UNIVERSITY OF PUERTO RICO AT MAYAGÜEZ

MAYAGÜEZ, PUERTO RICO

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

# WaveSphere

A PROJECT PROPOSAL SUBMITTED AS A PARTIAL REQUIREMENT OF THE MICROPROCESSOR INTERFACING COURSE ICOM-5217

by

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For: Dr. M. Jiménez
Course: ICOM 5217, Section 096
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## Abstract

Wave post-breaking dynamics is a phenomenon that is not yet well understood. This article proposes a series of improvements for a device that is used to measure variables that are essential to the physics of wave breaking. The aforementioned device is a spherical drifter with a diameter of 7.5cm designed to closely imitate the dynamics of a particle in the water. It will be equipped with a 3-axis accelerometer, gyroscope and magnetometer, allowing the sphere to measure its motion to 9 degrees of freedom. This will allow the researchers to reconstruct the device trajectory in the wave via dead reckoning. A GPS module, on-board flash memory for data storage and a wireless communication module for data retrieval will also be integrated into the spheres in order to solve various problems currently faced by researchers in this area. It is expected that, when used in synergy, multiple units will be able to greatly help researchers understand the dynamics of wave breaking.

# Table of Contents

# 1. Introduction

The waves are abundant at sea, yet it is known little about them. The waves break at shore and at sea, moving with dynamics that have not been understood precisely. This project intends to help researchers on their journey of discovering the natural physics and motion dynamics of waves. As the waves break, the water particles create twists and turns above and below them, sometimes forming vortices. These particle movements are the ones that describe the dynamics of the waves. The best way to study such dynamics is by imitating these particles [1]. Hence, this work proposes a device that somewhat mimics these particles.

Upon consultation with Dr. Miguel Canals, an assistant professor of Fluid Mechanics and Coastal Engineering at the University of Puerto Rico at Mayagüez and Director of the Fluid Mechanics and Ocean Engineering Laboratories, he presented the authors of this proposal with a problem currently being faced by his research team. Currently, his team is working on an NSF funded project titled "Lagrangian Observations of Turbulence in Breaking Waves", for which they have designed capsules to collect the data needed for their experiments [2]. The capsules that they have designed, although functional, could be greatly improved. The capsules[1] have limited capabilities that made the data collecting process difficult. A physical button outside the spherical casing was used to turn the capsule on which created an easy access for the water to enter inside the capsule, damaging the electrical components. A single sensor was present in the sphere, a triaxial accelerometer, which limited the data they could gather during an experiment. Moreover, because the size of the capsule is quite small, the spheres could be easily lost and needed to be tied so that they could be easily found, an action which might interfere with the integrity of the data being collected. The research team uses the capsules to perform the experiments that collect the necessary data. An experiment is performed by throwing the capsules into identified waves and gathering their data trough the capsule's sensor for at least thirty seconds. Once the thirty seconds had passed the wave would have finished and the sphere would eventually drift to the shore.

This work aims to aid the same group of researchers at the University of Puerto Rico at Mayagüez to create an improved implementation of the Lagrangian[2] drifters. This work proposes to redesign and improve their current implementation by adding several features and components. This includes adding more sensors to obtain other data such as a gyroscope, magnetometer and GPS. Implementing a base station that attaches to a computer and can communicate wirelessly with the capsules to solve the data retrieval problem and possibly the localizing problem. All while at the same time handling components to conserve energy for a successful day of experiments.

In order for the improved implementation to be successful it must still adhere to the constraints established in the original idea, that is, the capsule must have a spherical form and must be as small as possible, trying to imitate a water particle. Moreover, because more

[1] From hereon the terms "capsules" and "spheres" will be used interchangeably.

[2] The Lagrangian, L, of a dynamical system is a function that summarizes the dynamics of the system.

than one capsule will be used for an experiment they must also be cost effective. This work aims to create capsules that are in the same price range or lower than the previously created one by the research team while adding the extra features previously mentioned. The goal is an overall improvement of their solution so that they can use this system to obtain better results from their experiments.

## 2. System Block Diagram

The block diagram for the proposed system is shown in Figure 1. For simplicity and to avoid an overly-crowded diagram, not all modules were connected to the power conversion and management circuit. However, during the implementation phase, all modules should be connected to the power conversion and management circuit in order to operate properly.

