A Wireless Sensors Network System for Spatially Resolved Storm Surge Measurements

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ABSTRACT: Preliminary economic damage estimates from Hurricane Matthew indicate near $4-\$6$ billion out of which 10\% is due to storm surge. The need for accurate hydrologic model to assist in flood-damage analysis and design future flood mitigation has prompted FEMA to conduct studies to acquire discrete storm surge measurements via placement of water level sensors prior to a storm event. The crucial aspect of monitoring and transmitting information for the extreme weather condition in nearly real-time is vitally important and requires accurate, robust, and relatively inexpensive sensing systems. The present wireless sensor network (WSN) system for storm surge measurements is an adaptation of the Florida Tech developed hurricane monitoring system which satisfies the above requirements. The WSN system for storm surge application is undergoing trials in lab and field-tests in areas with river and sea water. This paper describes the overview, design, and performance testing of the system.

KEYWORDS: remote sensor network, storm surge measurements, water level sensor, submersible pressure sensor.

1 INTRODUCTION

As areas, proximate to bodies of water (river, lakes, and sea) continue to become densely populated, damage from natural disasters also continue to increase, as demonstrated by hurricanes Katrina, Ike, Sandy, and most recently Matthew \cite{1} \cite{2} \cite{3} \cite{4} \cite{5}. For decades, the U.S. Geological Survey (USGS) has provided critical information on near-shore storm hydrodynamics for decisions regarding emergency response and resource allocation before, during, and immediately after landfall of hurricanes and nor'easter. Much of this information was provided via a few real-time tide gages focused on near-shore waters that supplemented and extended the National Oceanographic and Atmospheric Administration’s (NOAA) National Ocean Service (NOS) tide-gage network. In addition, data from temporary sensors and high-water marks (HWM) occasionally obtained by the USGS in cooperation with the Federal Emergency Management Agency (FEMA), the U.S. Army Corps of Engineers (USACE), and various state agencies, provided post-storm documentation of coastal floods; however, neither strategy provided sufficient, timely information for emergency operations or to facilitate improvements in storm-tide and wave modeling and prediction \cite{6}.

Preliminary estimates from the most recent Hurricane Matthew indicate economic damage near $4-$6 billion, and does not include insured losses related to additional flooding and business interruption \cite{4} \cite{6}. Of this $4-6$ billion, 90\% of the insurance claims are expected to be related to wind and 10\% is expected to be related to storm surge \cite{5}. Figure 1 shows the model’s estimate of the storm surge prior to the arrival of the Hurricane Matthew along east coast of the US. However, storm surge flooding at St. Augustine area was reported to be 2.5 feet above ground level. The measured water levels were at discrete location (active tide gages for Florida is 24, Georgia is 1,
North Carolina is 7, and none for South Carolina [7]) and they do not paint a clear picture of the varying water levels at the entire south east coast.

Figure 1. Hurricane Matthew Storm surge forecast [8]

The need for hydrologic interpretation of monitoring data to assist in flood-damage analysis and future flood mitigation prompted FEMA to fund sensor placement before Hurricane Sandy to determine how high the water reached after the storm. The results demonstrated how the additional resolution and accuracy of flood depictions due to the data from the sensors resulted in greatly improved damage estimates, as well as vastly improved resiliency planning that would help communities prepare for future storms [9]. Figure 2 shows a before and during image of a surge event off the Melbourne coast during Hurricane Sandy taken by one of the authors of this proposal. Although the water level rise here is approximately a 1-2 ft, the whole beach including the volleyball court is inundated with water.

In order to reduce property damage and prevent loss of life (by evacuation from danger zones), it is essential to better predict the destruction caused by the unexpected events by accurately and preemptively monitoring environmental activity and relaying real-time updates for extreme weather conditions. The crucial aspect of monitoring and transmitting information for the extreme weather condition in nearly real-time is vitally important and requires accurate, robust, and relatively inexpensive sensing systems. The sensing systems should also be capable of monitoring a local area of interest while still being relatively easy to deploy. Current damage prediction models are not as robust as they could be due to the existing measurement systems not providing real-time data [10]. Large scale predictive models are available [11] [12] [13] [14] [15], but their resolution (as shown by the predicted hurricane Matthew storm surge forecast and the measured values which are still discrete) to predict small scale local effects are not good enough. Therefore, it is important to develop better prediction models based on actual real-time measurements on a local scale.

