Resistor Guide, 2016)

Infrared sensing was another type researched regarding optical sensing. This relied upon a two-part sensor as shown in Figure 9. The first being the source, usually an infrared LED, and the other being an infrared detector, usually a photodiode (Electronics Hub, 2015). This works by placing both units side by side, and when there is an object against the surface of this group, it will block and reflect the light from the LED into the sensor giving a readable change in value (Electronics Hub, 2015).

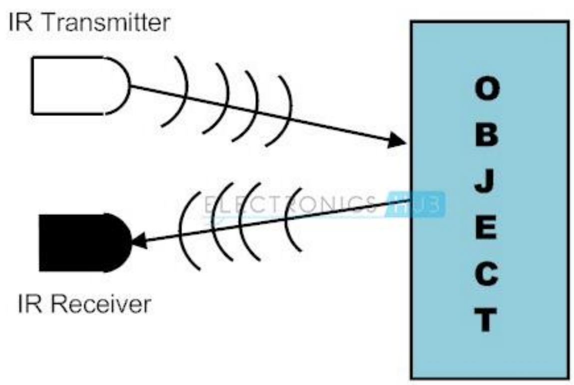


Figure 9: Infrared sensor system (Electronics Hub, 2015)

2.3 Preliminary Design Components

A general framework of what design components were needed for the product so that the team could determine how it would function. A product to meet the goal of measuring snow and transmitting it to a non-local area was determined to require: microcontrollers, sensors, batteries, a means of communication, and a structure. They were explained further in depth in their respective sections.

2.3.1 Microcontroller

Microcontrollers were the logic centers of the Smart Snow Meter. These needed to connect all the other parts of our design together so that it operated as efficiently as possible. While integrated circuits are powerful, this device had the goals of sending data to a distant location, and using a communication device required usage of a microcontroller as well to process that data before it was sent out. Due to size constraints, it was ideal to keep the device as low-profile as possible. Small microcontrollers were the preferred option such as the Teensy 2.0. The Teensy 2.0, seen in Figure 10 is a third-party continuation of the popular Arduino Nano (Teensy USB Development Board, n.d.) which was the preferred direction to go in terms of microcontrollers as they have useful libraries.

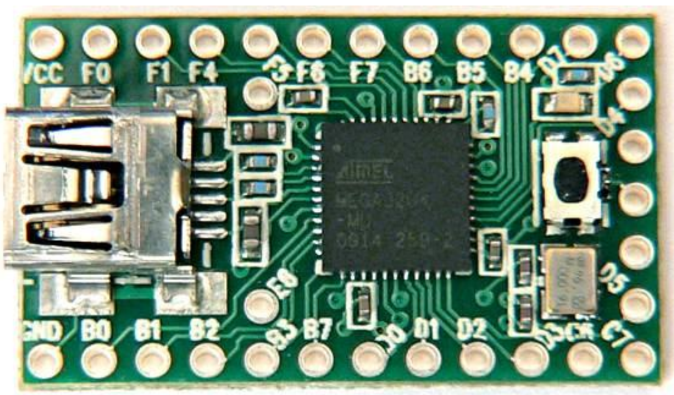


Figure 10: Teensy 2.0 product sold by PJRC (Teensy USB Development Board, n.d.)

2.3.2 Sensor

The device's main goal was to measure snow height. To this end, many sensors were needed to gauge snow at different heights so that an up-to-date and accurate reading can be taken and transmitted. For sensing, the team looked into capacitive sensors, shown in Figure 11, and optical infrared sensors, shown in Figure 12. An alternative means of sensing was explored using solar charging as a sort of detection method. This was deemed not accurate enough due to night time occurring and causing the same effect in the solar film as when covered.

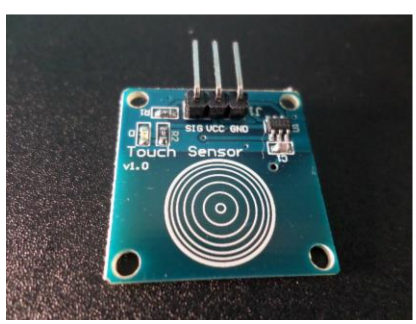


Figure 11: Arduino Capacitive Touch Sensor sold by Resistor Park (Arduino Capacitive Touch Sensor, 2016)

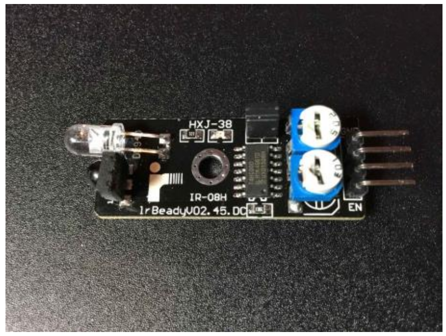


Figure 12: IR Infrared Obstacle Avoidance Sensor sold by Resistor Park (IR Infrared Obstacle Avoidance Sensor, 2016)

2.3.3 Power

The device required a supple amount of power in order to operate during the winter. The team considered various powering options. A very easy and convenient way to power the device would have been to use energy from the electric grid. However, the team came to the conclusion that the need for the device to be able to be portable, was more important than the convenience that drawing energy from the electrical grid would be for the project. The team wanted the product to be easy to use and install, and be able to be placed at locations where connections to the grid might not be possible, such as parks and fields for example.

The group decided on recharging the device's battery using solar energy to maintain the device all through winter. There were only two alternatives that seemed relevant if the team was to pursue this idea. In the first, the team would have to use a solar panel such as Figure 13, that would need to be placed on top of the device and would be able to produce enough current at an adequate voltage to charge the battery during the diminished daylight hours of winter. The group concluded that using this approach would make the installation of the product more difficult.

Figure 13: 6V 0.5W Solar panel (6V 0.6W Solar Panel Module DIY Small Cell Charger For Light Battery Phone, n.d.)

The second alternative would be to use thin-film solar cell around the body of the device. Thin-film solar cells are flexible, which would allow the group to place the cell around the body of the device. Thin-film solar cells, shown in Figure 14, however, have lower efficiency rates: cell efficiency in production modules currently range from 6%–12% (Appleyard, 2009). Some thin film materials have shown that degradation of performance over time and stabilized efficiencies can be 15-35% lower than initial values (Bergethon, n.d.). Additionally, placing the flexible cells at a 90° angle would not provide for the most efficiency.

Figure 14: Thin solar film (Ayre, 2012)

Therefore, even with the difficulty previously discussed, the team concluded that using a rechargeable battery and a solar cell to allow it to last all through the winter was the best option going forward to meet the goals set.

While choosing the batteries only two types of battery seemed right for this application: NiMH (Nickel Metal Hydride) or Li-ion/Li-Po. The team has chosen the NiMH over the Li-ion because of several reasons. The first is that Li-ion batteries require a protective circuit, it limits voltage and current, in order to use the battery safely (Battery University, 2016). Without a protective circuit, the battery might become volatile and even explode (leakeem, 2017). Though Li-ion batteries are more energy dense than rechargeable NiMH batteries, they often come in lower capacity packs (leakeem, 2017). NiMH batteries come in various shapes and they can easily be combined in series to fit the needs of the project (leakeem, 2017). Another major setback to Li-ion batteries are that they cannot be completely discharged without the risk of permanent damage being done to the battery (leakeem, 2017). With both batteries performing well in cold temperatures, having low discharge rates, the team concluded that NiMH would be a better fit for the project (leakeem, 2017).

2.3.4 Means of Communication

The goal of transmitting the data obtained by the product to an offsite location required a means of communication to get this data to that spot. As mentioned for the power, due to needing changes in infrastructure, the idea of having wires run from a city-wide grid was not feasible. This left the method to wireless communication. Protocols that were researched are detailed in the Communication section.

2.3.5 Structure

In regards to structure there was a need for some form of housing so that it can withstand the brutality of winter while still being operational. The structure had to also keep the Smart

Snow Meter upright, because it can't measure snow height if it has fallen over. To this regard, we looked into three designs to keep the device upright. These were inspired from form factors that already exist from products that stand upright.

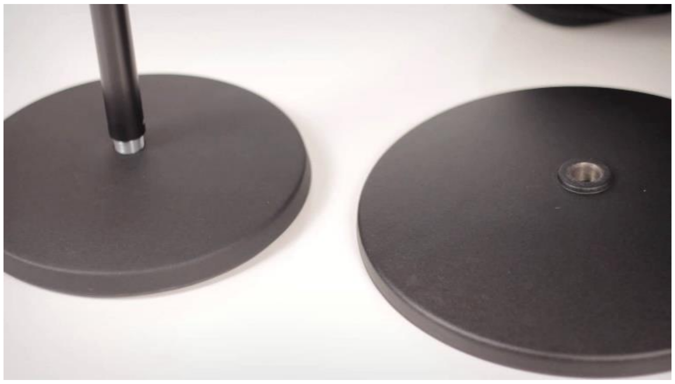


Figure 15: Mic stand showing an example of a flared bottom base (Connolly Music Company, 2014)

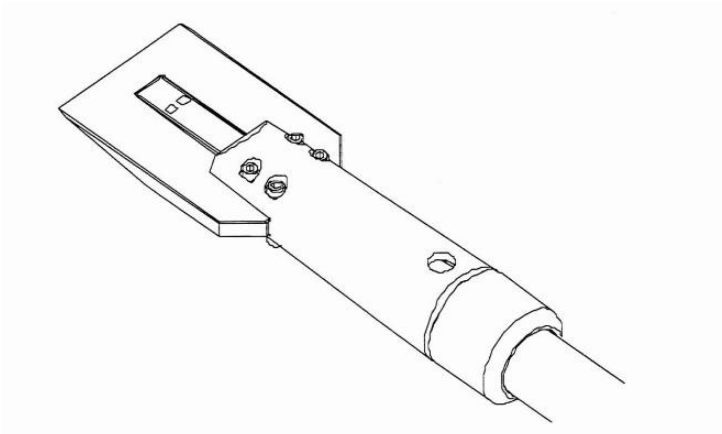


Figure 16: Wedge tip of a ground penetrating probe (Michel U. Louge, 1998)

The first is where the product would have a flat base that rests on the ground as seen in Figure 15. The second would be to have a wedge at the bottom so the product has to be dug into the ground such as the product in Figure 16. The flat base would allow for an exact bottom so that the snow would be exact when measured, however still has the potential of being moved, or tipped over if enough force is used (wind for example). The wedge however, would fit more with the modular design that the product is being considered for, and provides more space in the structure and opens the possibility of storing components underground if we pursue that path. The third is a metallic corkscrew, such as the Auger in Figure 17, that would allow the device to stabilize in the ground as it supports the weight of the entire device. One important consideration that needed to be taken into account was the height of this supporting structure if it changed the measurement from the ground.

Figure 17: Auger being used as an example of a Corkscrew base that would brainstormed (Harbor Freight, n.d.)

2.4 Communication

The Smart Snow Meter had two connections, one internal and one outgoing. The first was a local connection that will be from the head module in the device to the sensor modules. These sensor units were created to be modular (in accordance with the goals set) and can be disconnected and connected at will, but all needed to communicate with the main head module for when snow is blocking them so that the height would be established. The other connection was from that head module in the device to an outside location so that the data from multiple units would be gathered and plotted on a map on an outside application. Both of these uses required different protocols due to the distance of each, so many varying systems were looked into and were split between the following three sections: wired, wireless and cellular connection.

2.4.1 Wired

The sensor module to head module connection was the only one that could be wired. Due to the fact that the number of sensor units being attached varies due to the modular design, the group would need a protocol that works independent of the number of slave-connections on the line. To this end, I2C and SPI were the obvious contenders. Wired was determined to not be optimal to use for the head unit to an outside application due to the need for major infrastructure costs that would go against the ease and cheap cost of the device as pursued in the team's goals.