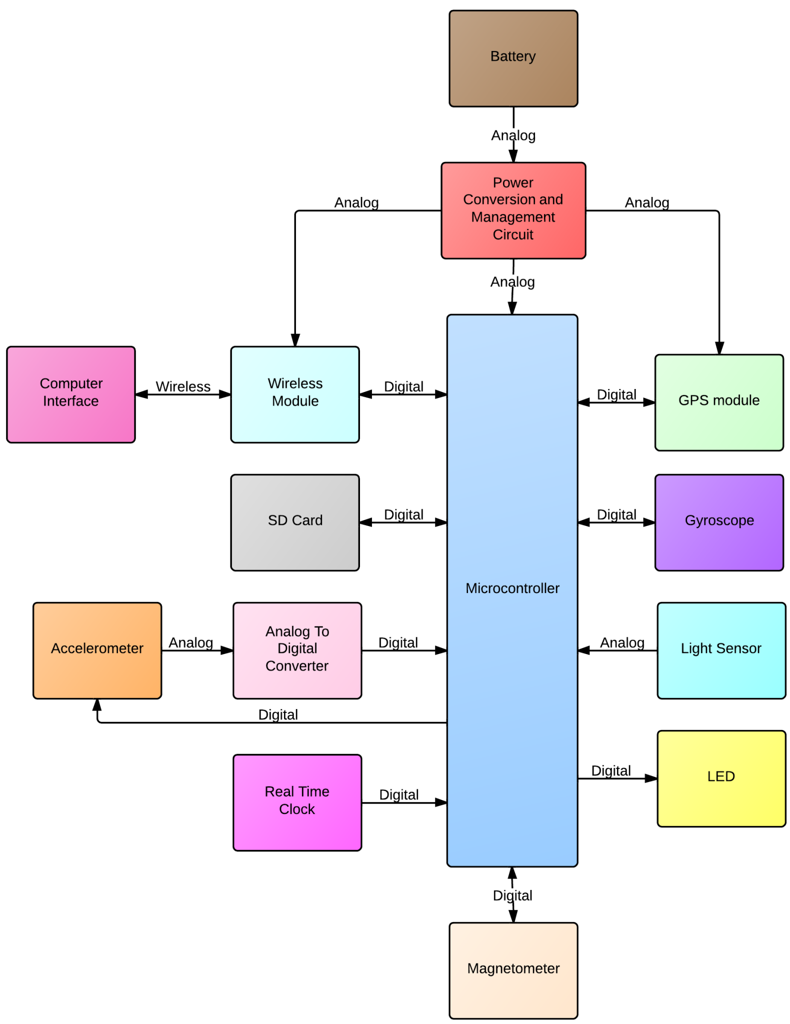


Figure 1: System Block Diagram

## 2.1 Necessary Components

1. Microcontroller
    - The microcontroller is needed in order to be able to establish the communication between components, control the different components, and process the output of the sensors.
2. Battery
    - A battery is needed because the sphere has to be portable and it is the only way to provide the necessary power.
3. Power Conversion and Management Circuit
    - Power Conversion and Management is needed in order to give the necessary and adequate power to each component so that they can work properly and efficiently. It contains voltage converters and a battery meter.
4. GPS Module
    - A GPS Module is needed in order to know the precise location of the spheres when the user has to recover them after they have been thrown at sea for an experiment.
5. Gyroscope
    - The gyroscope will be used to determine the sphere's orientation while being carried by a wave.
6. LED
    - An LED will be used to help the user find the sphere when conducting experiments at night and to indicate battery and data transfer status.
7. Light Sensor
    - A light sensor will be used in order to only turn on the LED at night to conserve energy. The LEDs will still display battery and transfer status, but will not flash continuously as would be the case with the LED that aids in finding the spheres at night.
8. Real Time Clock
    - A Real Time Clock is needed in this system in order to track and record the time at which each sample measurement is taken in order to be able to match it with the measurements taken by different spheres.
9. Accelerometer
    - The accelerometer will be used to measure the acceleration of the sphere while being carried by the waves.
10. Analog to Digital Converter (ADC)
    - An ADC is needed in order to take the data from the acceleratometer, which has an analog output, and convert it to digital signals so that the microcontroller can read them.

11. SD Card
    - The SD Card will be used to save the data measured during an experiment.
12. Wireless Module
    - The wireless module will be used to connect the spheres with a central base so that data can be retrieved without having to open the spheres.
13. Computer Interface
    - A computer interface is needed in order to be able to wirelessly retrieve the data collected via wireless and save it for future analysis.
14. Magnetometer
    - Provides the extra 3 degrees of freedom that the researchers need in order to employ dead reckoning algorithms [2].

# 3. Specifications

This section contains the requirements and technical specifications for the proposed capsules.