2 BACKGROUND WORK

Since 2002, a research team at Florida Institute of Technology (Florida Tech) has been developing a wireless sensor network (WSN) for monitoring the effects of weather conditions on man-made structures during natural disasters, such as a hurricane. The effort was boosted in 2006 when support from NSF (CMMI Award ID # 0625124) allowed for the development of a second generation WSN. The effort was further leveraged in 2009 with complementary support from the Florida Department of Community Affairs Division of Emergency Management. The current result is a 3rd generation WSN, which represents the state of the art in hurricane monitoring at an
affordable cost [16] [17] [18] [19] [20] [21] [22] [23]. As of today, it is the only operational and fully wireless local area multi-point sensing network of its kind. Other wireless sensor systems only provide average data over a wide area and, that too, at a much higher cost. For understanding the impact of large-scale natural events on localized communities both global and local scale measurements are necessary, but current systems only provide global measurements, whereas this technology provides local measurements.

The present system (Figure 3) offers at least three fully operational WSN systems each with 32 sensors for hurricane deployment and data collection on pre-instrumented houses that are available through the Florida Coastal Monitoring Program [24]. The network consists of three major sub-systems. The first sub-system includes up to 30 remote sensors units associated base unit and data collection laptop that are installed in the field. This sub-system is referred to as the field installation and it is responsible for performing sensing, measurements and data acquisition. Multiple sensor types are integrated within a sensor unit and the data collected by each one of them are sent to the base unit. The sensor elements that are accommodated by the sensor unit are measuring pressure, temperature, wind speed, and wind direction. The second sub-system is the communication network that connects individual WSN field installations to a central server. The communication network sends the data from the data collection laptop to a centralized location, which may be located anywhere within the Internet cloud. This approach allows for a real-time availability of the measured data and provides for real time monitoring and control of the WSN field installation. Finally, the third sub-system is the central server itself, which processes measured data and presents them to the end user. The processing of the data is performed in an automated fashion and in near real time, which no other technologies have been able to reproduce.

In summary, the key features of the wireless multi-sensors network system innovation are, the capability of measuring multi-point with multi-sensors on a structure, collecting data, and sending it to a server to process and publish on the Web in nearly real-time. The other aspect of the system is it has not only the wireless and networking capabilities, but it also has several in-situ controls such as individual sensor remote control, self-negotiating communication, and excellent data throughput, precision, and accuracy; it is robust, reliable, and portable, and allows simultaneous deployment on multiple residences in case of a hurricane landfall within a short time. Additionally, the system has been tested in various wind tunnels and outdoor testing facilities, such as at Florida
International University and at the University of Florida. The objective of the past tests and deployments was collection of real or simulated hurricane wind data.

The assembly exploded view of the pressure/temperature sensor node is shown in Figure 4. The base unit, battery pad, and the field laptop computer are placed in a ventilated waterproof box in the vicinity of the house (see Figure 4).

![Figure 4. Sensor assembly (on left), Current WSN fully deployed on rooftops of residential houses (on right)](image)

The development of this WSN system is a major achievement from the NSF grant, and has been described in several international journal and conference papers [16] [17] [18] [19] [20] [21] [22] [23]. Three graduate students completed their master thesis on the project [25] [26] [27]. In addition, several undergraduate students have been continuously involved with the research, helping with the design, assembly, testing, and deployment of the sensors.

3 REVIEW OF EXISTING TECHNOLOGIES AND THEIR DEFICIENCIES

The principal agency responsible for monitoring the storm surge levels in the US is the NOAA. The Center for Operational Oceanographic Products and Services (CO-OPS) manages the National Water Level Program (NWLP) and provides operationally sound observations and monitoring capabilities coupled with operational Nowcast/Forecast modeling [28]. These models cater for the insurance company risk assessment modelers, but are currently modeled on historical data, and limited real-time measurements; thus, current models are predictive only, and are only revised after the event, whereas future models based on data provided via the proposed system could be augmented in real-time.