I2C is a serial protocol in which it only requires two lines going to each slave device from the master (SFUptownMaker, n.d.). One is a data line, while the other is a clock line as shown in Figure 18 (SFUptownMaker, n.d.). This is ideal as we would only need two pins associated to this task, which taking into account the small form factor of everything, is better than 4+ pins being used if SPI was selected (SFUptownMaker, n.d.). Wired connections are always more power-conscious than wireless and the decision to make one of the two communication sections in our project wired helped conserve a lot of power that was necessary in making our product last longer in the winter.

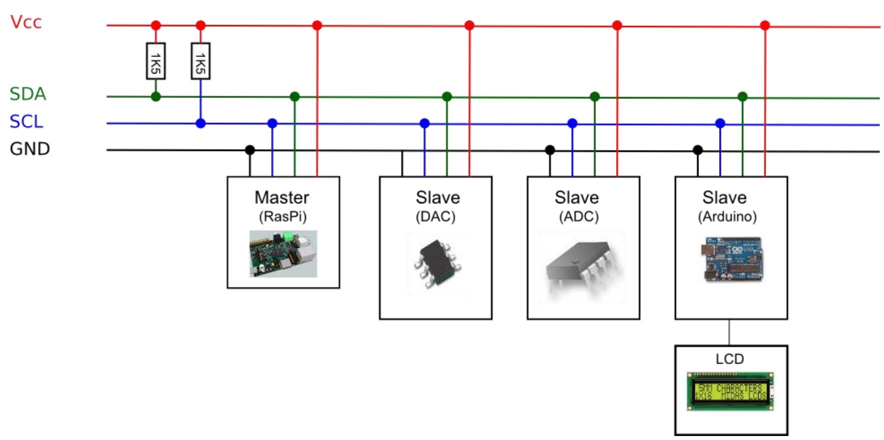


Figure 18: Example of a circuit using I2C (I2C and SPI, n.d.)

2.4.2 Wireless

Wireless is the main idea that is thought of when the term “communication” is heard. It is convenient as it allows for better organization. This allowed less wires to have to be routed throughout the product, which led to less tangling between the wires. For this product, the team looked into Bluetooth (normal and LE), ZigBee wireless, wi-fi adapters and using cellular network as methods to send outgoing data. While it was considered for the local communication of our device, the huge increase of price for a connection that was less than two feet in our device was a very big detriment pushing us to the aforementioned wired connection.

Bluetooth was researched due to its dominance in everyday products. Its downsides were that it is low-range, which would work for our sensor unit to head unit, however in that case the team was dealing with a master to multiple slave network in which the master unit would have to select which slave to listen to at each point. Bluetooth, with its max range of ~100m (Sponås, 2016) is nowhere large enough to cover an entire city, which was our goal, so it was not considered for the head unit to outside application selection.

ZigBee wireless was another local-area connection considered. Working similar to Bluetooth, ZigBee has become popular also due to its low power usage and fast transfer rate (RS Components, 2015). It has a similar range of only ~70m (Poole, n.d.), so the same problem exists for the local connection in the team’s device. The major downside in this protocol is the fact that it’s cost is even more than that of Bluetooth modules, being a minimum of $23 for a singular module (Adafruit, n.d.), which will be immensely expensive for a full-fledged product and makes it as undesirable as Bluetooth.

Connecting to local Wi-Fi was also an option considered for the Smart Snow Meter to get its data to an application, however there is no guarantee of Wi-Fi being anywhere near where this would be placed, meaning that it would heavily limit where it could be placed as much as it were wired. As this goes against the goals of having this device able to be placed anywhere, it also was deemed undesirable.

The last consideration is the strongest. A cellular connection allowed complete mobility for the product while having a stable connection. This required a sim card with GSM data capabilities, but after that and a GSM module were attached, it allowed for a stable connection outward. This option's cost depended on the data usage, however when we limited what we send out, it had the potential to be the strongest contender for connection protocol.

2.4.3 Cellular Connection

Further expanding on the cellular network choice, the team researched GSM. Gsm is the first, and still, most popular cellular network standard still in use. It was established in 1982 (Venkatesan, 2013). GSM consists of three parts: General Packet Radio Service (GPRS), Enhanced Data Rates for GSM Evolution (EDGE), Global Positioning System (GPS). GPS receivers are used for navigation, positioning, time dissemination and alternative analysis. The following image shows a GPS Control Monitor:

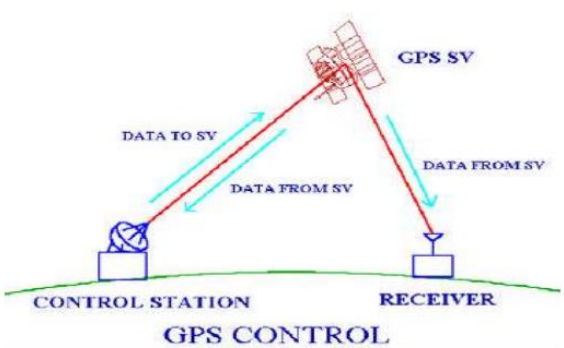


Figure 19: GPS Control Monitor (Venkatesan, 2013)

2-G TDMA standard sponsored ETSI is a special group under GSM. In the 1990's a debate took place between TDMA and CDMA in terms of capacity for 2G cellular networks. Around the same time, developing countries started planning for cellular networks and most of them accounted for 2G GSM TDMA digital cellular technology (Pahlavan & Krishnamurthy, 2013).

From the following Figure, it is clear that in terms of mobility, for outdoor applications, either 2G, 3G or 4G are the most reliable networks of communication (Pahlavan & Krishnamurthy, 2013).

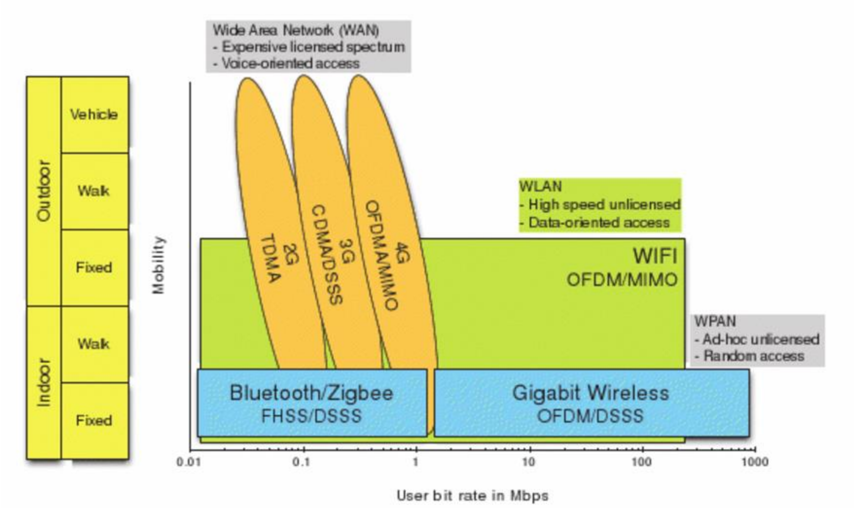


Figure 20: Various communication protocols compared by mobility and bit rate (Pahlavan & Krishnamurthy, 2013)

Furthermore, the elements of information technology are depicted in the following Figure 21. The following image depicts the relationship between the device, application and network and the connection among these. This breakdown will be considered when developing the Prototype for the GSM Module.

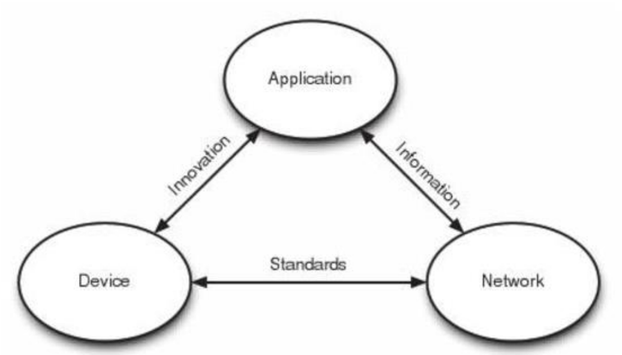


Figure 21: Relationship between Devices, Applications and Networks (Pahlavan & Krishnamurthy, 2013)

The following picture depicts the samples of licensed and unlicensed band spectrums in the United States. In terms of power using 2G, 3G are the most inefficient, but in terms of frequency, it uses the lowest frequency bands (Pahlavan & Krishnamurthy, 2013).

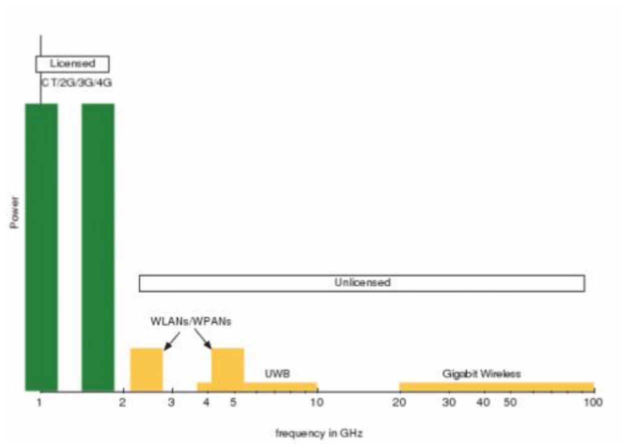


Figure 22: Power Usage vs Frequency for Communication Protocols (Pahlavan & Krishnamurthy, 2013)

2.4 Internet of Things

The Internet of Thing's main scope is to connect everyday objects and embedding intelligence with the user's environment (Gubbi, Buyya, Marusic, & Palaniswami, 2013). It refers to the "networked interconnection of everyday objects" (Gubbi, Buyya, Marusic, & Palaniswami, 2013). In other words, The Internet of Things concept encompasses the idea that information is transferred through platforms and the user can access this information remotely. Some of the common products that fit into the concept include smart phones, smart watches, smart thermostats, common appliances connected to the Internet network.

The concept of Internet of Things came about the 1980's when the popularity of phones started to increase and wireless networks became fundamental. In the 1990's, wireless local area network technology emerged. This allowed for mobile computing to connect laptops at homes and small office networks. In the year 2000, wireless personal area networking technology allowed connectivity of sensors that could allow for connectivity to the Internet of Things (Pahlavan & Krishnamurthy, 2013).

The IoT has presented several demands in terms of incorporating "intelligent appliances" to human's environment. The IoT has several demands in terms of embedding intelligence into the user's environment. The first demand is a shared understanding of the situation of its users and their appliances. In other words, it is the need to understand to a better degree the connection between the user and the appliances he or she uses every day. The second one is to develop software architectures that are capable of conveying information. The third demand is to implement analytics tools that aim for autonomous and smart behavior. In other words, these tools will be run by a computer program and save time and human effort to obtain specific data. With these demands, smart connectivity is enabled and it is possible to develop computer programs that solve day-to-day activities (Gubbi, Buyya, Marusic, & Palaniswami, 2013).

The definition of Internet of Things now includes a more inclusive wide range of applications in healthcare, utilities, transport, etc. "Fueled by the prevalence of devices enabled by open wireless technology such as Bluetooth, radio frequency identification (RFID), Wi-Fi, and telephonic data services as well as embedded sensor and actuator nodes, IoT has stepped out of its infancy and is on the verge of transforming the current static Internet into a fully integrated Future Internet" (Pahlavan & Krishnamurthy, 2013). As mentioned previously, IoT's main goal is to have computer sense information without the aid of human intervention.

Furthermore, there has been a radical evolution of the Internet into a connected network of interconnected objects. This revolution obtains information from sensing the environment and hence has an interaction with the physical world (through processes like actuation, and command and control). In addition to this, it uses the Internet standards to provide services that include information transfer, analytics, communications and applications. “IoT has transformed the current static Internet into a fully integrated Future Internet” (Pahlavan & Krishnamurthy, 2013). It is fueled by the prevalence of devices that are enabled by wireless technology.