## 3.1 Requirements and Features

1. The capsules must have a spherical geometry and have a symmetric mass distribution along an axis
2. The spheres must be compact. Their diameter must be between the ideal 7.5 cm and 10 cm.
3. The spheres must be able to measure their acceleration and orientation as it changes with the motion of the waves to 9 degrees of freedom.
4. The spheres must be able to take samples at a frequency of at least 256 Hz for a sampling window of 30 seconds.
5. The spheres must be able to broadcast their location to a base station after they have finished logging data and have resurfaced.
6. The spheres must be able to transfer their data wirelessly so that they do not have to be opened and risk water damage.
7. The spheres must be able to operate on batteries for a full day on the field, which might involve at most 20 throws a day, each throw lasting between 10 and 30 minutes.
8. The spheres must be shock resistant and water proof.
9. The spheres must be powered on and off wirelessly from the base station and should not require that the capsules be opened.
10. The spheres must have a flashing LED in order to aid locating them at night.

## 3.2 Limitations

1. The spheres operate on batteries, which means that a team cannot stay at sea for an indefinite amount of time without having replacement batteries.
2. There is a limited range in which the system can communicate with the base station. The system must have resurfaced and be close enough to the base station in order to transfer the acquired data.
3. When the system is submerged it can not be tracked by GPS.

## 3.3 Hardware Requirements

1. Global Positioning System Module
    - A module that will be able to locate the spheres to within 3 meters after an experiment is performed and concluded.
2. XBee Module
    - The XBee module will be used to communicate with the base station and allow the transfer of data from the spheres to the base station.
3. Triaxial Accelerometer Module
    - Will be used to measure the acceleration of the sphere while it is being carried by the waves. Must be capable of measuring a range of up to +/-250g.
4. Triaxial Gyroscope Module
    - Will be used to determine the system's orientation while it is being carried by the wave.
5. Triaxial Magnetic Field Sensor
    - The magnetic field sensor, in conjunction with the gyroscope and accelerometer completes the 9 degrees of freedom required in the system.
6. Real-Time Clock
    - The Real-Time clock will be used to precisely track and record the time at which sample data is taken in order to match the measurements taken by different spheres and be able to analyze the data conjointly.
7. microSD Card
    - The microSD card will act as mass storage in order to save the measurements taken during an experiment.
8. Indicator Lights
    - Will be used to indicate the transfer and battery status as well as to aid the location of the spheres at night.
9. Light Sensor

- A light sensor is needed so that the flashing LED that will help locate the spheres will only turn on at night.

10. Analog to Digital Converter (ADC)
    - An ADC of at least 12 bits is needed in order to convert the analog output of the accelerometer into digital values that can be read by the microprocessor.

## 3.4 Software Requirements

1. Sampling Mode
   - This mode will enable the spheres to take samples from its sensors for a sampling window of at least 30 seconds. It will also log the data into the mass storage so that it can be retrieved later.
2. Locating Mode
   - After the sampling is complete, the sphere should enter this mode in order to transmit its current location to the base station.
3. Transfer Mode
   - The spheres should have a mode that allows them to wirelessly transfer the acquired data to the base station.
4. Low powered or Sleep mode
   - This mode will be entered when the system is not taking samples, transferring data or transmitting its location. All the components should enter a low power mode if available
5. LED controller
   - The software must have an interface with the status and flasher LEDs in order to turn them on or off depending on the status of the capsule.
6. Out of Memory Alert
   - Since data persistency is very important, the software must have a means of raising an alert, through a combination of flashing LEDs or through the base station, if there is not enough memory on the mass storage to perform another experiment. This is to prevent a current experiment from overriding the data acquired during a previous experiment.

## 3.5 Essential Components

1. Communications
   - The system will communicate wirelessly with a base station. Data collected in the system will be transferred from the system to the base station while the base station communicates with a computer through a USB interface.

2. User Interface
    - The system will have an LED that serves as a status indicator. In addition to this, the computer attached to the base station will have a graphical user interface that will facilitate data transfer between the spheres and the computer.
3. Control Scheme
    - The system will control the sensors that will collect all experiment data. It must also control the power mode of all the attached modules during the different stages of an experiment. Whenever a peripheral is not needed, it should enter a low power state so as to prolong battery life. The wireless modules will also need to be controlled in order to transfer data when requested.
4. Microprocessor-based
    - The need of a microprocessor is justified by the use of multiple sensors, the need to synchronize the date acquired from all the sensors to the same point in time, the need to compress data in order to perform various experiments without the need to empty the mass storage and the need to transfer data from a mass storage to a base station upon request.

# 4. Market Description

The proposed system is designed to study the dynamics of surface waves, which is why the targeted market is any organization or individual that studies or researches the field of oceanography and wishes to perform Lagrangian or another similar analysis on the waves.