There are several methods used by NOAA, the USGS, and the FEMA to measure storm surge [28] [29]. Prior to the arrival of a hurricane, the USGS team deploys a multitude of instruments to acquire water level and meteorological data. Two of the instruments which are rapidly deployable are [30]:

1. Rapid deployment gages (RDG): Temporary stream gages setup to provide short-term water-level data for critical areas lacking stream gages during an event (see Figure 5). Although the
RDGs are semi-portable, the cost, manpower, and labor hours required to assemble, install, or disassemble and relocate are significantly cost prohibitive and therefore minimize the USGS’s ability to rapidly deploy and relocate on-demand (based on the uncertainty of the storm path). Moreover, the overall cost of each RDG, and the associated labor for use per RDG drastically reduces the number of RDGs afforded in any year’s budget [31].

![Figure 5](image5.png)

Figure 5. USGS Rapid-Deployment Gages a) Overview of the entire system, b) RDG for a bridge installation, c) Closeup view, and d) River bank installation [32]

2. USGS Storm Tide Sensor (STS) Pressure Water Level Sensors are temporary pressure sensors that provide information about storm surge duration, times of surge arrival and retreat, and maximum depths (Figure 6) [28]. In addition to RDGs, the USGS occasionally employs Storm Tide Sensors (STSs), which are more mobile than the RDGs and thus make up for the bulkiness and lack of mobility of the RDGs. However, these mobile storm tide sensors are not capable of transmitting data in real time. Although the data is recorded by the STSs during the storm event, it is only stored locally and collected after the storm has passed, and thus is not provided to any agency in real time.

![Figure 6](image6.png)

Figure 6. a) USGS Storm Surge Sensor (non-transmitting) b) close-up view [33]
In summary, the RDGs require significant power provisions, such as a bank of car batteries or solar panels (which can be unreliable given various weather patterns), and the STSs only provide data after the event, in which case neither provide the easy of deployment, reliability, and real-time data-access requisite for accurate and predictive modeling. Notwithstanding the immense strain on manpower to deploy/record/collect storm-tide data locally at various sensors, the lack of real-time data regarding storm surge levels delays the decision-making process regarding critical events, such as evacuation, relief values/controls, diverting water etc. Furthermore, these delays allow for more damage to be done; the prevention of which would more than justify the use of the proposed innovation. Finally, to further enhance the longevity of the proposed system, the WSN can be remotely reconfigured or modified to shut down, reboot, or even change sampling frequency in the absence of any significant weather event so as to save battery life and reduce labor costs needed to maintain the system.

There are several other sensors in the market, none of which provide the level of sophistication, real-time data capture, mobility, or power provisions requisite for current market demands for storm surge measurements, such as those of the USGS [34] [35] [36] [37] [38] [39]. Several of the wireless sensing systems investigated did not provide water level measurements in their sensor suite [40] [41] [42]. The submersible pressure transducer used in our proposed innovation alone is offered by a limited number of companies [43] [44] [45] [46] [47], but are not tied to package system that would address the needs of USGS for storm surge applications. Various wireless sensing systems have been developed by university teams to monitor either bridges or buildings [48] [49] [50] [51] [52] and was never successfully transitioned into a commercial product for storm surge measurements. There are few companies that have a flood monitoring package in list of products, one such company [53] [54] offers an ultrasonic level meter connected to a wireless transmitter and can transmit the data in nearly real-time in a field operation [53]. This product offered is a really competitive option, but relies on ultrasonic level meter, which is ideal for measuring rising or receding water levels in a controlled weather conditions. During conditions such as hurricane or hazardous wind may alter the orientation of the sensor placement which would then provide misleading values for the rising water levels. To monitor the storm surge levels, this sensor system would also require additional poles and columns specially constructed so the sensor has a clear unobstructed view of the surface of the water. The additional column, poles or pillar constructed are again prone to deflection from high wind conditions. The proposed sensor system in this proposal is not affected by the deflection or orientation of the sensor because the submersible sensor is still capable of reading the pressure in the fluid column. The orientation or alteration of the sensor head unit does not affect the transmission capability of the sensor head units. Each of the sensor head units will also contain a GPS tag to provide with location information as well as water levels. Some companies also provide a “flood detection and water level monitoring” packages but also clearly indicate the suitable application area are for river level monitoring, highways, railways, and even in cellars [55]. These packages are also not compact and require either a battery or solar power. Some companies also state a flood and water level detection system [56] but clearly state that the usage is limited to families with vacation homes or those who travel frequently, so they can remotely monitor any leaks or water level in the home.