2.5 3-D Printing

One topic that the team researched with regards to the structure of the device was the use of 3-D Printing to allocate the electric components inside the prototype. 3-D printing manufacturing process builds products layer by layer through a series of cross-sectional slices. It can be defined as “a type of technology which employs additive manufacturing along with stereolithography, fused deposition modelling, and selective laser sintering” (Schniederjans, 2017) [Mellor et al., 2014].In addition to this, all 3-D printers use CAD software that “measures thousands of cross-sections of each product to determine exactly how each layer is to be constructed” (Berman, 2012). Moreover, 3-D printers are able to generate simple products in a relatively short amount of time (usually in less than 1 hour). 3-D printing is also capable of generating products with free-moving capabilities.

3-D Printing is distinguished from other prototyping technologies due to two characteristics: Cost and production through computer-aided design (CAD) software (Berman, 2012). 3-D printing uses readily-available supplies that can be purchased from a small number of vendors.

Moreover, 3-D printing has been compared in multiple instances with mass customization, which has enabled firms to build products in small quantities. However, these are very different in terms of production, as their manufacturing technology and logistics requirements are not the same. Mass customization customizes computers by assembling “pre-assembled modular cards” that include combinations of cards, hard drives, microprocessors, and others. 3-D printing, in the other hand used CAD software to manufacture the embedded technologies to print objects by fusing a variety of materials with a laser. Some examples of materials that can be used to print models using 3-D printing include: plastics, resins, super alloys, titanium, ceramics and polymers.

In 3-D printing, the manufacturing process is automated based on CAD software. According to the chief executive officer of 3D Systems Inc., a maker of 3-D printers, the technology does not require constant attention by an operator, or jogs or fixtures to create a part: "All you have to do is load a file and you can replicate shapes that are not manufacturable through traditional methods… I call it a flexible factory in a box" (Berman, 2012).

Another advantage of 3-D printing is the minimization of inventory risk: The products are made after the order has been already paid for. Hence, 3-D printing improves working capital management. In conclusion, 3-D printing provides the unique ability for manufacturing innovative and customizable designs.

3.0 Methodology

After the team had researched and obtained a grasp on the overall picture of the project, the next step was to determine which parts would be chosen to create the device. The goal of the device was to be as inexpensive as possible and still have a self-sufficient array of smart sensors that would transmit the height of the snow at certain locations around a centralized area. To achieve these goals, the team had to determine what the ideal components would be for the following: microcontrollers, sensors, long-range communication, batteries, solar panels and structure choices.

3.1 Microcontroller

The microcontrollers were the main components of the whole device. They tie together all the other modules and had two main uses for the product. They would take in data from the sensors to detect the height of the snow, and also transmit that data along with the GPS coordinates to an external application. For the former use, it did not need to be a very powerful microcontroller. As many have large development boards, one with a small profile was desired. Considering that this microcontroller for the sensor unit needed to communicate with the head module with some protocol such as I2C, it needed to have the capability for that to occur. Existing libraries would make this task easier and thus were desired. As for the latter usage, a different microcontroller was necessary to be obtained to communicate with the GSM and GPS module and also drive it as it the transmitting will likely require a higher voltage (3.7V-4.2V) than what would be output by the team's batteries (3.6V) (Wijethunga, 2015).

3.2 Sensors

The sensors of the device were what gives it the ability to properly detect the height of the snow. As such, the team needed to take many capabilities of different sensors into account. Of the features that were considered, the sensors precision was what was most desired. This whole device was deemed to be useless if it could not accurately detect the difference in snow that is 2 inches high and snow that is 4 inches high. Cost, power usage, and reliability were also taken into account when deciding what sensors the team would test to determine which would be put into the device.

3.3 Long-range Communication

It is important for the device to connect to a network in order to communicate the data obtained from the sensors. When considering the available communication bands, different factors have to be considered such as reliability, coverage, signal to noise ratio and power. It is important for the band to be reliable because the information from the device has to be transmitted continuously and the user should be able to access this information at any time without discontinuities. It is important for the band to provide the best coverage for the device as these could be placed in remote areas, and will still need to send the data. Furthermore, the signal to noise ratio is a significant factor, as when the signal is transmitted, there will be obstacles among the transmitter (antenna) and receiver.

3.4 Battery

The battery is the sole container of power for the Smart Snow Meter. It powers all the modules and if it discharges, the device won't be able to function. Therefore, it is essential to choose the right battery type to prevent this from happening.

Since the battery needed to last throughout the winter months, usually December through March in the New England area as discussed in the background, the battery needed to be able to withstand low temperatures such as -4 F^{o}. Additionally, the battery would have a low self-discharging characteristic in order to prevent it from completely discharging during the winter months.

The battery ideally would have the ability to be recharged in order to ensure that it will last through the winter months and to reduce costs from replacing batteries constantly. It is also important that the battery had high enough voltage so that it is able to power the other components of the device.

3.5 Solar Charging

The device's solar cell was responsible for generating current to recharge the battery. It needed to provide a little more current than the battery's self-discharge current in order to offset the battery's self-discharge rate and still be able to charge it. The solar cell needed to have a high voltage in order to charge the device with a comfortable margin.

Finally, to get the most accurate measurements possible, none of the solar cell's dimensions, ideally, should have been larger than the dimensions of the device's structural casing.

3.6 Structure

The structure of the device was as important as the components that are placed inside of it. There were several options already considered by the team at the start of the brainstorming process. These included the standard PVC tubing, and 3-D printed enclosures. Anything outside of these would have been outside the ability of the team. The key thing the team deemed that was necessary in a structure would be the ability to be rapidly prototyped. Cost was also kept in mind as there is a budget provided for the device so the team did not want to spend the main bulk of it on non-final iterations of our structure.

4.0 Findings

Following our methodology process, we obtained results for the different modules of the product that we created. The team had configured, tested, and finalized the individual modules that would come together for our complete device. This consisted of the choice and individual testing of: microcontrollers, sensors, long-range communication, batteries, solar charging circuit, and the structure. After that was complete, the individual sections were put together to result in the first prototype. After the device was tested, design choices were noted for further considerations of this product.

4.1 Microcontroller

The Teensy 2.0 microcontroller was chosen to control the operation of the sensor modules due to several reasons. These include its small profile, the ability to operate on a voltage as low as 2.4 V if needed, and lastly it is adaptable and widely-used ATMEGA32U4 processor that had many libraries already created to integrate with many modules and features including one for I2C which was planned to be used for the team's project (Teensy Main Page, n.d.).

As for the head module, the team went with the Arduino Uno. This was not an ideal pick for this module, as it was discovered that this needed a voltage of 7-12V (Arduino UNO & Genuino UNO, n.d.). However due to time constraints, this was not able to be accounted for in the pick for this module. As this microcontroller also was one that was compatible with Arduino-friendly libraries, it allowed for wire to easily transfer data between the sensor modules and this head module.

4.2 Sensors

The team had identified that there were three easily accessible types of sensors that could be implemented for the application of this project. While there are countless other sensors that would also likely work for the team's purpose, these were acquired at low-cost allowing for the entire product to attempt to remain inexpensive. These were the: Capacitive sensor, Photosensitive sensor and infrared LED and sensor. Each of these were setup in a test circuit and then tested first for general operation, then secondly with a plastic coating to protect the circuit and snow on top of that to simulate the conditions that the product would be used in.

For the capacitive sensor, relying on the value of capacitance proved unreliable due to the varying densities of snow/ice as it was touched upon in the Background. Additionally, the value of capacitance easily floats which impacts the accuracy in detecting if it would be snow blocking the sensor or just interference. With fine-tuning and proper grounding, a capacitive sensor can correctly detect snow accurately to the degree of even detecting if it is avalanche-prone, however that was deemed outside the scope of the team's purpose (Foster & Manning, 2002).

The photosensitive sensor was the next tested. It consisted of a circuit driving a photoresistor so that the resistance would change as the value of light was blocked due to snow. This sensor was originally included so that a comparison could be made in the performance of the other two sensors. However, the sensor itself contains the glaring issue of only being accurate during day-time and would not be reliable during night-time.

The Infrared LED and sensor combination proved to be the best option for its accuracy in simply detecting if there would be snow at the level of the sensor. The module that was purchased for testing included potentiometers that would allow the sensitivity to be tweaked to create an optimal condition for accurately detect when the sensor is blocked. Furthermore, due to providing its own source of IR light, nighttime would not be an issue as in the photoresistor. In addition, a plastic covering for the device to make it waterproof could also be calibrated for, leading to a very adjustable device.

The end result of all the testing led the team to choose the infrared LED and sensor combinations. It was then implemented in the sensor modules of the device for the extent of our testing.

4.3 Long-range Communication

Data can be transmitted through a reliable source network through 2G, 3G, 4G and LTE's extensive coverage. Due to cellular network's extensive national coverage, these bands were considered for use. Bluetooth and Zigbee have an approximate coverage range of 100 meters that would not allow for long range communication (Sponås, 2016). Wi-Fi is available locally through routers that serve as points of access. Hence if the device was to be installed in a remote area, Wi-Fi would not be a reliable network. The readings from the sensor need to be sent through a reliable network that could be expanded to encompass a whole city. The team chose GSM for this purpose due to the fact that unlike other considerations, there is widespread coverage for cellular service, allowing for these to be placed at a remote location. The GSM module we chose sends data remotely through 2G network. This module of the device is able to communicate through 2G and send the data received from the sensor module.

Considering that the device would send data through cellular network, a GSM module is needed. Currently, there are several options available in terms of choosing a GSM chip capable of sending data through a network. Most of these are versions of the SIM800. The SIM800L needs a voltage regulator when connected to an adjoining microcontroller for its input voltage. The SIM800 is an upgraded version of the SIM800L which has a voltage regulator built in to input a voltage of 5V, therefore there is no need for an extra circuit components.

In order to send the information through 2G, T-Mobile was chosen as the network provider due to its cost and coverage in remote areas in the United States. T-Mobile has stated that it will continue to support IoT customers using 2G networks, and the 2G-M2M network will continue supporting 2G solutions through 2020 (T-Mobile, n.d.). Unfortunately, many network providers are not enabling 2G because it has been considered outdated in comparison to 3G, 4G and LTE. “It has been known… that the major telecom companies will decommission their 2G networks from December 2016” (Stiles, 2016) . The SIM800 was selected as the GSM board mainly due to its low power consumption and dimensions (Wijethunga, 2015).

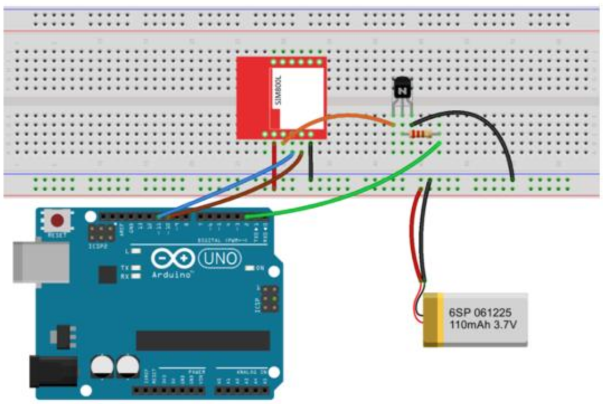


Figure 23: Head Module Setup

The SIM800 was connected to the Arduino through the input voltage (5V), ground, RDX, and TDX. These last two pins enable data communication with the Arduino UNO and the SIM800. The code was implemented using the Arduino IDE enabling the device to send data remotely and then go to into sleep mode. The user is able to receive the data through email or through SMS. For the purpose of this project, a Google Voice account was used in order to record incoming messages received from GSM module.