The system is designed to be small and to be used throughout an entire day of experiments and not over an extended period of time. It is also intended to be used on surface waves and currents and not in deep sea currents. These two characteristics make the proposed system greatly different from other oceanographic products such as drifters or buoys that are commercially available. A similar but somewhat limited implementation of the system exists and is currently being used by the research team that the authors of this work are trying to help. This implementation costs around $500 to $800 for each sphere and it only measures the sphere's acceleration using a triaxial accelerometer, it also has to be turned on with a physical button and must be tied to a small cable with other capsules for it to not get lost. This work aims to add more functionality for the same price and if possible attempt to lower the cost.

# 5. Design Criteria

1. Power and Energy
   - The sphere must be as energy efficient as possible, since it must endure long days on the field with a very limited space for storing energy. The limited space for energy storage can be remedied by the use of energy harvesting techniques. Since the sphere will be rocked by the waves, the energy harvesting techniques are viable.
2. Sustainability
   - To be cost effective, the sphere should endure as long as possible. The chassis design must be strong and rugged to resist heavy shock from the waves and possible rocks. The internal electrical components should be of the most recent models so that they reach their obsolescence phase in a longer time. The internal components should also be tightened securely to the chassis so that they do not get damaged by bumping against the sphere chassis. Since multiple uses is expected from the sphere, extra care will be taken to design a long lasting and long cycle power system.
3. System Integrity
   - Integrity of the data is of utmost important in the application in which the spheres are intended to be used. The chassis design is an important criteria for ensuring data integrity, since the internal memory and measurement components could be damaged by a faulty chassis that did not absorb shock correctly.

# 6. Project Timetable

Figure 2 shows an overly simplified Gantt chart that only contains the milestones and deadlines for the semester. The complete Gantt chart was too complex to include in the report. A modified version suitable for printing has been included in Appendix C. The complete Gantt chart is available online and can be found at the following web address: `http://tinyurl.com/Gantt-WaveSphere`

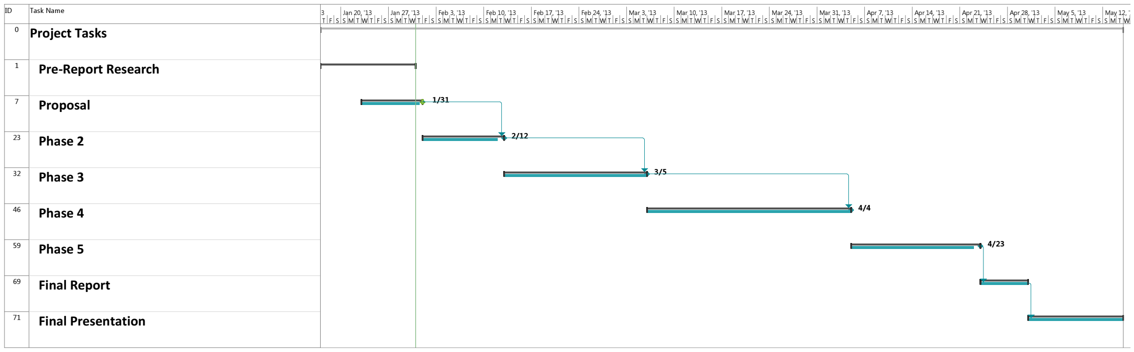


Figure 2: An overly simplified Gantt Chart.

# 7. System Conception

## 7.1 Global System View

The proposed system aims to aid the study of the dynamics associated with the wave breaking process. The system consists of a base station, which is composed of a computer with the necessary software and hardware components to communicate with the spheres, which comprise the rest of the system. The system must be able to handle at least five spheres at once with a single base station.

The spheres are meant to emulate fluid particles in movement as they are carried by the waves. For this reason, the spheres should be as small as possible so that they could better emulate the particles of a fluid. Previous work has been done with spheres of 7.5 cm in diameter [2], however these capsules lacked some of the capabilities that are proposed in this work. One of the goals of this work is to attempt to add the extra functionality while keeping the current sphere dimensions.

The spheres should be transparent with the printed circuit boards containing the necessary circuitry aligned as much as possible with a single axis to ensure an axisymmetric design. Figure 3 shows a very rough model of what the spheres should look like. Note that this model does not aim to accurately depict the final product, but rather to give the reader a visual idea of the devices this report has tried and continues to describe.

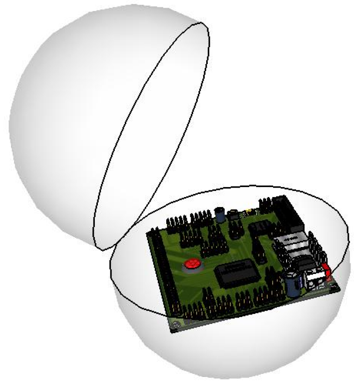

Figure 3: A rough model of the spheres.