4 WIRELESS SENSOR NETWORK SYSTEM FOR STORM SURGE APPLICATION
This section presents the overview of the WSN concept for storm surge application from the very beginning when the research team found the active need for this application during a NSF I-Corps contract. This section also provides an overview of the feasibility of the WSN concept for storm surge application, as well as development of the prototype.
4.1 NSF I-Corps

The wireless sensors network (WSN) system developed with NSF (CMMI 0625124) sponsorship represents the one-of-a-kind for monitoring local environmental (harsh) conditions surrounding a manmade structure exposed to extreme environments (a hurricane or flood). Localized multi-point sensing is vital for accurately modeling the effect of large scale average data (e.g. wind speed) on small scale structures (e.g. residential roof pressure). The WSN system has the capability of measuring pressure and temperature on a roof, collecting data (rate up to 1400 samples/s) and sending it to a server to process and publish on the web in nearly real-time. Also, wind speed and direction are measured by the system with the use of an anemometer. The innovative aspect of the system is it has important wireless and networking capabilities, including individual sensor remote control, self-negotiating communication, and excellent data throughput, precision, and accuracy; it is robust, reliable, and portable, and allows simultaneous deployment on multiple residences in case of a hurricane landfall. Since the land falling hurricanes have random wind fields a large portion of the continuously collected data may be unimportant.

The major goal for the NSF I-Corps contract was to determine if this product was commercially viable. The intent was to adapt the WSN system to other environments like lab settings of full scale or even for normal wind tunnels. The WSN system could also be expanded to several other types of measurements like meteorological, seismic, oceanographic and structure condition monitoring. This goal was to verify whether this technology could make a significant commercial impact. The preliminary product presented, was funded by the NSF I-Corps contract and a detailed customer discovery was pursued for a period of 7 weeks [57]. The preliminary product consisted of a cluster of 32 wireless pressure sensors in a weather proof enclosures, which can be readily deployed in the field (on top of a house or a building), and be capable of recording pressure measurements over a continuous acquisition period of 12 hours. The technical details and comprehensive capabilities of the product are presented in this reference [16] [17] [18] [19] [20] [21] [22] [23].

The initial value proposition and the associated customer segment was developed using the dynamic Business Model Canvas (see Figure 7) [58] [59] [60] [61].
The initial value propositions considered not only the physical component of the product, but also services that would have to be rendered to process the acquired data. This meant that the physical product (cluster of wireless pressure sensors, anemometer, and a laptop with wireless networking enabled) would be deployed by our team. Our team would also collect the data and process the data and if required, perform numerical simulations to identify the potential damage location on the rooftops of a building.

The initial customer segment was really diverse and had specific initial value propositions for each segment.
### Table 1 Initial Value Proposition and Customer Segments [57]

<table>
<thead>
<tr>
<th>Value Proposition</th>
<th>Customer Segments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Lessen (or save money) property damage</td>
<td>• Home Owners&lt;br&gt;• State Government&lt;br&gt;• National Hurricane Center&lt;br&gt;• Federal Emergency Management Agency&lt;br&gt;• Building Codes&lt;br&gt;• Emergency Response Center&lt;br&gt;• Insurance Companies&lt;br&gt;• Re-insurance Companies&lt;br&gt;• Construction&lt;br&gt;• Contractors&lt;br&gt;• Architectural Engineers&lt;br&gt;• Department of Transportation (Bridge Safety)</td>
</tr>
<tr>
<td>2. Measurements would improve modeling and prediction capabilities</td>
<td>• Home Owners&lt;br&gt;• State Government&lt;br&gt;• National Hurricane Center&lt;br&gt;• Federal Emergency Management Agency&lt;br&gt;• Building Codes&lt;br&gt;• Emergency Response Center&lt;br&gt;• Insurance Companies&lt;br&gt;• Re-insurance Companies&lt;br&gt;• Construction&lt;br&gt;• Contractors&lt;br&gt;• Architectural Engineers&lt;br&gt;• Department of Transportation (Bridge Safety)</td>
</tr>
<tr>
<td>3. Ease of setup and data collection</td>
<td>• Researchers&lt;br&gt;• Field Engineers</td>
</tr>
</tbody>
</table>

At the conclusion of the 6 weeks’ period (86 interviews), the value proposition for customer segment of home owners was determined to be a passive interest.