The Smart Snow Meter is capable of sending automated data on a set amount of time without human intervention when it is running. Its characteristics fit into the scope of Internet of Things, as described in background, as it enables communication between the device and a computer or cell phone. The data that consists of an SMS message containing the height of the snow measured and the location of the device, would be sent to an accessible platform. However due to time constraints, there are two sets of Arduino code (see Appendix C and Appendix D) that perform these functions separately.

4.4 Battery

The battery chosen was the NiMH Nickel–Metal Hydride), manufactured by Panasonic Corporation. This battery was specifically chosen, among the other batteries considered, because it has a very good low self-discharge rate, the manufacturer claims that cells retain about 70% of their capacity when stored for 10 years at 68°F (Panasonic Corporation, n.d.) (Battery University, 2017).Another reason why this battery composition was chosen over others considered is because of its great performance in cold temperatures (Panasonic Corporation, 2014).

A supply voltage of 3.6 V was chosen for this application because of two primary reasons. Most rechargeable NiMH batteries (including Panasonic Eneloop batteries) have a rated voltage of 1.2V; therefore, the group had to work with 1.2 Volt increments. The second reason why the group chose a supply voltage of 3.6 V was because 2.4 V is the absolute minimum voltage that the microprocessor will work with – operating at 2 MHz (PJRC). Any variation in the supply voltage could prevent it from functioning properly. Furthermore, the microprocessor needs at least 3.4 V to work with an 8 MHz clock speed and have USB operation (PJRC). For these reasons, the team opted to use 3 AA batteries in series to obtain a voltage of 3.6 V in order to have a comfortable margin to operate the microprocessor without any interruption in its functionality. In reality however, the fully charged batteries each have a voltage of 1.3 V, even though 1.2 V is advertised. This brings our total battery voltage to about 3.9 V. which still works perfectly for the device's purposes.

The group considered using single-use lithium AA batteries due to its ability to have large capacity and exceptional performance in colder temperatures (Energizer), but ultimately chose to use a rechargeable battery to ensure that our device could be self-sustained at remote locations without the need to change the batteries at constant intervals. This would also be cheaper in the long run since recharging the battery proves to be cheaper than disposing of and replacing them after every winter period; as that would require money to be spent on new batteries and on personnel to change them periodically.

The team did consider using other rechargeable battery chemistries, but ultimately settled on NiMH because, while NiMH should be recharged every 6 to 9 months for optimal performance, Lithium-Ion batteries should be recharged frequently (even after discharges as little as 10%) in order to function optimally (REI coop). And even though it is the project's goal to recharge the batteries using solar energy, there may be long periods of time where the battery won't be able to recharge, which if prolonged, could cause the battery's life to decrease, especially if the battery was not fully charged at the beginning of winter. Another reason why the group moved away from Lithium-Ion batteries is because battery capacity was going to be affected by the passing of time, even if the battery was not used. The amount of the loss changes according to the size and the configuration of the battery (REI coop).

It was the project's goal to have a battery that could last all throughout the winter. The group needed, consequently, a battery whose capacity would not be greatly affected by both its self-discharge rate, and by a reduction in capacity due to the low temperatures of winter. Technological advances made in NiMH batteries allow it to have a low temperature rating down to -4 °F.

4.5 Solar Charging

The solar cell chosen was a 9.0V 70mA 0.6W Solar Cell manufactured by Futurlec. However, the part never arrived, and the group was forced to use a 9 V 56 mV 0.5W solar cell from RadioShack. The team used a voltage regulator to ensure that the voltage output from the solar cell was always adequate to charge the battery. The solar cell charges the 3.6 V battery pack when the sunlight is powerful enough to generate a voltage greater or equal to around 6V. That is so because of the dropout voltage (the smallest possible difference between the input voltage and output voltage to remain inside the linear regulator's intended operating range) of the regulator at the working temperatures (Texas Instruments, 2015).

With that in mind, the group chose a solar cell with enough voltage that would be able to provide a voltage greater than the needed 6 V to charge the batteries and a current of at least 50 mA. The team did that to ensure that the cell would have a comfortable margin to ensure the battery is charged while the sun is not at full strength, and to maximize the times that the battery is charging the battery.

The team could have chosen a much more powerful solar cell to charge the battery, but one of the goals of the project was not to have a solar cell whose dimensions was larger than any of the dimensions of the casing. This was in order to prevent the cell from affecting the snowfall around the device. Even though the team had to make compromises with the solar cell used, the new solar cell matches this requirement, since the largest dimension of the cell is 85 mm (3.35 in) and the device's diameter is 89 mm (3.5 in) (Amazon, n.d.). Therefore, a 9 V solar cell was the cell with the greatest voltage the team could find within a reasonable price and given the size constraints.

The team planned to charge the battery constantly with a "trickle" charge whenever the sunshine is powerful enough to generate a voltage that is sufficient to charge the battery. The cell had a peak current (Imp) of 56 mA, and the trickle charge current for the chosen battery was 50mA – assuming a capacity of 2000 mAh (C/40 = 2000/40 = 50 mA) (Amazon, n.d.). In reality, since the capacity of the battery will vary according to its temperature and other factors, the trickle charge current was still likely to decrease. Therefore, the new solar cell will still be effective even after considering its lower Isc. Given the battery's chemistry and the recent technological advancements in NiMH batteries, this is a low enough current that won't significantly damage the battery over prolonged periods of charging.

The team will use a voltage regulator to stabilize the voltage down to 4.5 V in order to achieve the necessary voltage to charge the batteries. The team needed 4.2 V to charge the battery (1.4 V*3 = 4.2 V) but had to account to a 0.3 V drop due to the diode placed in order to prevent the battery from discharging at night and clouded days. The team opted to use a linear regulator because of its easy to use configuration and due to its low noise output. This was accomplished by using a LM317 voltage regulator along with the simple circuit shown below:

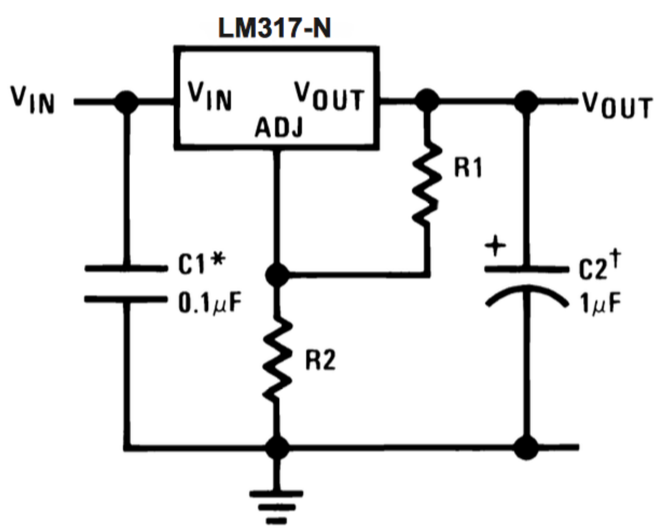


Figure 24: LM317 Voltage Regulator Circuit (Texas Instruments, 2015)

Where C_1 is needed if device is more than 6 inches from filter capacitors and C_2 improves transient response. V_{out} is given by:

$$V_{out}=1.25V\,(1+R_2/R_1)+I_{ADJ}(R_2)$$

Because I_{ADJ} is less than 100µA, the second term of the equation can be ignored. Therefore, R_2 is about 2 KΩ (assuming a R_1 value of 750 Ω)

Because of the low current output by the solar cell, it was not necessary to use a heat sink in the system:

$$P_{heat}= (V_{in} - V_{out})*I_{out} =(9V - 4.5V)*0.05A =0.252W$$

Even if the group had used the 0.6 W solar cell that was initially chosen, a heat sink would not have been necessary since P_{heat} would have equaled 0.315W.

4.6 Structure

Some of the considerations for the structure of the device were developing a 3-D model using Solidworks that would hold the electric components inside the device preventing them to shift around during a storm or harsh weather conditions.

Characteristic	3-D Printing
Manufacturing Technology	Automated manufacturing based on CAD software and additive manufacturing.
Supply Chain Integration Requirements	Uses readily available supplies available from multiple vendors.
Economic Benefits	Ability to produce custom products at relatively low prices. Low inventory risk. Improved working capital management.
Range of Products	Prototypes; mockups; replacement parts; dental crowns; artificial limbs.

Figure 25: Brief Synopsis of 3-D printing (Berman, 2012)

As seen in Figure 25, 3-D printing has been applied to making prototypes, replacement parts, etc. using single materials which would be perfect for our application. 3-D Printing uses readily-available supplies that can be purchased from a small number of vendors and it is a reliable method of production. Due to the main aspects of 3-D printing such as low cost production, effectiveness and speed; future considerations for the model of the prototype were made in terms of this method.

Moreover, for our application 3-D Printing is recommended, however PVC was chosen as the main material component for the structure. PVC is available in different sizes, it is durable, it is possible to obtain at a low cost and it is easy to manipulate with hand tools. The scope of this project is mainly focused on the electronic circuitry components of the prototype rather than the hardware aspect of the device. In addition to this, the use of software such as Solidworks goes beyond the expertise of the members of the team.

5.0 Implementation

In Findings, the team has made part choices for each component of our device. In implementation, the team took those choices and created the three types of modules that would come together to allow for our device to function. These consisted of the: Sensor modules, head module, and power circuit. After these components were assembled, they were then tested individually then assembled to obtain the full device as seen in Figure 26. This testing data is included in the System Testing chapter of the report. This chapter however will focus on the circuits that the modules consist of and the physical connections between them.

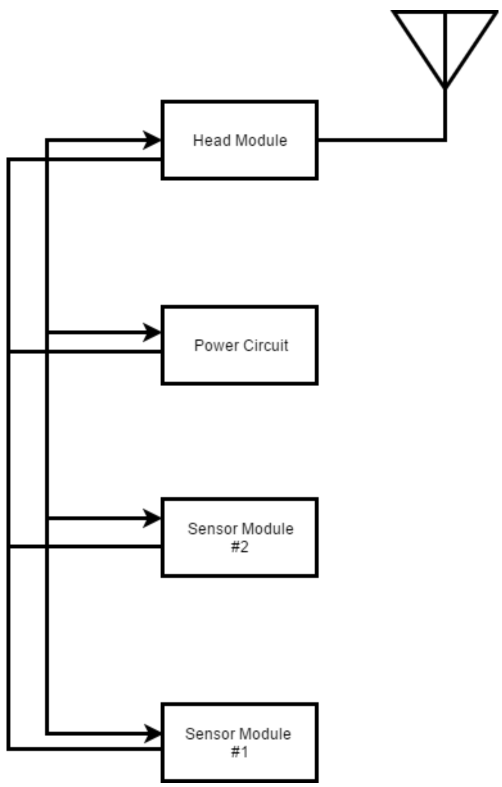


Figure 26: Top-level Block Diagram

5.1 Sensor Module

The decision was made to go with the infrared sensors and the Teensy 2.0 for the microcontroller for the sensor modules as detailed in the Findings chapter. As shown in Figure

27, since the infrared LED and sensor combos are self-contained, they simply have to be connected to power, ground and their output to one of the digital GPIO pins on the Teensy. There were two sensor modules made for the device to demonstrate that it is of modular design. One was a six-sensor module while the other was a two-sensor module.