Each sphere must perform a series of tasks in a specific order during an experiment. First, the sphere will be activated wirelessly by the base station and will be signaled to start collecting data. The sphere will then be thrown into the waves, where it will continue to collect and save data continuously for at least 30 seconds. Once the sampling is completed, the sphere will attempt to signal its location, as determined by the GPS module inside, to the base station. At the same time, if the light sensors indicate that the experiment is being conducted at night, the indicator lights must start flashing in order to aid the researchers in the search for the sphere. Once the sphere has been recovered, it needs be either reset for another experiment, set in data transfer mode or deactivated. The base station will allow the user to select one of these options. If the user resets the sphere for another experiment, then the previously described process is repeated without deleting the data of the previous experiment. After this point, if the sphere does not have enough memory to perform another experiment, then the base station should alert the user and at the same time an LED will light up in a particular manner to call attention to this situation. If the user chooses to deactivate the sphere, the data must persist in the mass storage until it is retrieved.

If the user instead selects the option to transfer the data, then the sphere will enter the data transfer mode and will indicate the user that the process has begun by flashing a blue LED. At the same time, the software at the base station will indicate to the user that the data transfer process is underway. The base station must acquire the data in each sphere and create a separate file to save the data acquired for each experiment. After this, the user should be asked if they wish to delete the data on the mass storage in the sphere. If they select this option, then all the data from previous experiments will be deleted. After the data transfer has concluded, the sphere will deactivate itself and return to the original state described earlier.

## 7.2 User Interface Level

Dr. Miguel Canals and Andre Amador have stated that the system currently being used, although functional, has a series of problems that limit their experiments. These limitations include not being able to let the sphere run free due to the lack of a location system, the need of breaking the sphere to include a button to turn it on, the need to open the sphere in order to get the data, the need to wait until the spheres are completely dry in order to be able to open them to prevent hardware damage, the inability to take out the data in the field, the inability to do these experiments at night due to the fear of losing sight of them and the inability to reuse the sphere right away for another experiment (because of the way the data is collected)

In order to attend their needs, the proposed system will be divided in two parts from the user's perspective: the sphere and a computer interface. The sphere will contain an LED that will be turned on during the night to help the user find the sphere, allowing them to do their work at night. The LED will also serve to indicate transfer and battery status.

On the computer, the user will have a simple program with a Graphical User Interface (GUI) that will enable them to interact with the spheres. Figure 4 shows a mock-up illustrating the concept of how the GUI might look like but does not aim to depict the final product. As it can be seen, the proposed GUI displays options for locating spheres, turning the sphere system ON or OFF, changing the sample interval, retrieving data from an individual sphere or from all at the same time, deleting the data from one sphere or from all of them, manually turning on the LED strobe and seeing additional information for each sphere such as ID number, sample start date and last retrieved location. Features and options, as well as the look, will change on the final product based on the necessities and requirements of the researchers, which are, ultimately, the end-users.

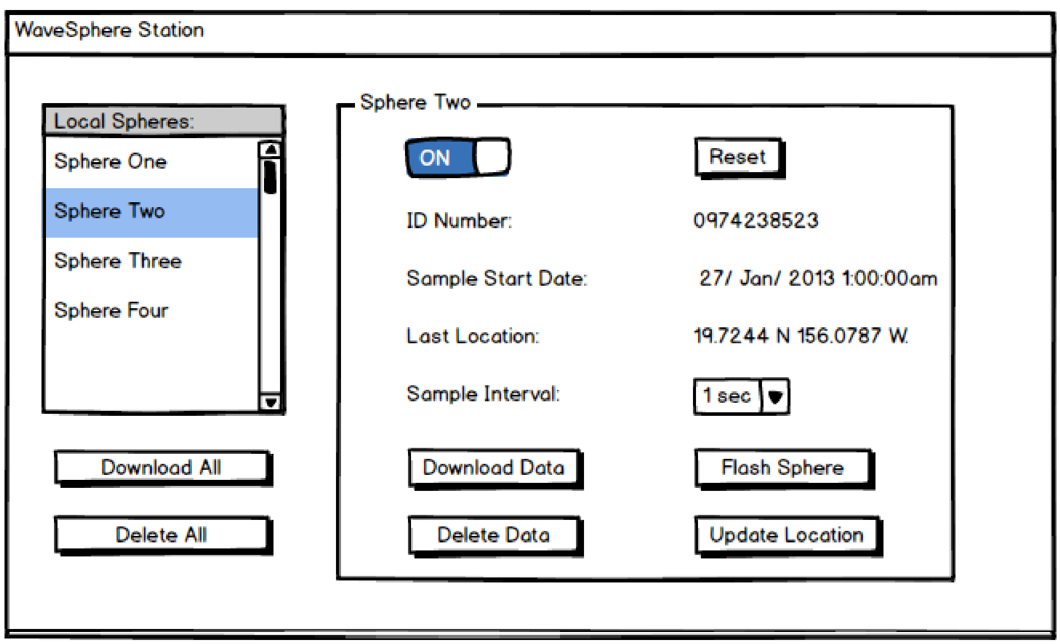


Figure 4: Graphical User Interface of the software housed in the computer acting as a base station.