### Table 2 Customer Feedback [57]

<table>
<thead>
<tr>
<th>Value Proposition</th>
<th>Must Have</th>
<th>Nice to Have</th>
<th>Don’t Care</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lessen (or save money) property damage</td>
<td>15</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Measurements would improve modeling and prediction capabilities</td>
<td>49</td>
<td>19</td>
<td>6</td>
</tr>
<tr>
<td>Ease of setup and data collection</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Customer Segments</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>State Government/NHC/FEMA/Building Codes/ Emergency Response</td>
<td>2</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Insurance Companies</td>
<td>2</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Construction, Contractors and Architectural Engineers</td>
<td>6</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Researchers</td>
<td>15</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Field Engineers</td>
<td>6</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Home Owners</td>
<td>10</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>Re-insurance Companies</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
The cost of acquiring the customer was also prohibitively high and the retention rate was nil. Most of the customer segments deemed pressure measurements as a passive need. A product pivot was initiated after assimilating preliminary data from the interviews. Sensor specific data collection would be desirable to different customer segments.

1. Water level measurements: For example, real time monitoring of the water levels.
2. Structural health monitoring for historical and expensive bridges and structures: Strain measurements
3. Structure or vehicle stability monitoring during operations: Accelerometers
4. Monitor air quality (or any offgassing related issues) in office buildings

4.2 Modification, Lab Testing, and Data Validation

The post I-Corps customer discovery determined that there is an active need for a temporary water level sensing system which can provide real-time accurate measurements of rising water levels, and can be easily deployed. To ensure the current WSN system can acquire the water level measurement and continue to operate in real-time, a series of tests were performed at our Hurricane lab at Florida Tech. Figure 8 shows a basic concept of the current sensor node reading the hydrostatic pressure (instead of the ambient pressure reading) at a test location (location 1) and transmitting to the laptop wirelessly located at location 2. A series of tests were also performed to verify the multiple sensors nodes working in tandem to acquire the hydrostatic pressure reading and transmitting it wirelessly.

Figure 8. Overview of the setup during Lab Testing

Figure 9 and Figure 10 shows a sample plot of a pressure reading for a receding water level by emptying a test tank. Digital manometer readings corroborated this data as well.
Figure 9. Samples Drain Tests Conducted with a 38 cm Tall Container

Lab Testing also was also conducted with a 71-cm tall container. The sensor (on right of the figure) is adjacent to the tank and measuring the hydrostatic pressure at specified sampling rate. The sensor is on a constant communication with the router and the laptop (left in the figure).

Figure 10. Samples Drain Tests Conducted with a 71 cm Tall Container
4.3 Storm Surge Prototype Development

After the completion of the lab testing with the modified sensors, a feature list for a prototype for storm surge measurement was designed. The storm surge prototype would address the need for real-time water level measurements and the network architecture is derived from WSN and consists of three major sub-systems (Figure 11). The first sub-system includes several remote sensors units, associated base unit and data collection laptop that are installed in the field. This sub-system is referred to as the field installation and it is responsible for performing sensing, measurements, and data acquisition. The submerged pressure sensor would be connected to a sensor head unit via a long cable (approximately 5-7 m long). The cable length would be adequate and reinforced (to avoid straining the cable as well as protect from debris) to capture rising water level as seen from a strong hurricane such as hurricane Matthew where the recorded peak water levels were at 3.8 m [9].

The second sub-system is the communication network that connects individual WSN field installations to a central server. The communication network (private wireless network) sends the data from the data collection device to a centralized server location either through Wi-Fi or cellular data networks (3G – 3rd Generation) using the IEEE 802.15.4 protocol. This approach allows for a real-time availability of the measured data and provides for real-time monitoring and control of the WSN field installation. In case the real-time link fails, all the data is stored locally in the

Figure 11. Schematic of the WSN for storm surge application
memory, which can be retrieved after the storm passes or when the connection is reestablished. Finally, the third sub-system is the central server (or cloud storage) itself, which processes measured data and presents them to the end user (via graphs or dedicated specific mobile app). The processing of the data is performed in an automated fashion and in near real time, which no other technologies have been able to reproduce. As this is done through the world-wide web, the remote logging-in operation can be performed from a computer anywhere in the world (not restricted to the localized server). A Control Client application is used to monitor status, control individual or group of endpoints (sensor nodes), display sensor data in real-time, and generate logs of sensor data. The design is a user-friendly Graphical User Interface that is meant to be an easy to use method of monitoring and controlling the wireless sensor network. In the WSN system for storm surge, the sensor head unit can be interfaced with a buoy so the sensor head unit is always above water or the sensor head unit can be constrained to a post, pole, or column for a pier. If a buoy is preferred for the purpose of recording sea level rise, it would be anchored to a location to ensure there is minimal movement of the sensor and less strain on the reinforced cable connection. The sensor head unit will also contain a GPS chip which would uniquely identify each sensor units in the network as well as provide an exact location in real time. In an event of failure of one or multiple sensor units, the remaining sensor units in the network will continue to perform flawlessly. The battery pack in the sensor head unit will last more than 5-7 days (on normal operation mode) on a single charge (a metric to validate during field testing of the prototype). Additionally, we could incorporate solar recharging to ensure extended duration for the sensor unit.