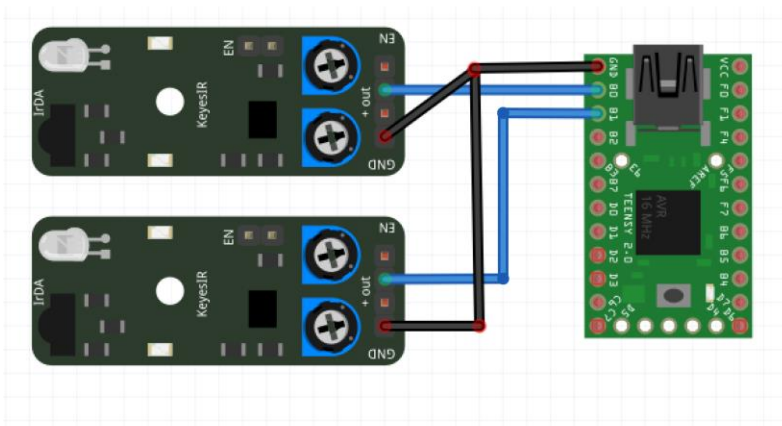


Figure 27: Circuit Layout for Sensor Module

5.2 Head Module

Assembling the head module consisted of the Arduino Uno and SIM800 that were picked in the Findings chapter. After connecting these together as seen in Figure 28, code was loaded so that when the Uno obtains the snowfall data from the sensor modules, it has the ability to send this out using the GSM module attached.

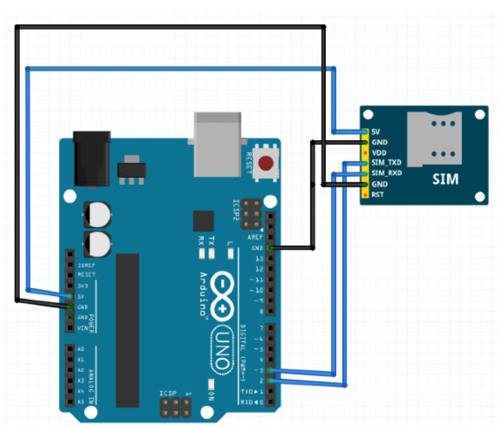


Figure 28: Circuit Layout for Head Module

5.3 Power Circuit

The Power circuit was the last component that needed to be assembled. Using the parts determined in the findings, the NiMH battery was connected to a solar cell that would be regulated through a circuit designed for that application. The team used a voltage regulator to ensure that the voltage output of the solar cell would always be at the correct voltage to charge the battery without error. The team calculated that 4.2 V were necessary to charge the battery, since V_{charge} needs to be larger than V_{batt}.

$$V_{charge} = 1.4 \text{ V} * 3 = 4.2 \text{ V}$$

The regulating circuit also prevents the battery from discharging at night and other times where V_{solar} is not enough to charge the battery. The minimum value is about 6 V due to the dropout voltage given the ambient temperature. The dropout voltage is the minimum difference between V_{out} and V_{in} that the LM317 can output. Which is about 1.8 V at 32 ºF. The regulatory circuit, solar panel and battery pack are shown in Figure 29.

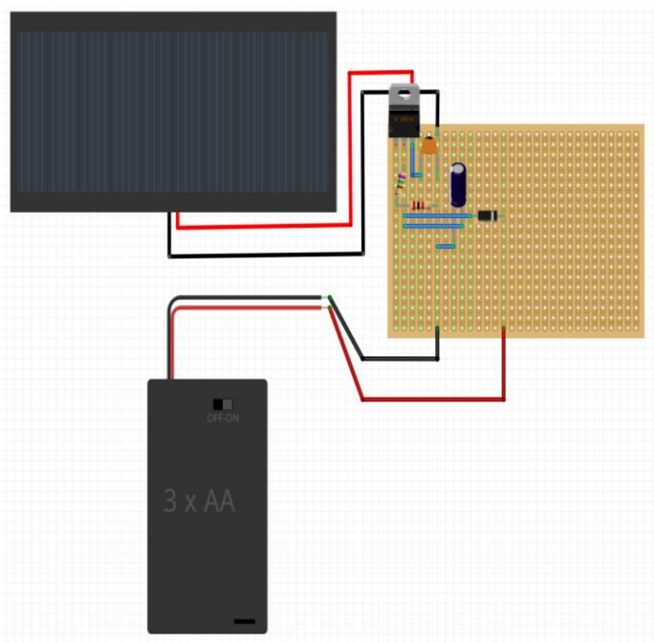


Figure 29: Circuit Layout for Power Circuit

The team used a DC/DC boost converter to step up V_{batt} to the 7 volts required to power the Arduino Uno being used in the head module. The converter used was the DROK LM2577 DC Boost Power Converter that is capable of stepping up voltages from 3-34 V to 4-35 V.

5.4 Operation

Each module had performed well for individual testing, so the device was pieced together so that testing on the final implementation could be performed. This is detailed in the *6.4 Overall Testing* section. As for the final implementation, the device is shown in Figure 30. The whole device shared a common ground and communicated between the sensors and the head unit by using the two-wire interface of I2C. The system allowed these common interfaces while remaining modular through the use of male-female wires that would be hidden inside the PVC connectors.

Figure 30: Full Prototype of the Smart Snow Meter

As for the operation of the Smart Snow Meter, it currently works as intended as detailed in the System Testing chapter. The team had attempted to link the device with Google Map's API so that the location and snowfall data would be portrayed on a map connected to a website that the team had acquired. This was cancelled after testing on campus proved that the website hosting service (Weebly) that the team was using was blocked with regard to WPI's internet filter, rendering it useless when proving as an application of the device. Keeping that in mind, the GPS location and the snowfall data are instead just transmitted to a cell number to demonstrate that the device works as intended.

6.0 System Testing

While assembling the separate modules, testing was done so that the team could ensure that the device would work as intended once put together. There was individual testing done on the sensor modules, the head modules, and power circuit. Once that was complete, the team did final testing with the Smart Snow Meter fully assembled.

6.1 Sensor Module Test

To test the sensor module, the team chose to gauge the accuracy of the sensor's and if that data would be accurate when transmitted through I2C to the head module. The infrared sensors in this module contain an LED that correlates to the reading of the output. In combination with the potentiometers that adjust the sensitivity of the sensors, this led to very accurate readings for whatever medium the team used to block the reading. While normally it would be snow, for testing it was changed to work for a white sheet of paper to emulate snow. The results after calibration are shown in the table below. The results are accurate because the sensitivity of the sensors was adjusted to match the groups desired range.

Table 1: Final Calibration for Sensor Readings

Blocked [inches]	0	1	2	3	4	5	6	7	8
Reading [inches]	0	1	2	3	4	5	6	7	8

The second round of testing was to ensure that these readings stored inside of the sensor module would transmit through the wired connection to the head module. This is where the team had issues. When reading an output of the data being sent across I2C, instead of a number we were receiving a 'ʔ' symbol. To ensure that it was not the sensor module itself, more testing was done until it was determined that it was the difference in the reference voltages of the two microcontrollers, one of which was 3.3V and the other which was 5V which was affecting the

I2C readings. To remedy this, a pull-up resistor was created so that the logic levels would be compatible with these differences. After this was implemented, testing results of the I2C communication displayed that data was transferred accurately.

6.2 Head Module Test

The data transmitted from the sensor module was received through the Arduino UNO and transmitted using the SIM800. The user is able to access the data through an application of their choice. For the purpose of this project, SMS messages were received using Google Voice and they were forwarded as an email to the user as shown in the Figures below.

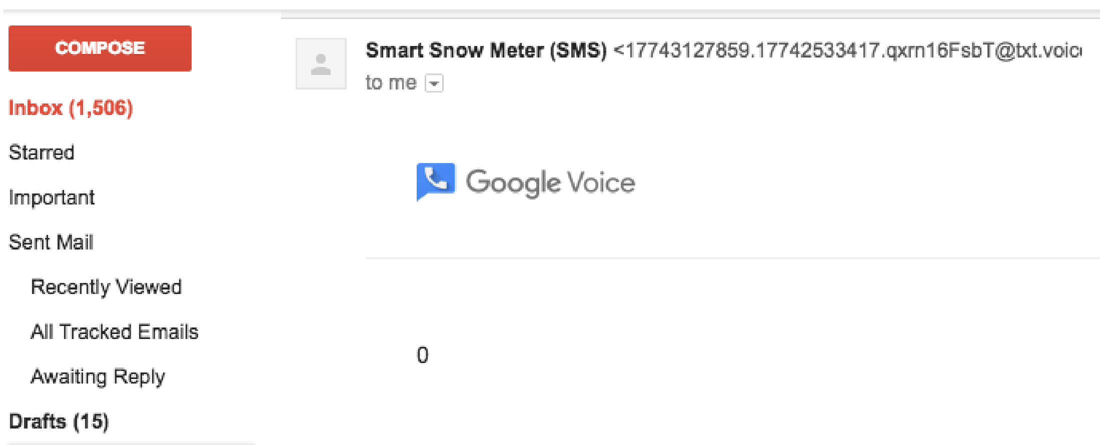


Figure 31: E-mail received by the user with the desired snowfall depth in terms of inches

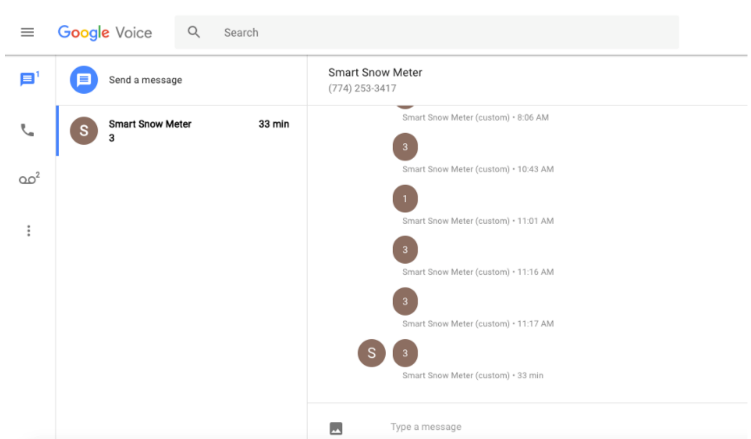


Figure 32: SMS messages received by user with current snowfall height in terms of inches

The following table displays results from testing the device for a variable amount of snow depth and the obtained results through SMS and email. For every inch, a reflective screen was placed in front of the sensors to simulate snowfall. This was repeated six times to test for the received data for every inch.

Table 2: I2C readings from the Sensor Module

Expected Snowfall Height [inches]	Snowfall Height Received [inches]
0.0	0.0
1.0	1.0
2.0	2.0
3.0	3.0
4.0	4.0
5.0	5.0
6.0	6.0

The recorded data above shows 100% success of the data transmission between the device and the user's application (SMS message, email). As seen from the table the device was able to communicate accordingly.

In order to display the location data for the user, the variables latitude and longitude were sent through an SMS. The values obtained were mapped using reverse geolocation through Google Maps to obtain a clear picture of the location on a map. Appendix E shows examples of the testing for GPS location through the data sent through SMS messages.

Using Google Maps, it was possible to determine the precise value for the location where testing was done. The following table shows a comparison between the values obtained by the GPS and the actual values obtained using Google Maps.

Table 3: Comparison between GPS data and Google Map Coordinates

Location address:	Values from Google Maps		Experimental Values	
	Latitude	**Longitude**	**Latitude**	**Longitude**
16 Dayton St., Worcester	42.26893070000001	-71.8096342	42.268930701003	-71.8086342
Atwater Kent Laboratories at WPI	42.268912199999995	-71.8096651	42.2753791	-71.8076982640021
Wooberry Frozen Yogurt, Highland St.	42.270712	-71.808202	42.27021311	-71.818212

As seen from the table above, the values obtained from the GPS module differed from the values obtained through Google Maps. The possible margin of error may originate from interference around the area. The values were also taken inside buildings, so thick walls may oppose an error to the values obtained. Moreover, the actual data obtained from Google Maps is from an exact city address. Hence, there is room for error as the user might not be standing at the latitude and longitude point that represents that city address.