## 8. Expert Opinion

This project, will be a collaboration with Dr. Miguel Canals and his graduate student, André Amador, on the development of a system that will be part of their research. They have agreed, along with Carlos Ortiz (who works with them), to collaborate with this project by providing guidance and advice on the technical aspects and requirements of their research. Since this is part of a reserach project, they will no doubt be an excellent resource throughout the development of the proposed solution. A statement from Dr. Canals himself follows:

> "Por este medio les solicito la asistencia del grupo del curso Micro-procesadores II para colaborar en nuestro proyecto de NSF titulado "Lagrangian observations of turbulence in breaking waves". El peritaje de su grupo nos será muy útil en continuar desarrollando nuestros instrumentos y a la vez les permitirá a su grupo llevar a cabo un proyecto con aplicación real en la investigación.
>
> Cualquier cosa me llaman al celular 787-393-3283.
>
> En cuanto a los aspectos técnicos de las esferas deben estar en contacto con André Amador"


Dr. Miguel Canals
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Carlos Ortiz
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## 9. References


[1] A. Amador, "Lagrangian observations of turbulence in breaking surface waves," Tech. Rep. May, 2012.

[2] A. Amador, M. Canals, G. Guerrero, J. Cruz, and E. Ortiz, "Development of novel instrumented lagrangian drifters to probe the internal structure of breaking surface waves," in *Oceans, 2012*, pp. 1 –6, oct. 2012.

# Appendices

## A. Work Distribution Table

Table 1: A work distribution table showing a list of tasks to be performed for this project and the resources assigned to them

| Task Title | Adrian | Daniel | Nelian | Samuel |
|---|---|---|---|---|
| Topic Research | ✓ | ✓ | ✓ | ✓ |
| Define System Requirements and Specifications | ✓ | ✓ | ✓ | ✓ |
| Define Essential Hardware and Software | ✓ | ✓ | ✓ | ✓ |
| Create System Block Diagram | | | ✓ | |
| Set up Project Website | | ✓ | | |
| Cover Page, Table of Contents, Report Format | ✓ | | | |
| Specifications: Requirements and Features | ✓ | ✓ | ✓ | ✓ |
| Specifications: Limitations | | | | ✓ |
| Market Description | | ✓ | | |
| Specifications: Essential HW/SW | | | ✓ | |
| Block Diagram | | | ✓ | |
| System Conception: Global System View | ✓ | | | |
| System Conception: UI Level | | | ✓ | |
| Design Criteria | | ✓ | | ✓ |
| Expert Opinion | | | ✓ | |
| Introduction | | ✓ | | |
| Abstract | ✓ | | | |
| Proof Reading | ✓ | ✓ | ✓ | ✓ |
| Project Journal | | | | ✓ |
| Project and Work Distribution Table | ✓ | | | |
| MCU Research | ✓ | ✓ | ✓ | ✓ |
| Other Components Research | ✓ | ✓ | ✓ | ✓ |
| Discussion and Selection of MCU | ✓ | ✓ | ✓ | ✓ |
| Block Diagram Revision | ✓ | ✓ | ✓ | ✓ |
| Design Team Logo and Poster | ✓ | | ✓ | |
| Set up Git Repository | | ✓ | | ✓ |
| Component Selection | ✓ | ✓ | ✓ | ✓ |
| Update Block Diagram | ✓ | ✓ | ✓ | ✓ |
| Build System Schematics | ✓ | | ✓ | |
| Cost Analysis | | ✓ | | ✓ |