4.4 Overview of the Prototype

This section consists of making a device capable of storing data from a water pressure transducer at sea (Figure 13). Such data will then be transmitted wirelessly to a remote server to allow its access from any location. The main components of the prototype are discussed below:

Submersible Water Pressure Transducer: This is the sensor that will measure the water pressure. Its output ranges from 4-20 mA, and it is powered with 24V.

Atmeg328P: This 3.3V microcontroller will be in charge of running the WiFi and Cellular modules. It will also collect the sensor’s data, save it in an SD card, and retrieve the information when needed to be sent out to the server.

Figure 12. Submersible Water Pressure Transducer
Sim808: This cellular GSM GPRS module will be in charge of transferring the data to the server. It supports HTTP and FTP applications. Its quad band allows it to connect to any global GSM network. It communicates directly with the Atmega328P via Software Serial. This module can be powered directly with a 4.2V Lithium-polymer battery.

ESP8266-12: This module has the versatility of granting microcontrollers access to WiFi networks, or acting as a microcontroller with PWM, ADC, and SPI capabilities. It communicates directly with the Atmega328P via Software Serial. This module requires a 3.3V voltage to work properly.

4-20mA ADC: This integrated circuit will convert the sensor’s output from milliamps to voltage. The conversion is required so that the Atmega328P can interpret the sensor’s output values. It communicates directly with the Atmega328P via I²C. The chip can be powered with 3.3V or 5V.

3.3V Regulator: This component will regulate the input voltage of the battery to supply 3.3V to the following parts:
- Atmega328P
- ESP8266
- 4-20 mA ADC
- SD Card Reader

Sim Card: A 2G mini SIM card is required for the Cellular module.

DC/DC Booster: This chip will boost the input voltage to 24V. Required for the water sensor to work properly.
Battery Charger: This is a single-cell linear charge management controller suitable for 4.20V, 4.35V, 4.40V, and 4.50V. It features a programmable charge current that ranges from 15mA - 500mA

MicroSD Card: Here is where all the sensor’s readings will be stored. It communicates directly with the Atmega328P via SPI using an SD card reader.

Battery: A lithium polymer battery of 4.2V with a capacity of approximately 6000 mAh will be used to power the entire device. Assuming the device is active (transmitting data) every hour, the battery can last up to one day without a recharge. The battery can be recharged through a micro USB cable using a 5V input.

Case: The following case will be used to enclosure and protect the PCB: This case is made of flame retardant polycarbonate. Furthermore, it includes a silicone rubber gasket for dust and moisture resistance. These features make it tough, heat-resistant, water-resistant, and a good electrical insulator. Perfect for electrical hardware used outdoors.

The CAD representation of the completed prototype and the CAD visual of the exploded view is shown in Figure 14.

The workflow needed to acquire detailed storm surge measurements is shown in Figure 15.
5 CONCLUSION AND FUTURE WORK

The key features of this prototype and differentiators from the current state of the art or competing technologies are that there is no product containing a combination of the requisite set of technologies that would meet the needs of the customer; specifically, a light-weight, portable, easy-to-install, wireless, real-time, water propagation enabled device that records and propagates pressure based measurements that are also not limited to specific heights, depths, times, or are subject to damage from wind, or other elements and are contained in a durable, marinized enclosure.

Field testing of the prototype WSN system is underway near the Melbourne beach. Field testing will also be conducted with one of our prospective customers for field performance assessment in collaboration with the local NOAA staff. The system will be deployed and tested at locations specified by NOAA and USGS in addition to other field environments identified during our market and partner validation. The test of success will be the ability to real-time multi-point data acquisition of water level height and remote communication of the data over cellular network.
6 ACKNOWLEDGEMENTS

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