6.3 Power Circuit Test

In order to fully ensure that the power circuit worked, the team came up with some tests to examine the different components of the circuit. First the team tested the solar cell to check it worked perfectly. The cell's V_{oc} and I_{sc} were measured during full sunlight. The values acquired were a V_{oc} of 9.2 V and an I_{sc} of 60 mAh.

The charging circuit was tested next. To test the regulating circuit, the team used a DC voltage supply to simulate the solar cell operating at full capacity. The team then measured the output of the regulating circuit. The measurements can be seen in the table below:

Table 4: Input and Outputs of the Regulatory Circuit

Voltage In	Voltage Out
10 V	4.212 V
9 V	4.212 V
8 V	4.212 V
7 V	4.212 V
6 V	4.212 V
5 V	4.010 V
4 V	3.350 V
3 V	2.558 V

The test was conducted at room temperature (70° F), therefore the dropout voltage of the LM317 would vary a miniscule amount from its dropout voltage at 32° F. However, this did not have a huge impact on the test; especially given the voltage resolution chosen. The results showed that the voltage regulator worked as expected and the voltage stabilized around 4.2 V.

Lastly, the group needed to test the power circuit as a whole. To accomplish this, the group measured the battery voltage of a device when left on overnight to lower the battery voltage, and then in the morning put the entire system outside where the sun was shining bright. After an hour, the team measured the battery voltage again. The information obtained can be found in the table below, allowing us to conclude that the battery was able to be charged successfully. This data is backed in Appendix F.

Table 5: Battery Voltage Before and After Charge

Battery Voltage Before Charge [Volts]	Battery Voltage After Charge [Volts]
3.8752 V	3.9209 V

6.4 Overall Test

Testing for the overall device functionality involved a combination of the several previous tests. Considering the full implementation of the prototype was successful in all the previous tests, there were no errors when those modules were combined. When powered on from the battery pack and a number of sensors were blocked, the corresponding number would be sent from the device to an external source through an SMS.

7.0 Conclusions & Recommendations

Overall, the team considers the device a success, taking into account several setbacks that occurred during the timespan of this project. In relation to our goals, all but one were met which was “wirelessly relay it’s GPS locations along with the inches of snowfall at that area”. While the team was able to develop code that could do both of these tasks separately, there were issues that could not be resolved in the scope of this project with sending both of these details concurrently in the same code. While a success, the device is not without its problems, which occurred due to shipping delays and some parts that were ordered never having arrived. This resulted in less than ideal parts for some of the modules leading to much higher current draw than originally planned through the forced inclusion of a buck-boost converter and the need to run the whole system at 5V rather than the original 3.6V planned for.

There are several system constraints that exist currently with the Smart Snow Meter. One such is that the subscription for the SIM card service has to remain active. The maximum number of sensors depends on the current limit of the +5V rail of the Arduino Uno currently.

Daily recommendations for the current device should be accounted for when operating it. This device should be used on a field when measuring snowfall so that snow drifts do not interfere with the readings. The solar cell on the device should face south. The device should also be buried so that the first sensor is exactly (or as close to) 1 inch from the ground. There should be clearance around the device so as to not cause false positives.

If the Smart Snow Meter is to be worked on in the future, the team has several further considerations that should be addressed as to improve the iteration. These are divided into 3 main sections: Hardware improvements, Software improvements and Application Improvements. For hardware improvements, the team recommends that the structure be 3-D printed as opposed to the PVC that was used in the current project. It is more aesthetic, organized and would solve many of the assembly problems that occurred when creating the device. Additionally, instead of Arduinos, it would be ideal if the CPUs were just obtained and custom PCBs were created for these circuits as they are currently soldered on through-hole board. The software should also be upgraded so that it can use a better power-saving mode than currently designed and so that the user could change the frequency at which the unit samples snowfall, and the total number of sensors with an easier option than currently changing the code of the head module. Lastly, the team recommends to develop a better method of using the snowfall and GPS, perhaps implementing the Google API so that a map could be generated.

References

Panasonic Corporation. (n.d.). *eneloop product lineup*. Retrieved from Panasonic Corporation: https://www.panasonic.com/global/consumer/battery/eneloop/lineup.html

6V 0.6W Solar Panel Module DIY Small Cell Charger For Light Battery Phone. (n.d.). Retrieved from ebay: http://www.ebay.com/itm/6V-0-6W-Solar-Panel-Module-DIY-Small-Cell-Charger-For-Light-Battery-Phone-/121978497728

Adafruit. (n.d.). *XBee Module - Series 1 - 1mW with Wire Antenna - XB24-AWI-001*. Retrieved from Adafruit: https://www.adafruit.com/products/128

Amazon. (n.d.). *RadioShack 0.5W 0.5 Watt Solar Panel 9V 3.77" x 2.12" x 0.125" with 20cm Output Cable 2770047 DIY For Mini Solar Panel Module Solar Power System Solar Cell Battery Charger*. Retrieved from Amazon: amazon.com/RadioShack-Output-2770047-Battery-Charger/dp/B007Z7TVS8?sa-no-redirect=1

Appleyard, D. (2009, March 11). *Utility-Scale Thin-Film: Three New Plants in Germany Total Almost 50 MW*. Retrieved from Renewable Energy World: http://www.renewableenergyworld.com/articles/print/volume-12/issue-1/solar-energy/utility-scale-thin-film-three-new-plants-in-germany-total-almost-50-mw.html

Arduino Capacitive Touch Sensor. (2016). Retrieved from Resistor Park: http://www.resistorpark.com/arduino-capacitive-touch-sensor/?utm_medium=googleshopping&utm_source=bc&gclid=CKat3vHs1dACFRtMDQodBU0BmQ

Arduino UNO & Genuino UNO. (n.d.). Retrieved from Arduino: https://www.arduino.cc/en/main/arduinoBoardUno

Ayre, J. (2012, October 15). *Improvement in Thin Film Solar Cell Degradation*. Retrieved from Planetsave: http://planetsave.com/2014/05/27/thin-film-solar-cells-short-film-narrated-han-solar/

Battery University. (2016, May 4). *BU-304b: Making Lithium-ion Safe*. Retrieved from Battery University: http://batteryuniversity.com/learn/article/bu_304b_making_lithium_ion_safe

Battery University. (2017, April 20). *BU-203: Nickel-based Batteries*. Retrieved from Battery University: http://batteryuniversity.com/learn/article/nickel_based_batteries

Bergethon, K. (n.d.). *Advantages and Disadvantages of Solar Film Cells*. Retrieved from articlecity: http://www.articlecity.com/articles/environment_and_going_green/article_251.shtml

Berman, B. (2012, March-April). 3-D printing: The new industrial revolution. *Business Horizons, 55*(2), 155–162.

Bombard, N. R. (2016, February 14). *Record low temperatures recorded in Boston, Worcester; so how cold did it get?* Retrieved from Masslive: http://www.masslive.com/weather/index.ssf/2016/02/record_low_temperatures_record.html

Burt, C. C. (2014, April 1). *Record and Average Dates of Late Season Snowfall in the U.S.* Retrieved from Weather Underground: https://www.wunderground.com/blog/weatherhistorian/record-and-average-dates-of-late-season-snowfall-in-the-us

Climate Worcester- Massachusetts. (n.d.). Retrieved from U.S. climate data: http://www.usclimatedata.com/climate/worcester/massachusetts/united-states/usma0502

Connolly Music Company. (2014, August 11). *K&M Round Base Mic Stands*. Retrieved from Youtube: https://www.youtube.com/watch?v=ukxihgPRkw0

DeRusha, J. (2009, December 9). *Good Question: How Do They Measure Snow?* Retrieved from WCCO | CBS Minnesota: http://minnesota.cbslocal.com/2009/12/09/good-question-how-do-they-measure-snow/

Egan, B. (2015, December 17). *SNOW JOB*. Retrieved from Worcester Mag: https://worcestermag.com/2015/12/17/snow-job-2/38796

Electronics Hub. (2015, February 2). *IR (Infrared) Obstacle Detection Sensor Circuit*. Retrieved from Electronics Hub: http://www.electronicshub.org/ir-sensor/

Energizer. (n.d.). *Cylindrical Primary Lithium Handbook and Application Manual.* Retrieved from Energizer: http://data.energizer.com/pdfs/lithiuml91l92_appman.pdf

Erdman, J. (2016, October 24). *When the First Snow of the Season Typically Falls*. Retrieved from The Weather Channel: https://weather.com/storms/winter/news/first-snow-average-date

Finn Valley College. (2011). *Weather Instruments*. Retrieved from Geography @ Finn Valley College: https://fvcgeography.wordpress.com/the-restless-atmosphere/weather-instruments/

Foster, R. L., & Manning, B. (2002, March). Capacitive Density Sensors Help Detect Avalanche Conditions. *Sensor: Technology and Design*.

Gubbi, J., Buyya, R., Marusic, S., & Palaniswami, M. (2013). Internet of Things (IoT): A vision, architectural elements, and future directions. *Future Generation Computer Systems, 29*(7), 1645-1660.

Harbor Freight. (n.d.). *6 in. Diameter Auger Bit*. Retrieved from Harbor Freight: http://www.harborfreight.com/6-inch-diameter-auger-bit-95973.html

I2C and SPI. (n.d.). Retrieved from Quick2wire: http://quick2wire.com/articles/i2c-and-spi/

IR Infrared Obstacle Avoidance Sensor. (2016). Retrieved from Resistor Park: http://www.resistorpark.com/ir-infrared-obstacle-avoidance-sensor/

Jones, H. G., Pomeroy, J. W., Walker, D. A., & Hoham, R. W. (2001, January). Snow Ecology. *Snow Ecology*. Retrieved from https://www.researchgate.net/profile/John_Pomeroy2/publication/252454769_Snow_Ecology/links/5863689108ae8fce490a7cfc.pdf.

leakeem. (2017, March 24). *NiMH vs. Li-ion: A Battery Comparison*. Retrieved from Turbo Future: https://turbofuture.com/misc/Which-is-better-Nickel-Metal-Hydride-NiMH-or-Lithium-Ion-Li-ion-batteries

Legates, D. R., & DeLiberty, T. L. (1993, October). Precipitation Measurement Biases in the United States. *Journal of the American Water Resources Association, 29*(5), 855- 861.

Levenson, E. (2015, February 18). *Boston to Set Record for Most Dollars Spent on Snow Removal*. Retrieved from Boston: http://www.boston.com/news/local-news/2015/02/18/boston-to-set-record-for-most-dollars-spent-on-snow-removal

Male, D. H. (1980). The Seasonal Snowcover. In S. C. Colbeck, *Dynamics of Snow and Ice Masses* (pp. 305 - 395). Toronto: Academic Press.

Michel U. Louge, R. L. (1998). *A Portable Capacitance Snow Sounding Instrument.* Retrieved from International Snow Science Workshop Proceedings - Montana State University Libraryskip navigation: http://arc.lib.montana.edu/snow-science/objects/issw-1998-202-207.pdf

NASA. (2007). *North America 10-year Average Insolation kWh/m2/day.* Retrieved from stalix: http://stalix.com/isolation.pdf

NiMH vs. Li-ion batteries - A battery Comparison. (2015, May 8). Retrieved from HubPages: http://hubpages.com/technology/Which-is-better-Nickel-Metal-Hydride-NiMH-or-Lithium-Ion-Li-ion-batteries

Pahlavan, K., & Krishnamurthy, P. (2013). *Principles of Wireless Access and Localization.* Hoboken, United States: John Wiley & Sons, Ltd.