| Task Title | Adrian | Daniel | Nelian | Samuel |
|---|---|---|---|---|
| Timing Analysis and Diagrams | | ✓ | ✓ | |
| Power Analysis | ✓ | | | ✓ |
| Software Requirement Definition and Verification | ✓ | ✓ | ✓ | ✓ |
| Midterm Exam | ✓ | ✓ | ✓ | ✓ |
| Use Case Diagrams | ✓ | | ✓ | |
| Design User Interface | | ✓ | | ✓ |
| Flow Charts, Module and Interface Design for MCU Software | ✓ | ✓ | ✓ | ✓ |
| Connect and Work with Accelerometer and Gyroscope | ✓ | ✓ | | |
| Connect and Work with Magnetic Field and Light Sensor | | | ✓ | ✓ |
| Connect and Work with GPS Software and Hardware Module | | ✓ | ✓ | |
| Connect and Work with SD Card Software and Hardware Module | ✓ | | | ✓ |
| Connect and Work with Power Supply and Management | ✓ | | ✓ | |
| Connect and Work with Xbees | | ✓ | | ✓ |
| Implement Sampling Mode Software Module | ✓ | ✓ | ✓ | ✓ |
| Implement Transfer Mode Software Module | ✓ | ✓ | ✓ | ✓ |
| Implement LED Controller Module | | | ✓ | ✓ |
| Software and Hardware Testing and Debugging | ✓ | ✓ | ✓ | ✓ |
| Implement Out of Memory Alert Software Module | | ✓ | | ✓ |
| Implement Low Power State Software Module | ✓ | | ✓ | |
| Implement User Interface | ✓ | ✓ | ✓ | ✓ |
| Design and Make PCBs | ✓ | ✓ | | |
| Connect, Solder, Test | ✓ | ✓ | ✓ | ✓ |
| Field Testing (Water Tank) | ✓ | ✓ | ✓ | ✓ |
| Software Testing and Debugging | ✓ | ✓ | ✓ | ✓ |
| Hardware Testing and Debugging | ✓ | ✓ | ✓ | ✓ |

# B. Project Journal

Wordpress, an open source blogging tool, will be used to keep the project journal. A blog was chosen because it is accessible online and it provides an easy to use interface for creating multiple entries. An entry will be created for each work session as well as any important news, major ideas, part selection, design choices and implementation changes. One advantage of this approach is that the course instructor or assistant can access the project's journal at any time to get a status update on the development and progress of this project. The blog can be accessed at `http://tinyurl.com/WaveSphere` with the password "Interfacing".

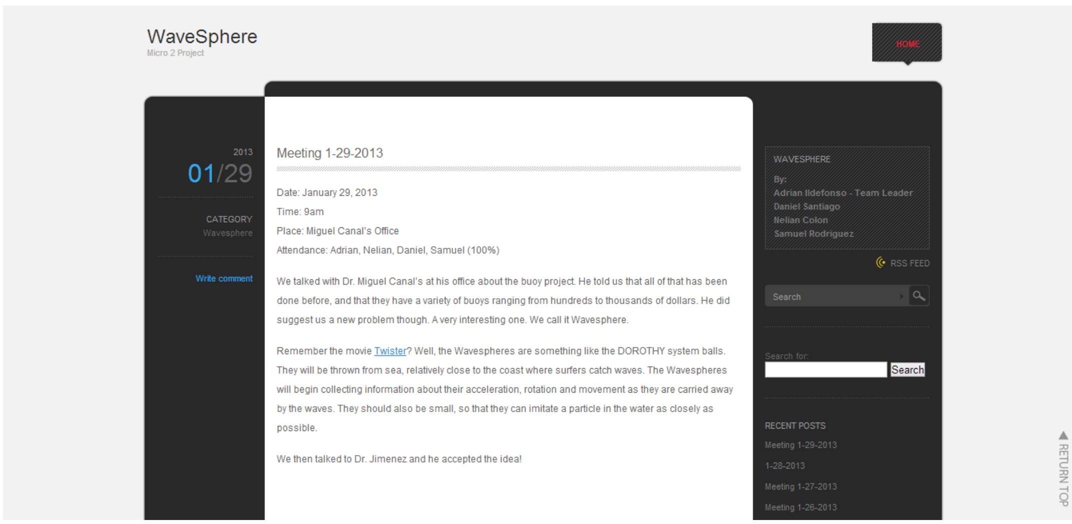
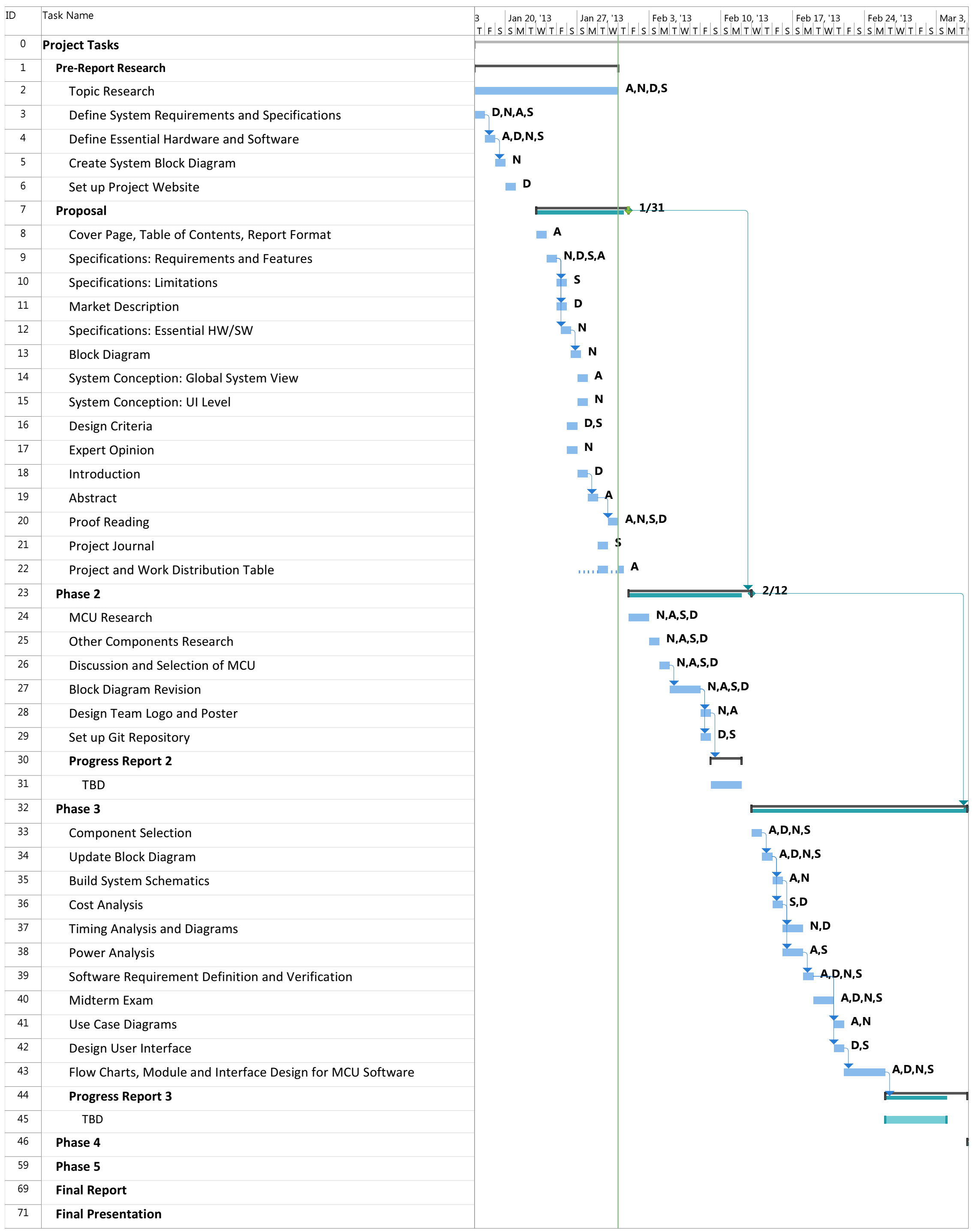



Figure 5: Wordpress blog

# C. Detailed Gantt Chart

Due to its complexity, the Gantt chart had to be separated in order to include it in this report. The complete Gantt Chart, which can be zoomed into in order to read it more easily, can be found at the following web address: `http://tinyurl.com/Gantt-WaveSphere`



| ID | Task Name |
|---|---|
| 0 | **Project Tasks** |
| 1 | **Pre-Report Research** |
| 7 | **Proposal** |
| 23 | **Phase 2** |
| 32 | **Phase 3** |
| 46 | **Phase 4** |
| 47 | Connect and Work with Accelerometer and Gyroscope |
| 48 | Connect and Work with Magnetic Field and Light Sensor |
| 49 | Connect and Work with GPS Software and Hardware Module |
| 50 | Connect and Work with SD Card Software and Hardware Module |
| 51 | Connect and Work with Power Supply and Management |
| 52 | Connect and Work with Xbees |
| 53 | Implement Sampling Mode Software Module |
| 54 | Implement Transfer Mode Software Module |
| 55 | Implement LED Controller Module |
| 56 | Software and Hardware Testing and Debugging |
| 57 | **Progress Report 4** |
| 58 | TBD |
| 59 | **Phase 5** |
| 60 | Implement Out of Memory Alert Software Module |
| 61 | Implement Low Power State Software Module |
| 62 | Implement User Interface |
| 63 | Design and Make PCBs |
| 64 | Connect, Solder, Test |
| 65 | Field Testing (Water Tank) |
| 66 | Software and Hardware Testing and Debugging |
| 67 | **Progress Report 5** |
| 68 | TBD |
| 69 | **Final Report** |
| 70 | TBD |
| 71 | **Final Presentation** |
| 72 | TBD |