Panasonic Corporation. (2014). *BK200AAB.* Retrieved from Panasonic Corporation: http://industrial.panasonic.com/cdbs/www-data/pdf2/ACG4000/ACG4000CE266.pdf

PJRC. (n.d.). *Using External Power and USB.* Retrieved from PJRC: https://www.pjrc.com/teensy/external_power.html

Poole, I. (n.d.). *ZigBee Technology Tutorial*. Retrieved from Radio-electronics: http://www.radio-electronics.com/info/wireless/zigbee/zigbee.php

REI coop. (n.d.). *Batteries: How to Choose.* Retrieved from REI coop: https://www.rei.com/learn/expert-advice/batteries.html

Resistor Guide. (2016). *Photo resistor*. Retrieved from Resistor Guide: http://www.resistorguide.com/photoresistor/

RS Components. (2015, April 20). *11 Internet of Things (IoT) Protocols You Need to Know About*. Retrieved from Design Spark: https://www.rs-online.com/designspark/eleven-internet-of-things-iot-protocols-you-need-to-know-about

Schniederjans, D. G. (2017, January). Adoption of 3D-printing technologies in manufacturing: A survey analysis. *International Journal of Production Economics, 183*(A), 287-298.

SFUptownMaker. (n.d.). *I2C*. Retrieved from sparkfun: https://learn.sparkfun.com/tutorials/i2c

Sponås, J. G. (2016, June 2). *Things you should know about Bluetooth range*. Retrieved from Get Connected Blog: http://blog.nordicsemi.com/getconnected/things-you-should-know-about-bluetooth-range

Stiles, J. (2016, March 16). *Half a million phones set to become obsolete*. Retrieved from The New Daily: http://thenewdaily.com.au/life/tech/2016/03/16/2g-decommission/

Teensy Main Page. (n.d.). Retrieved from PJRC: https://www.pjrc.com/teensy/index.html

Teensy USB Development Board. (n.d.). Retrieved from PJRC: https://www.pjrc.com/store/teensy.html

Texas Instruments. (2015, October). *LM117,LM317-NWide TemperatureThree-PinAdjustableRegulator.* Retrieved from Texas Instruments: http://www.ti.com/lit/ds/symlink/lm117.pdf

Texas Instruments Incorporated. (2014, December). *FDC1004:Basicsof CapacitiveSensingand Applications.* Retrieved from Texas Instruments: http://www.ti.com/lit/an/snoa927/snoa927.pdf

T-Mobile. (n.d.). *STAY CONNECTED. DRIVE SMARTER.* Retrieved from T-Mobile: http://iot.t-mobile.com/solutions/

Venkatesan, K. (2013). Comparison of CDMA and GSM Mobile Technology. *Middle-East Journal of Scientific Research* , 1590-1594.

Wijethunga, A. G. (2015, November 25). *QUICKSTART SIM800 (SIM800L) WITH ARDUINO*. Retrieved from WEBSITE AND BLOG OF AYOMA WIJETHUNGA: http://www.ayomaonline.com/programming/quickstart-sim800-sim800l-with-arduino/

Worcester Snowfall Totals & Accumulation Averages. (n.d.). Retrieved from Current Results: https://www.currentresults.com/Weather/Massachusetts/Places/worcester-snowfall-totals-snow-accumulation-averages.php

Appendix A: 6-Sensor Module Code

```
#include <Arduino.h>
#include <TM1637Display.h>
#include <Wire.h>


//GPIO defines
#define irSensor1 0
#define irSensor2 1
#define irSensor3 2
#define irSensor4 3
#define irSensor5 4
#define scl 5
#define sca 6
#define irSensor6 7
int ledPin = LED_BUILTIN; //Pin 11


//Power-save toggles and global inches
const int usb_usb_disable = 0; //1 to disable USB
const int use_idle = 0;
const int disable_adc = 1; //1 to disable ADC
char inches_detected = '0';


void setup() {
 // put your setup code here, to run once:
 pinMode(irSensor1, INPUT);
 pinMode(irSensor2, INPUT);
 pinMode(irSensor3, INPUT);
 pinMode(irSensor4, INPUT);
 pinMode(irSensor5, INPUT);
 pinMode(irSensor6, INPUT);

 //Configure Unused Pins 7-21 and LEDPin 11 to output to lower power consumption if they toggle
 for (int i=8; i<22; i++) {
   pinMode(i, OUTPUT);
 }


 //DEBUG 7SEG
 //display.setBrightness(0x0f);
 //Power-save if statements
 if (disable_adc) ADCSRA = 0;   // shut off ADC
 if (usb_usb_disable) Serial.end();

 //Configure Wire i2c
 Wire.begin(1);              // join i2c bus with address #8
 Wire.onRequest(requestEvent); // register event


 //DEBUG
 //Serial.begin(9600);      // open the serial port at 9600 bps:
```

```
}

void loop()
{
  if (!digitalRead(irSensor1) && !digitalRead(irSensor2) && !digitalRead(irSensor3) && !digitalRead(irSensor4) &&
!digitalRead(irSensor5) && !digitalRead(irSensor6))
  {
    inches_detected = '6';
  }
  else if(!digitalRead(irSensor1) && !digitalRead(irSensor2) && !digitalRead(irSensor3) && !digitalRead(irSensor4)
&& !digitalRead(irSensor5)/* && digitalRead(irSensor6)*/)
  {
    inches_detected = '5';
  }
  else if(!digitalRead(irSensor1) && !digitalRead(irSensor2) && !digitalRead(irSensor3) && !digitalRead(irSensor4)/*
&& digitalRead(irSensor5) && digitalRead(irSensor6)*/)
  {
    inches_detected = '4';
  }
  else if(!digitalRead(irSensor1) && !digitalRead(irSensor2) && !digitalRead(irSensor3)/* && digitalRead(irSensor4)
&& digitalRead(irSensor5) && digitalRead(irSensor6)*/)
  {
    inches_detected = '3';
  }
  else if(!digitalRead(irSensor1) && !digitalRead(irSensor2))
  {
    inches_detected = '2';
  }
  else if(!digitalRead(irSensor1))
  {
    inches_detected = '1';
  }
  else
  {
   //digitalWrite(ledPin, HIGH);
   inches_detected = '0';
  }


 //DEBUG 7SEG
 //display.showNumberDec(inches_detected);


 delay(1000); //use 200 for debugging, loops one per second
}
// function that executes whenever data is requested by master
// this function is registered as an event, see setup()
void requestEvent() {
 Wire.write(inches_detected); // respond with message of 1 bytes
 // as expected by master
}
```

Appendix B: 2-Sensor Module Code

```
#include <Arduino.h>
#include <TM1637Display.h>
#include <Wire.h>


//GPIO defines
#define irSensor1 0
#define irSensor2 1
#define scl 5
#define sca 6
int ledPin = LED_BUILTIN; //Pin 11


//Power-save toggles and global inches
const int usb_usb_disable = 0; //1 to disable USB
const int use_idle = 0;
const int disable_adc = 1; //1 to disable ADC
char inches_detected = '0';


//DEBUG init display
//TM1637Display display(CLK, DIO);


void setup() {
 // put your setup code here, to run once:
 pinMode(irSensor1, INPUT);
 pinMode(irSensor2, INPUT);

 //Configure Unused Pins 7-21 and LEDPin 11 to output to lower power consumption if they toggle
 for (int i=8; i<22; i++) {
   pinMode(i, OUTPUT);
 }

 //display.setBrightness(0x0f);
 //Power-save if statements
 if (disable_adc) ADCSRA = 0;   // shut off ADC
 if (usb_usb_disable) Serial.end();


 Wire.begin(2);                // join i2c bus with address #2
 Wire.onRequest(requestEvent); // register event
 //DEBUG
 //Serial.begin(9600);      // open the serial port at 9600 bps:
}


void loop()
{
  if(!digitalRead(irSensor1) && !digitalRead(irSensor2))
  {
   inches_detected = '2';
```

```
  }
  else if(!digitalRead(irSensor1) && digitalRead(irSensor2))
  {
   inches_detected = '1';
  }
  else
  {
   digitalWrite(ledPin, HIGH);
   inches_detected = '0';
  }


 //DEBUG 7SEG
 //display.showNumberDec(inches_detected);


 delay(1000); //use 200 for debugging
}


// function that executes whenever data is requested by master
// this function is registered as an event, see setup()
void requestEvent() {
 Wire.write(inches_detected); // respond with message of 1 bytes
 // as expected by master
}
```

Appendix C: Head Module Code

```
#include "SIM900.h"
#include <SoftwareSerial.h>
#include <Wire.h>


#include "sms.h"
SMSGSM sms;


int numdata;
boolean started=false;
char smsbuffer[160];
char n[20];
char inches='0';
int sendmessage=1;
char message[160];


void setup() {
 // put your setup code here, to run once:
 Wire.begin();
 //Serial connection.
 Serial.begin(9600);
 Serial.println("GSM Shield testing.");
 //Start configuration of shield with baudrate.
 //For http uses is raccomanded to use 4800 or slower.
 if (gsm.begin(2400)){
  Serial.println("\nstatus=READY");
  started=true;
 }
 else Serial.println("\nstatus=IDLE");



}


void loop() {
 // put your main code here, to run repeatedly:
 Wire.requestFrom(1, 1);

 while (Wire.available()) { // slave may send less than requested
  char c = Wire.read(); // receive a byte as character
  Serial.print(c);        // print the character
  inches = c;
 }


 if (inches == '6') {
   Serial.println(inches);
   Wire.requestFrom(2,1);
```

```
  while (Wire.available()) { // slave may send less than requested
    char d = Wire.read(); // receive a byte as character
    Serial.print(d);        // print the character
    inches = d;
    inches=inches + 6; //Accounting for the 6 inches from the first module when full
  }
 }

 if(started){
  //Read if there are messages on SIM card and print them.
  if(gsm.readSMS(smsbuffer, 160, n, 20)){
    Serial.println(n);
    Serial.println(smsbuffer);
  }
  if(sendmessage){
  //Enable this two lines if you want to send an SMS.
  Serial.println(inches);
  message[0] = inches;
  if (sms.SendSMS("7743127859", message))
    Serial.println("\nSMS sent OK");
  sendmessage=0;
              }
 }
 delay(500);
}
```

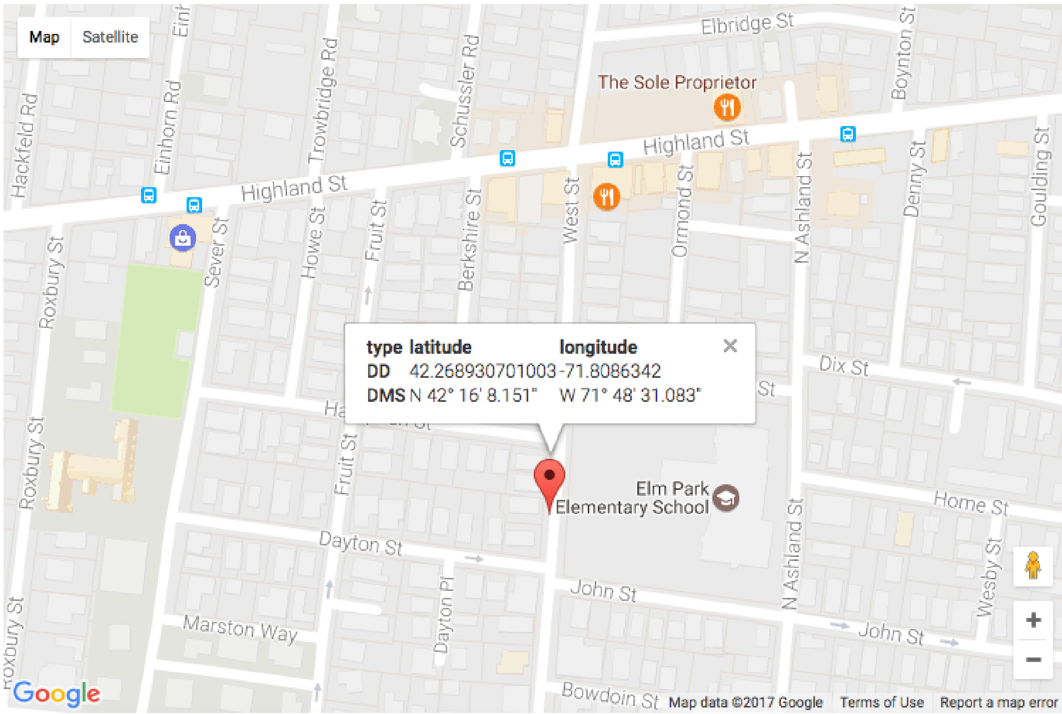
Appendix D: Alternate Head Module Code to Obtain GPS Location

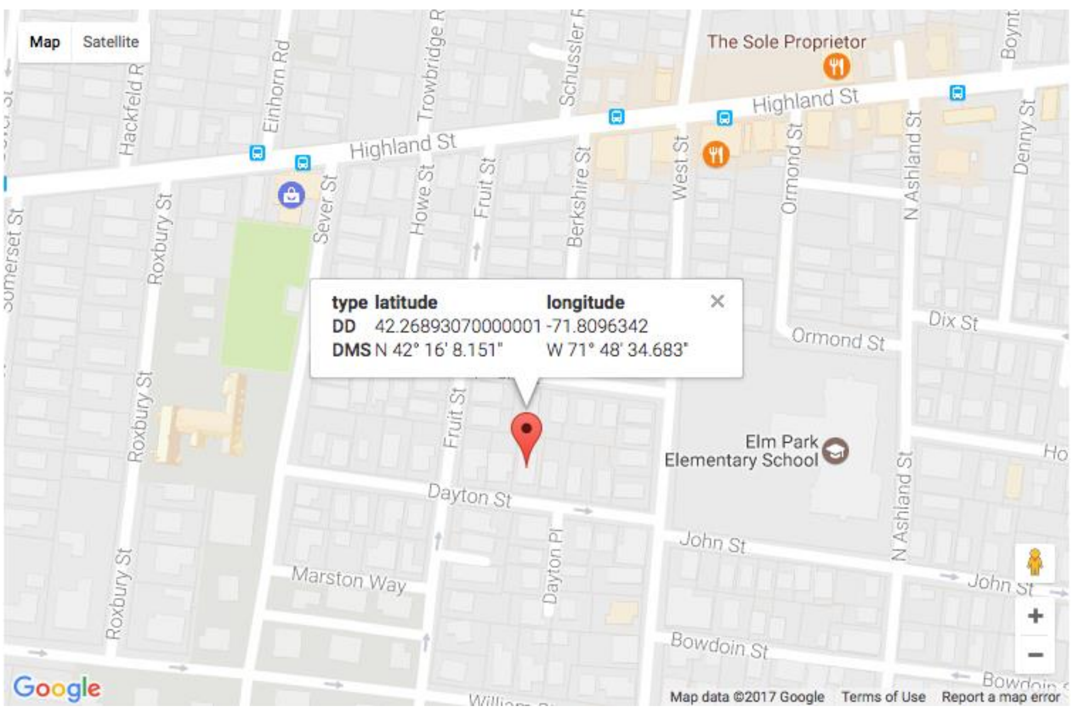
```
#include <SoftwareSerial.h>
#include <string.h>
#include <TinyGPS.h>
SoftwareSerial Sim800Serial(2, 3);
byte buffer[64];
int count=0;
SoftwareSerial GPS(2, 3);
TinyGPS gps;
unsigned long fix_age;
long lat, lon;
float LAT, LON;
void gpsdump(TinyGPS &gps);
bool feedgps();
void getGPS();
void setup()
{
 Sim800Serial.begin(19200);
 GPS.begin(9600);
 Serial.begin(9600);
 delay(500);
 Sim800_Inti();
}
void loop()
{
 Sim800Serial.listen();
 if (Sim800Serial.available())
 {
   while(Sim800Serial.available())
   {
     buffer[count ]=Sim900Serial.read();
     if(count == 64)break;
    }
   Serial.write(buffer,count);
   //Cmd_Read_Act();
   clearBufferArray();
   count = 0;
 }
 if (Serial.available())
   Sim800Serial.println(Serial.read());
}
void clearBufferArray()
{
 for (int i=0; i<count;i )
   { buffer[i]=NULL;}
}
void Sim800_Inti(void)
{
 Sim800Serial.println("AT CMGF=1");
 Serial.println("AT CMGF=1");
 delay(500);
 Sim800Serial.println("AT CNMI=2,2");
```

```
 Serial.println("AT CMGF=1");
 delay(500);
}


void SendTextMessage()
{


Sim800Serial.print("AT CMGF=1\r");
delay(100);
Sim800Serial.println("AT CMGS = \"5088318920\"");
delay(100);
Sim800Serial.println("Please wait while GPS calculates position");
delay(100);
Sim800Serial.println((char)26);
delay(100);
Sim800Serial.println();
int counter=0;
GPS.listen();


for (;;)
{
  long lat, lon;
  unsigned long fix_age, time, date, speed, course;
  unsigned long chars;
  unsigned short sentences, failed_checksum;
  long Latitude, Longitude;


  gps.get_position(&lat, &lon, &fix_age);
  getGPS();
  Serial.print("Latitude : ");
  Serial.print(LAT/1000000,7);
  Serial.print(" :: Longitude : ");
  Serial.println(LON/1000000,7);
  if (LAT == 0 && LON == 0)
 {
   continue;
 }
 counter ;
 if (counter<30)
 {
   continue;
 }

 Sim800Serial.print("AT CMGF=1\r");
 delay(100);
 Sim800Serial.println("AT CMGS = \"5088318920\"");
 delay(100);
 Sim800Serial.print("Latitude : ");
```

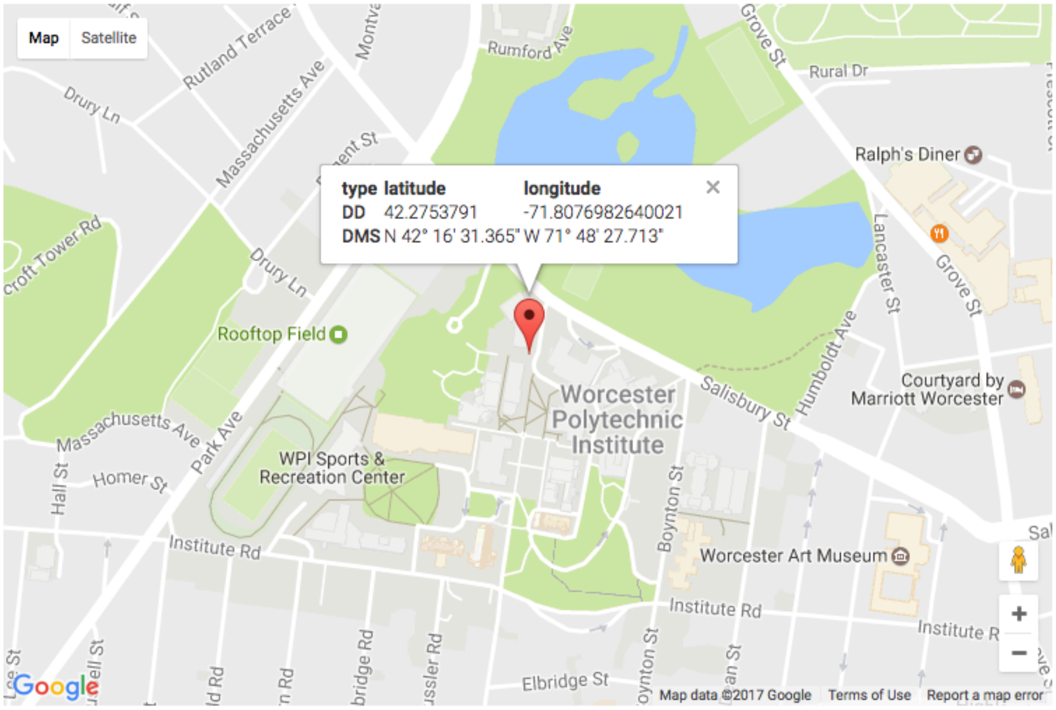
```
 Sim800Serial.print(LAT/1000000,7);
 Sim800Serial.print(" :: Longitude : ");
 Sim800Serial.println(LON/1000000,7);
 delay(100);
 Sim800Serial.println((char)26);
 delay(100);
 Sim800Serial.println();
 counter=0;
 break;
}
}


void getGPS()
{
  bool newdata = false;
  unsigned long start = millis();
  while (millis() - start < 1000)
  {
    if (feedgps ())
    {
      newdata = true;
     }
   }
   if (newdata)
  {
    gpsdump(gps);
   }
}
bool feedgps()
{
  while (GPS.available())
{
    if (gps.encode(GPS.read()))
      return true;
    }return 0;
}
void gpsdump(TinyGPS &gps)
{
  gps.get_position(&lat, &lon);
  LAT = lat;
  LON = lon;
  {
    feedgps();
   }
}
```

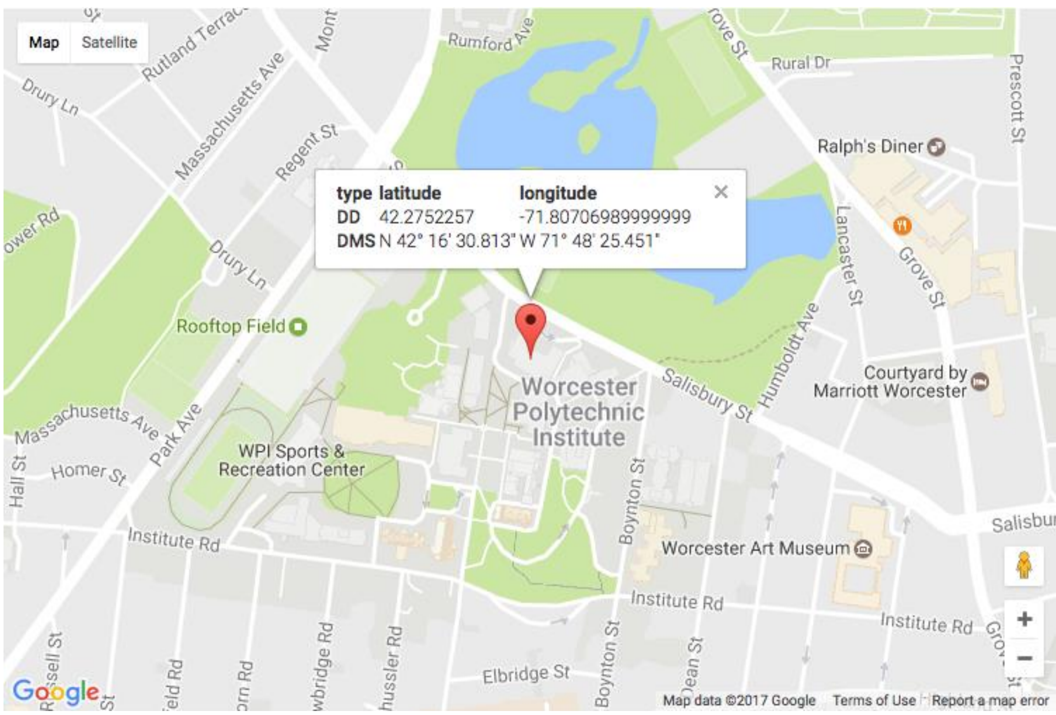
Appendix E: Google Maps Geolocation





Location 1: Top = Data Received, Bottom = Actual Location





Location 2: Top = Data Received. Bottom = Atwater Kent Laboratories at WPI Actual Location

Appendix F: Battery Charging Test

Before:

After 1 hour charging: