



ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA (ICAI)

MÁSTER EN INGENIERÍA DE TELECOMUNICACIÓN

# **A COST-EFFECTIVE MODULAR INTERNET-CONNECTED WEATHER STATION FOR HAITI**

Autor: Antonio Juan García Viciano

Director: William Eisenstadt

**Madrid**

Junio 2018



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Director: William Eisenstadt

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# **Agradecimientos**

A mis padres, que siempre han sido un apoyo constante durante estos años de carrera.



# **A COST-EFFECTIVE MODULAR INTERNET-CONNECTED WEATHER STATION FOR HAITI.**

**Autor: García Viciano, Antonio Juan.**

Supervisor: Eisenstadt, William.

Entidad Colaboradora: University of Florida.

## **RESUMEN DEL PROYECTO**

El alto nivel de pobreza en Haití ha derivado en la búsqueda de soluciones modernas y de bajo coste que puedan impulsar el desarrollo del país. Una estación meteorológica económica, modular y conectada a Internet ha sido desarrollada, y testada con óptimos y razonables resultados en Florida, para cubrir la necesidad de Haití en cuanto a la obtención de datos meteorológicos públicos y apoyar tareas de planificación en el sector agrícola y medioambiental.

**Palabras clave:** IoT, Estación meteorológica, Haití

### **1. Introducción**

Por un lado, Haití es la nación mas pobre del hemisferio oeste y esta constantemente siendo agitada por catástrofes naturales. Los huracanes y terremotos son muy frecuentes en Haití debido a su localización en el medio del Caribe. Por ello, Haití necesita métodos tecnológicos de medición meteorológica para avisar y predecir desastres naturales, un objetivo que el gobierno de Haití ha estado constantemente persiguiendo, pero las frecuentes catástrofes no paran de frenar los avances. Este análisis de datos meteorológicos es crítico para apoyar tareas de planificación en el sector agrícola y medioambiental, para que el país pueda comenzar a crecer económicamente.

Por otro lado, el Internet de las Cosas (IoT) está permitiendo modernas soluciones tecnológicas alrededor del mundo y la aparición de proyectos mas simples y económicos, que pueden llevar mejoras tecnológicas a aquellos lugares donde antes no era posible.

Este proyecto, *A modular Internet-connected Weather station for Haiti*, propone el desarrollo de una estación meteorológica que pueda cubrir la necesidad de Haití para la obtención de datos meteorológicos públicos a través del University of Florida's Institute of Food and Agricultural Sciences (UF IFAS). Por lo tanto, los haitianos podrían usar la estación para analizar datos meteorológicos y estar mas preparados frente a los desastres naturales que afectan al sector agrícola.

### **2. Definición del proyecto**

El principal objetivo del proyecto es el desarrollo de una estación meteorológica modular que use sensores IoT económicos y el montaje e instalación de la estación en Haití para el final del proyecto. Para conseguir esto, este objetivo general ha sido dividido en varios subjetivos.

- Conocer e identificar los diferentes sensores y tecnologías IoT y las plataformas que van a ser usadas para el desarrollo de la estación, de tal modo que se obtenga el suficiente conocimiento previo que el proyecto requiere.
- El desarrollo de un modelo de estación modular en el que cada unidad pueda funcionar individualmente, y el añadido o extraído de futuras unidades pueda hacerse de una forma sencilla y rápida sin interferir en la operación de las demás unidades.
- Almacenamiento de los datos recogidos en una tarjeta de memoria SD para minimizar la dependencia de la estación con el wifi, por lo que no se perderán datos en caso de que el router se caiga.

Permitir la visualización de datos en vivo que la estación esta obteniendo y subiendo a una plataforma meteorológica pública y global, de tal modo que los investigadores en Haití puedan trabajar fácilmente con los datos.

### **3. Sistema desarrollado**

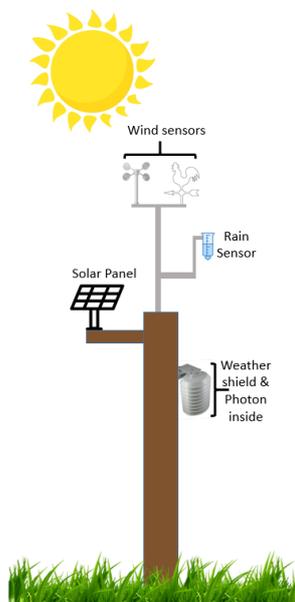
Para tener la estación meteorológica funcionando óptimamente, su desarrollo ha pasado por varias fases, desde la adquisición de los módulos hasta su implementación software. En primer lugar, varias reuniones han tenido lugar para decidir los requisitos básicos que debe cumplir la estación y que tecnologías hay en el mercado que puedan garantizar la medición de los datos de manera económica y efectiva, de tal modo que sea asequible para los haitianos.

Más tarde, se ha decidido que el controlador de la estación iba a ser una unidad llamada Photon, desarrollada por la empresa Particle, y que permite una infinidad de oportunidad a la hora de integrar nuevos módulos o programarlos, debido a la plataforma de software que la misma compañía ofrece. El Photon va a ir acompañado de sensores de temperatura, humedad, presión, lluvia y velocidad y dirección de viento que van a ser las principales características de la estación. Además, la estación ha sido integrada con un panel solar y una batería de litio para darle autonomía en cuanto a alimentación eléctrica y una placa de tarjeta de memoria SD que pueda eliminar la dependencia de la estación con el wifi.

Para la unión de todos los módulos al microprocesador, un plan de implementación software ha sido realizado de tal modo que cada unidad estuviera funcionando en un espacio de tiempo óptimo. Cada modulo ha sido propiamente analizado para conocer su funcionamiento y su forma de obtención de datos, de tal forma que el Photon pueda gestionar los datos provenientes de cada sensor. Además, varias conversiones de unidad y funciones de código han tenido que ser realizadas para almacenar cada parámetro meteorológico en el formato apropiado.

Finalmente, el Photon ha sido enlazado con dos salidas de datos principales, una plataforma pública y global, Weather Underground, y una placa de tarjeta de memoria SD. Mientras que Weather Underground dota a la estación de una herramienta moderna para ver los datos en

vivo y registros pasados, la tarjeta SD sirve como una forma de eliminar la dependencia de la estación con el wifi porque no es posible garantizar una conexión constante en Haití.



*Ilustración 1 – Concepto de la arquitectura de la estación meteorológica*

#### **4. Resultados**

Por un lado, Weather Underground ha recibido exitosamente los datos recogidos por la estación y la página web de visualización ha sido capaz de desarrollar varias gráficas que muestran la evolución de los parámetros meteorológicos durante un día, mes o año. Además, el sitio web está siendo actualizado cada 5 minutos y va mostrando los datos en vivo a través de su intuitiva interfaz.

Por otro lado, la tarjeta de memoria SD está generando un archivo de texto que almacena cada una de las instancias de datos que envía la estación. Además, esta salida tiene un formato compatible con Excel o otras herramientas Big Data, de tal forma que los datos puedan ser volcados en la herramienta si los investigadores quisieran analizarlos para el desarrollo de métodos predictivos que puedan ser beneficiosos para Haití.

En ambos casos, los resultados han sido acordes con un día normal de verano en Gainesville, Florida, que es donde las pruebas han sido realizadas. Florida tiene un clima semitropical y, en verano, se caracteriza por altas temperaturas durante el día, acompañadas de un alto porcentaje de humedad relativa, una presión a nivel del mar y frecuentes lluvias tropicales. Los resultados obtenidos por la estación han reflejado este escenario, por lo que ha sido posible demostrar que está obteniendo datos meteorológicos razonables.

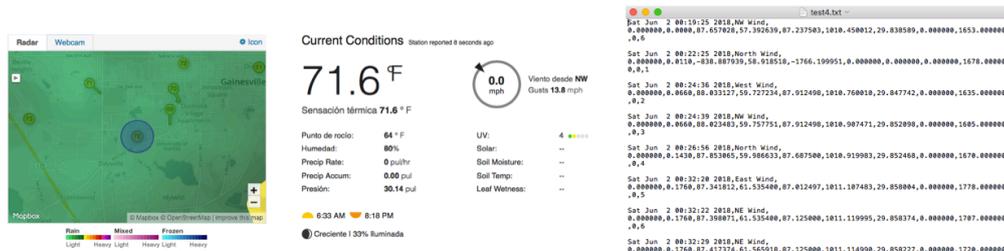


Ilustración 2 – Ejemplo de resultados en Wunderground (izquierda) y fichero de texto (derecha)

## 5. Conclusiones

Este proyecto ha dado un gran impulso a la implementación de soluciones IoT en países en subdesarrollados, como Haití. Se ha demostrado que estas soluciones no son solo validas para países desarrollados, y que pueden servir como una base para el inicio de autodesarrollo del país. Además, un modelo de estación meteorológica modular ha sido diseñado exitosamente y estará preparado para su implementación en Haití en los próximos meses, por lo que los haitianos podrían usarla como una herramienta meteorológica fácil de usar que les permita gestionar la agricultura, entre otros.

En términos de futuros avances, está previsto integrar un sensor de humedad del suelo antes de implementar la estación en Haití, que está previsto para antes de que acabe 2018. Además, han aparecido en el mercado nuevas soluciones IoT que pueden dotar a la estación de nuevas capacidades y se está estudiando su implementación en futuras versiones de la estación, como mejores microprocesadores inalámbricos de Particle o sensores más baratos de otras compañías. Finalmente, el código está siendo optimizado para mejorar el funcionamiento de la estación meteorológica y tener una solución que gestione mejor el ahorro de energía.

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- [3] "WunderMap," [Online]. Available: <https://www.wunderground.com/wundermap>

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Supervisor: Eisenstadt, William.

Collaborating entity: University of Florida.

## **ABSTRACT**

Haiti's poverty has derived in looking for modern low-cost technological solutions that could boost the country development. A low-cost modular IoT weather station has been developed, and tested with optimal and reasonable results at Florida, to serve Haiti's need for public weather data, so it could support planning in environmental and agriculture sectors

**Keywords:** IoT, Weather station, Haiti

## **1. Introduction**

On the one hand, Haiti is the poorest nation in the western hemisphere and it is always being damaged by the causes of natural catastrophes. Hurricanes or earthquakes are extremely common at Haiti every year due to its location on the middle Caribbean. Accordingly, technological weather measurements are needed at Haiti to warn and predict natural disasters, a goal that the government of Haiti is always pursuing but the constant natural disasters are slowing it down. This meteorological data analysis is critical to support planning in environmental and agriculture sectors, so Haiti could start growing economically.

On the other hand, Internet of Things (IoT) is bringing modern technological solutions around the globe and it is enabling the emergence of simpler and cost-effective projects, that could bring technological improvements to those locations where it was not possible before.

This project, *A modular Internet-connected Weather Station for Haiti*, propose the creation of a cost-effective modular IoT weather station at Haiti that can serve Haiti's need for public weather data through the University of Florida's Institute of Food and Agricultural Sciences (UF IFAS). Therefore, Haitians could use the weather station to analyze weather data and be more prepared to natural disasters, that will affect its agricultural sector.

## **2. Project Definition**

The main scope of this project is to develop a modular weather station with IoT low-cost sensors and to assembly and install it on Haiti by the end of the project. To accomplish it, this general objective is going to be divided on several sub-objectives.

- Knowing and identifying the different sensors and IoT technologies and platforms that are going to be used on the station development to obtain the enough background that this project requires.

- The development of a modular station model on which each unit could work by their own, so the add-on or put-out of future units could be done in an easy and agile way without interfering other units' operations.
- Storage of all the collected data in a Secure Digital (SD) card to minimize the station Wi-Fi dependence, so any data will be lost if the Wi-Fi router is down.
- To enable the visualization of live data obtained by the weather station on a public and global platform, so researches at Haiti could easily work with the data.

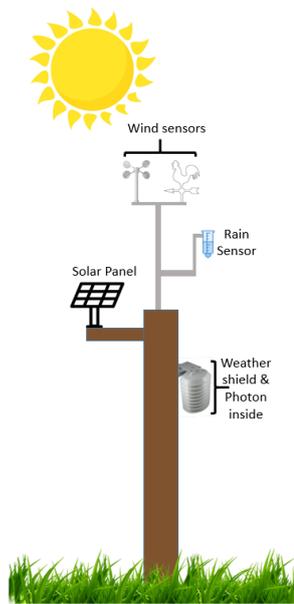
### **3. Developed system**

To have a workable and optimal weather station, its development went through several phases, from modules acquisitions to software implementation. First, several meetings took place to decide the station basic requirements and which units or IoT technologies the market has that assure weather measurement in a cost-effective way, so it could be affordable by Haitians.

Then, it was decided that the station controller was going to be a unit named Photon, developed by the company Particle, and it gives an infinity of possibilities when integrating new modules or to program it, due to a software platform developed by the same company. The Photon is going to be surrounded by temperature, humidity, pressure, rain and wind speed & direction sensors that are going to compose the station main capabilities. Moreover, the station has been integrated with a solar panel and lithium battery to give it power self-autonomy and with a SD card board that is going to save each data instance to remove the station Wi-Fi dependence.

To assembly every unit to the microcontroller, a software implementation plan was scheduled to have each unit properly working in an appropriate space of time. Each module was properly analyzed to know how it works and the way it has to obtain data, so the Photon could manage data that came from each sensor. Several data unit conversions and code functions were done to have every weather parameter in its proper format.

Finally, the Photon was linked to two main outputs, a public and global weather platform named Weather Underground and a SD card board to record every measurement instance. While Weather Underground provides the station with a modern tool to visualize live and past data, the SD card serves as a way of removing the station Wi-Fi dependence because it is not possible to guarantee a full-time connection at Haiti.



*Illustration 1: Weather station architecture concept*

#### **4. Results**

In this project, the success of the results has been mainly analyzed by looking on the two main outputs where the station is dumping the weather data instances, Weather Underground and the SD card.

On the one hand, Weather Underground has successfully received the data collected by the weather station and the visualization website has been able to develop several weather graphics that show weather parameters evolution through a day, month or year. Moreover, the website is constantly being updated each 5 minute and it is showing live conditions through its intuitive interface.

On the other hand, the SD card board is generating a text file output that records each one of the data instances that are being sent by the station. Moreover, this output has a format compatible with Excel or other Big Data tools, so data could be dump in that tool if researchers want to deeply analyze it to develop prediction methods that would be useful for Haiti's benefits.

On both cases, results have been consistent with a normal summer day in Gainesville, Florida, where testing has been done. Florida is a semitropical climate and it is mainly characteristic in summer by hot temperatures during the day, accompanied by a high relative humidity percentage, a sea level pressure and frequent tropical rains. The results obtained by the weather station have mainly reflect this scenario, so it has been possible to demonstrate that it is obtaining reasonable weather data measures.

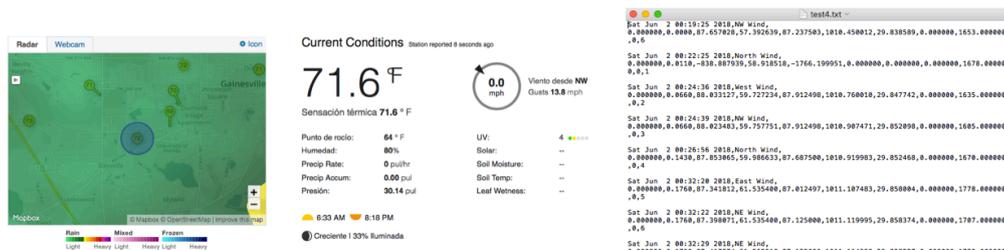


Illustration 2: Wunderground (left) and text file (right) results sample

## 5. Conclusions

This project has given an enormous impulse to implement IoT solutions in developing countries, such as Haiti. It has been demonstrated that these solutions are not only valid for developed countries, and that they could serve as a basis for a country self-development, if they are implemented in a nonprofit way. Moreover, a valid modular weather solution has been successfully designed and it will be ready to be implemented at Haiti in the next few months, so Haitians could use it as an easy-to-use weather tool to manage agriculture, among others.

In terms of project future development, it is planned to integrate a soil moisture sensor before implementing the weather station at Haiti, which is scheduled before the end of 2018. Moreover, new IoT solutions that would give the station more capabilities have emerged to the market while this project was being developed, so new versions of the station would probably use these improvements, as new wireless microcontrollers from Particle or more accurate sensors from another companies. Last but not least, code is being optimized to improve the weather station performance and to have a better power saving solution.

## 6. Bibliography

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## Chapter 1. INTRODUCTION

Haiti is the poorest nation in the western hemisphere and it is always being damaged by the causes of natural catastrophes. Hurricanes or earthquakes are extremely common at Haiti every year due to its location on the middle Caribbean. This poor economy added to the natural disasters have not enabled Haiti to develop itself technologically as the developed countries have done these past years. Moreover, two-thirds of Haitians depend on the agricultural sector, which is a 30% of its GDP.

Accordingly, technological weather measurements are needed at Haiti to warn and predict natural disasters, a goal that the government of Haiti is always pursuing but the constant natural disasters are slowing it down. This meteorological data analysis is critical to support planning in environmental and agriculture sectors, so Haiti could start growing economically.

On the other hand, manufacturing technologies are suffering from what is commonly named as Industry 4.0 or “Fourth Industrial Revolution”, where interconnected Internet systems are knocking down borders between digital, physical and biological fields. Internet of Things (IoT) is one of the most important pieces of this revolution and new developments around the globe on these fields are enabling the emergence of simpler and cost-effective solutions, that could bring technological improvements to those locations where it was not possible before.

This project, *A modular Internet-connected Weather Station for Haiti*, propose the creation of a cost-effective modular IoT weather station at Haiti that can serve Haiti’s need for public weather data through the University of Florida’s Institute of Food and Agricultural Sciences (UF IFAS). Therefore, Haitians could use the weather station to analyze weather data and be more prepared to natural disasters, that will affect its agricultural sector.



## Chapter 2. STATE OF ART

### 2.1 HAITI

Environmental projects have not been really popular on Haiti due to the environmental difficulties and economical limitations that the country uses to suffer every year. Environmental projects have not been really popular on Haiti due to the environmental difficulties and economical limitations that the country used to suffer every year. In fact, since 2010, there have mainly been two natural disasters that have devastated the country: a huge earthquake by 2010 and Matthew hurricane by 2016.

In 2016, Matthew hurricane destroyed an important part of the country leaving near 800 deaths and the egregious amount of \$2,700 millions of material losses [1]. Nevertheless, the most recent catastrophic natural disaster that Haiti has suffered is the 2010 earthquake. The earthquake completely ravaged the country causing 316,000 deaths, more than 1.5 million people that lost their home and \$7,900 million material losses [2].



*Figure 1: Haiti Royal Palace after the 2010 earthquake*

By 2010, the government of Haiti had recently built a National Meteorological and Hydrological Services for Haiti to support socio-economic, disaster risk management and early warning systems. In fact, there were several projects under implementation to help the development of Haiti's National Meteorological Service (NMS) [3] but the catastrophic earthquake, that destroyed the country on 2010, broke down all the advances done on these projects:

- A project on risks and disaster management that was going to bring six new computers to the NMS. The coordinator died during the earthquake.
- The European Union started a project in which ten automatic meteorological stations were going to be delivered to the NMS, but the whole team of the National Geospatial Information Center perished on the event.

Moreover, the telecommunication and meteorological networks development is extremely poor in the country. For instance, by 2010, only two locations had automatic weather stations: the Port-au-Prince airport and the northern Cap-Haitien airport. This poverty and all the difficulties in improving technologically have derived in seeking for cost-effective and quality solutions, which Haitians could afford and use them to start their technological development.

In Figure 2, the weather measurement development on March 2018 between Haiti and its close neighbor, Dominican Republic, can be appreciated. The difference is quite notable in spite of being countries that have similar weather conditions but that have not had the same economic limitations when investing in technology.

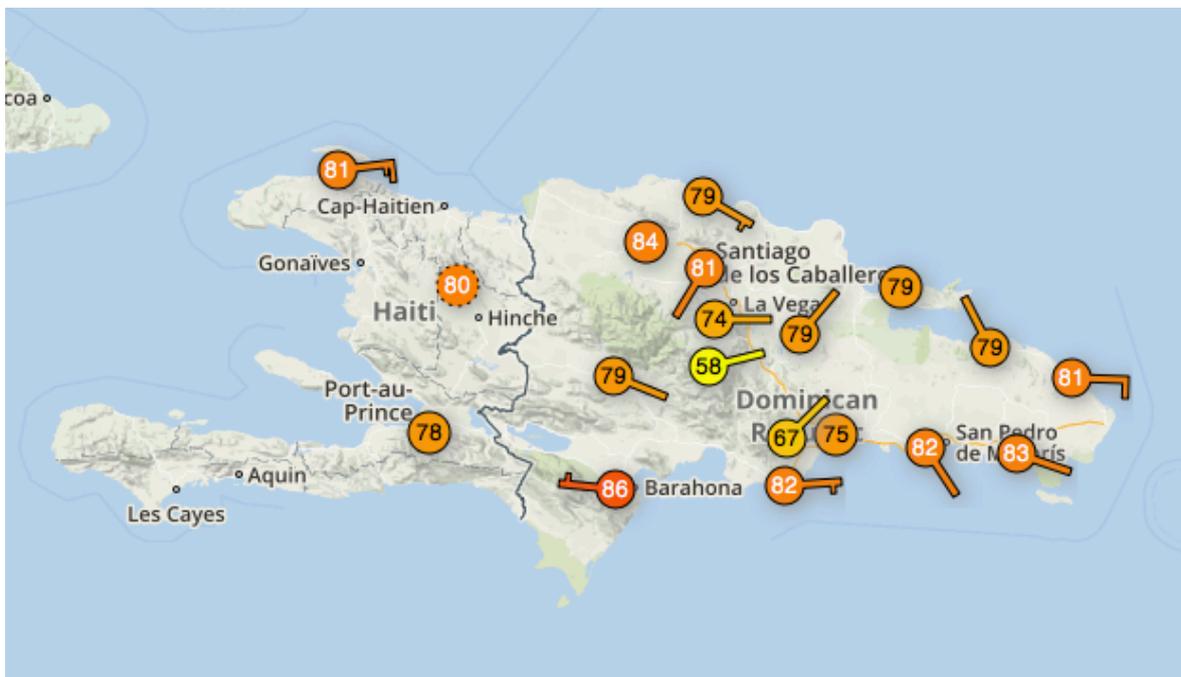


Figure 2: Haiti and Dominican Republic public weather stations comparison. [4]

## 2.2 INTERNET OF THINGS

The exponential growth and magnitude, which Internet of Things is having nowadays on technological improvements and investigations, have derived into multiple of innovative projects that are optimizing the way on which humans interact with technology.

To understand the real magnitude and scope that IoT is going to have in the future, several predictions have been made by many technological companies and, in this epigraph, the most characteristics ones are going to be summarized.

- McKinsey Global Institute predicts that IoT will generate earnings from \$3.9 trillion to \$11 trillion by 2025 [5].

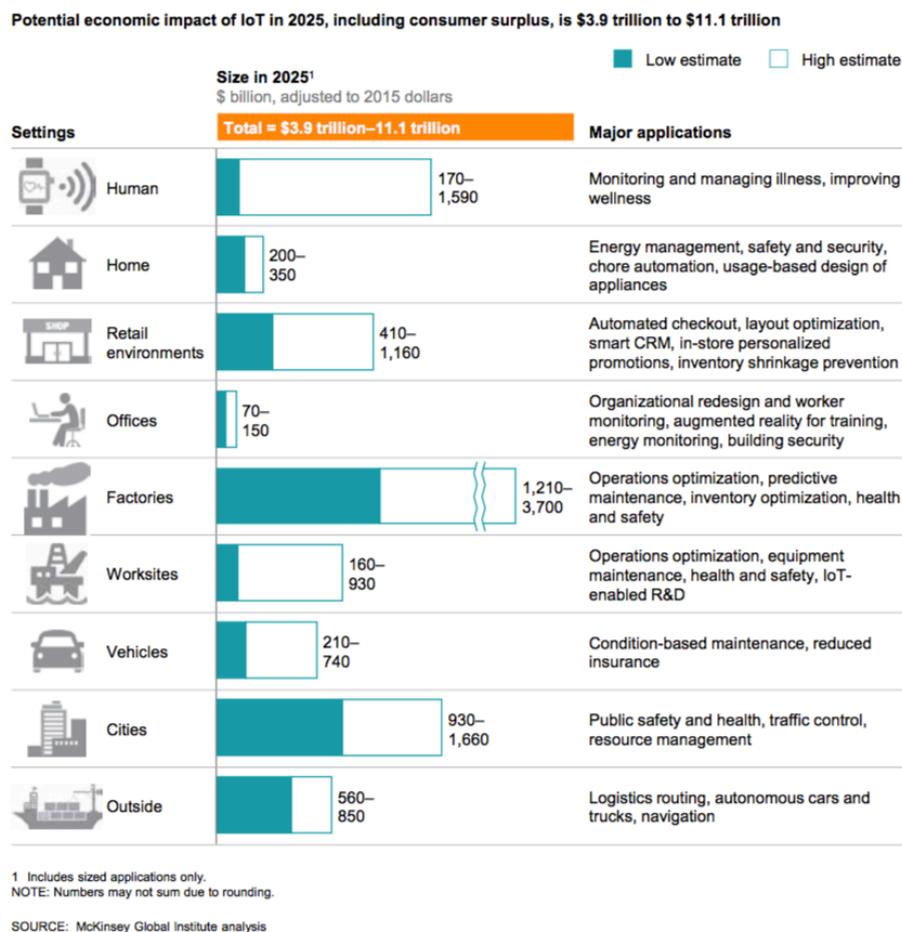


Figure 3: Potential economic impact of IoT in 2025

- The North American IoT consumer electronics market could increase up to \$180B in 2022 from the \$90B of 2017 [6].

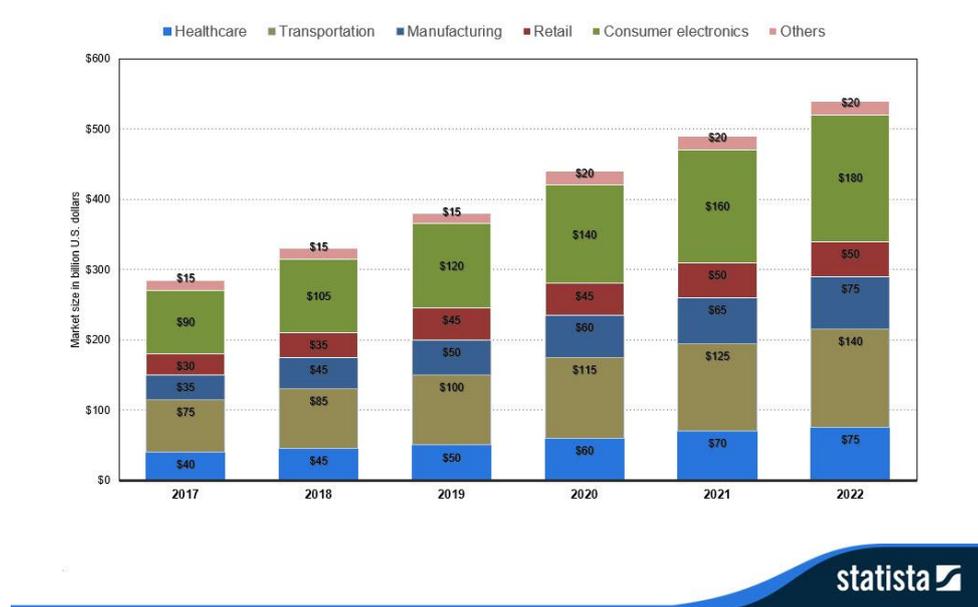


Figure 4: Size of the IoT market in North America from 2017 to 2022 [6]

- There will be in use 12.86 billion devices and sensors by 2020, and this number will be growing at a 34.89% CAGR (Compound Annual Growth Rate) from 2017 [6].

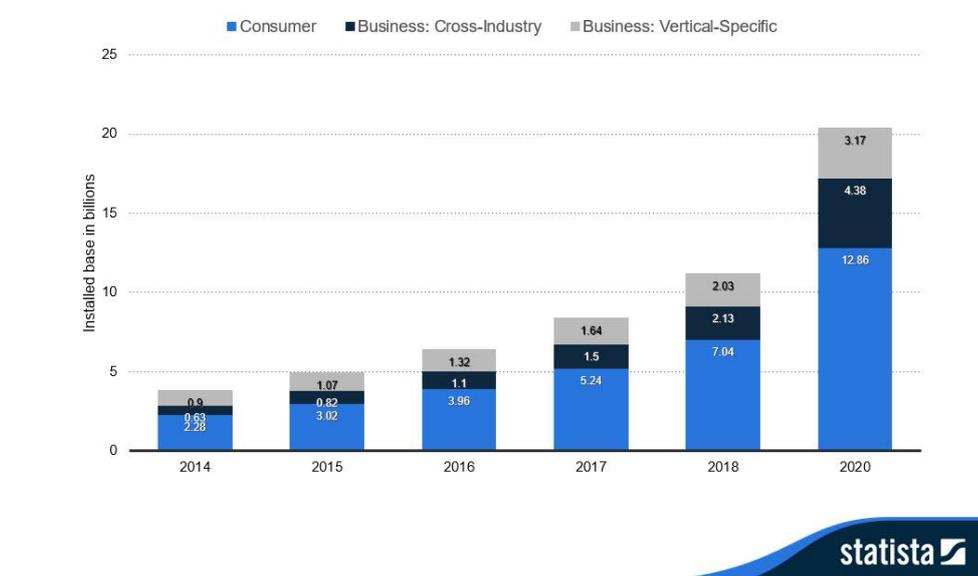


Figure 5: IoT units installed base by category from 2014 to 2020 (in billions of units) [6]

Unfortunately, IoT might be seen as a developed countries topic and that developing countries does not play any role inside IoT. Nevertheless, McKinsey affirms that the amount of IoT value that is possible to realize in developing countries is comparable to that of advanced economies. In fact, the company has estimated that, by 2025, the 38% of the IoT value will be in developing countries and the other 62% will be in advanced ones [5], so the gap is not so different between both economies. Accordingly, if the predictions are taken into account, bringing IoT to Haiti is not disproportionate idea as it might be firstly thought.

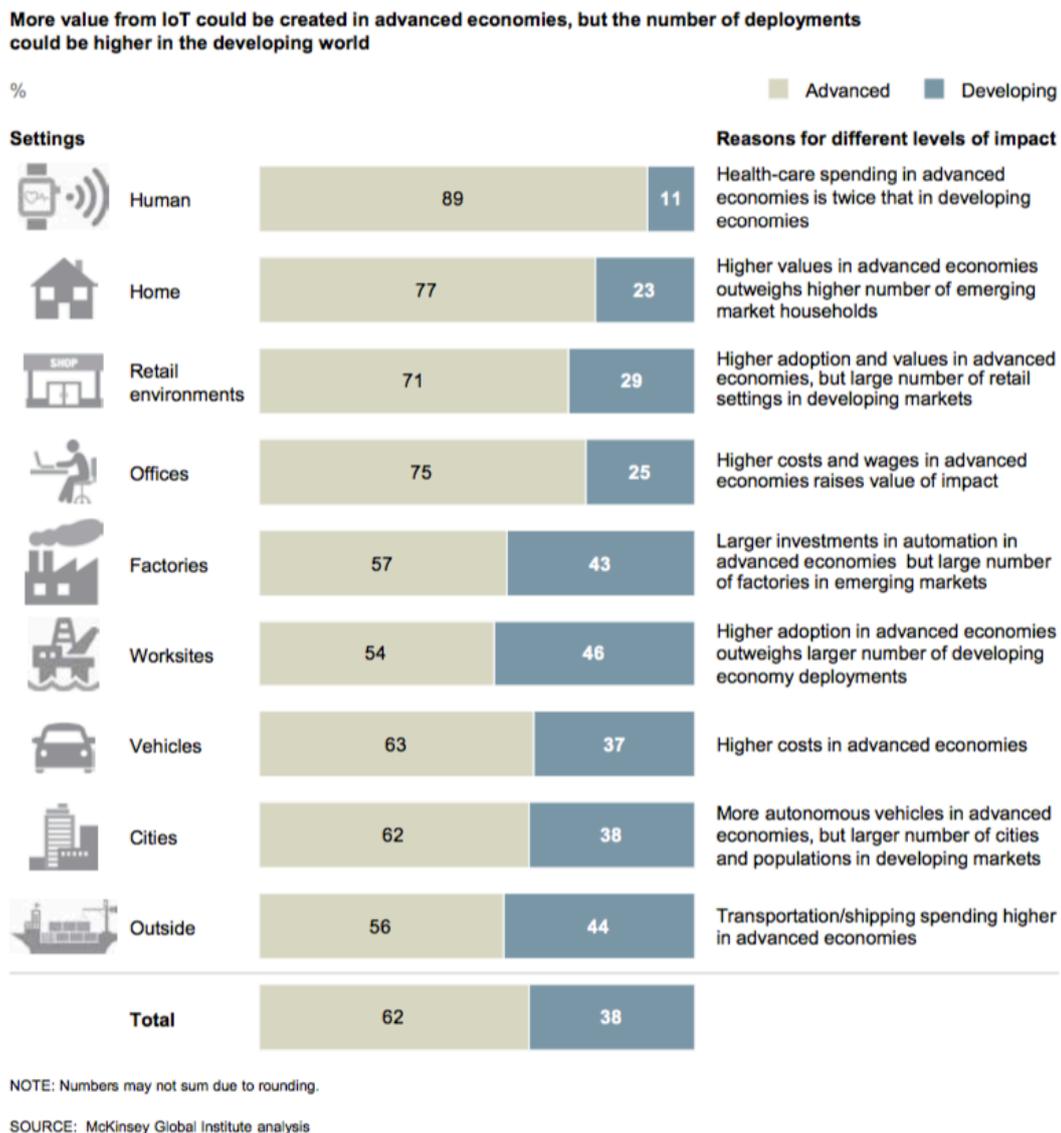


Figure 6: Value from IoT that could be created in advanced/developing countries [5]

Last but not least, University of Florida has not wanted to stay behind on this new and innovative field and has done others IoT project apart for the one that is presented on this paper. For example, on December 2017, the University finished a project called Smart Lake. On this project, several IoT sensors were assembled together to monitor floods on a lake that was always affected by heavy rains, so researches could apply solutions to these floods base on the data that was collected from the sensors.



## **Chapter 3. PROJECT DEFINITION**

### ***3.1 PROJECT MOTIVATION***

Haiti's poor technological development and its dependence on the agricultural sector are clear indicators that foreign projects are needed to boost the country development. Haitians need help to be more prepared and able to predict the usual natural catastrophes that threaten their country.

Therefore, this project is needed at Haiti because of several factors that have been summarized on the following list:

- Haiti is vulnerable to natural hazards and disasters and currently there is virtually no public real-time information available thus limiting their ability to issue forecasts.
- Two-thirds of all Haitians depend on the agricultural sector. With climate changes and at high risk for natural disasters, it is critical to support a medium and long-term planning in agriculture, water resource, and the environment.
- The lack of modularity of weather stations in Haiti often leaves researchers with expensive and unusable equipment. Due to the economical limitations that the country has, a modular station will give those researchers a tool to optimally analyze weather data and get rid of the cost overruns that a normal station usually has.

Finally, it is really interesting to use my background experience to help those who need help and do not have enough possibilities to carry out a project like this. As it is known in the engineer code of ethics, an engineer has to always do his best to use his knowledge in a responsible and helpful way, and this project is a clear example of this.

## **3.2 PROJECT OBJECTIVES**

The main scope of this project is to develop a modular weather station with IoT low-cost sensors and to assemble and install it on Haiti by the end of the project. To accomplish it, this general objective is going to be divided on several sub-objectives.

- Knowing and identifying the different sensors and IoT technologies and platforms that are going to be used on the station development to obtain the enough background that this project requires.
- The development of a modular station model on which each unit could work by their own, so the add-on or put-out of future units could be done in an easy and agile way without interfering other units' operations.
- Creation and testing of a single station by the assembly of all the individual modules, so a unique solution could be presented to Haitians and they could set it up as an easy-to-use tool.
- Storage of all the collected data in a Secure Digital (SD) card to minimize the station Wi-Fi dependence, so any data will be lost if the Wi-Fi router is down.
- To enable the visualization of live data obtained by the weather station on a public and global platform, so researches at Haiti could easily work with the data.

### **3.3 PROJECT METHODOLOGY**

To develop this project, the methodology of a common electrical & computer project is going to be followed. The different steps that the project will go through are summarized on the list below

- Step 1. Project Training. There is going to be a training period where it will be learned how the sensors work and which technology they use. This period is going to be split on three parts, a period for understanding the project, another one for understanding how sensors work and one for understanding the programming language and software platforms.
- Step 2. Coding & Testing. In this stage, each sensor is going to be coded and tested separately and then they will be programmed to work together. The different parts that need to be coded are the wind, rain, temperature, humidity and pressure sensors and the SD card to store all the data when Wi-Fi would fail.
- Step 3. Assembly and Field Testing. There is needed a time for assembly each unit to the station and, then, field test the whole station to assure that it operates as it should. This period is also useful to fix any error that could have not be noticed on the previous period and to optimize the station operations.
- Step 4. Installation at Haiti. A trip to Haiti is planned by the end of the project to set up the station there and explain to Haitians how it operates.

Moreover, on Figure 7, an initial workplan has been posted to visualize better the phases and processes that are expected to be followed during the project.

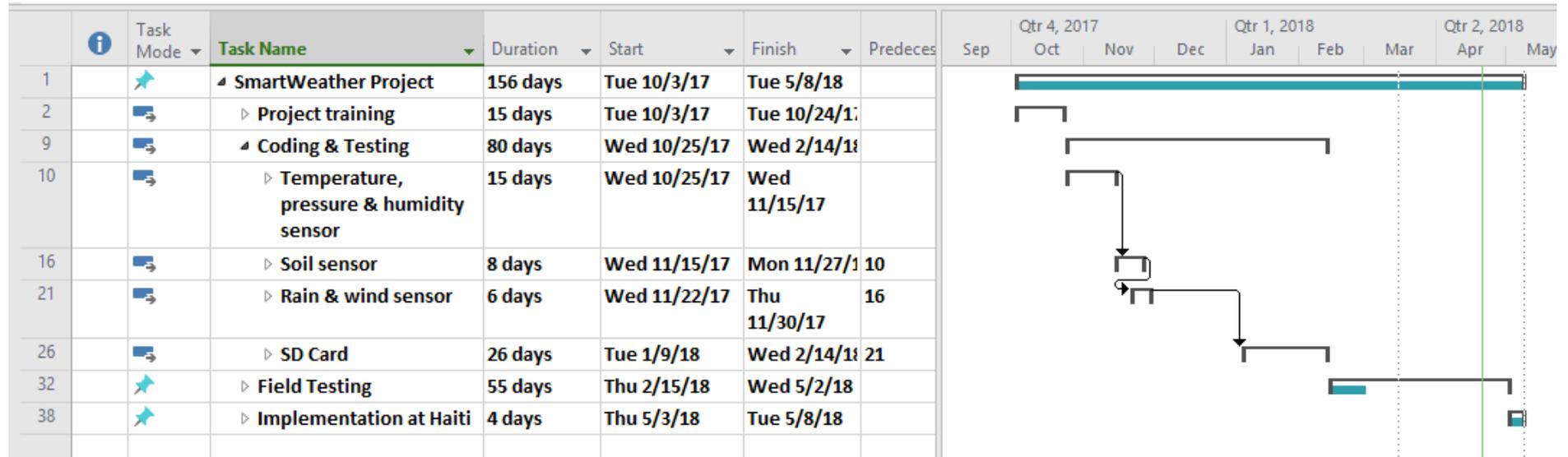


Figure 7: Project Methodology

### 3.4 COSTS ESTIMATION

From the labor cost part, this project going to have zero cost because it is similar to a volunteering project where the professor and the students are going to do it just to help Haitians to improve their weather measurement and prediction registers.

Nevertheless, there are going to be some technological and travelling costs that have to be taken into account. In the following table, these “physical” costs could be appreciated.

<i>Item</i>	<i>Cost</i>
Photon microprocessor	\$19
Rainfall and wind sensors	\$76.95
Sparkfun Photon weather shield	\$32.95
Solar panel	\$29
Lithium Ion battery	\$29.95
MicroSD Card board	\$7.5
16 GB SD Card	\$7
Travel to Haiti (Orlando, Florida - Port au Prince, Haiti) for 4 persons	\$350/p = \$1400
<b>Total</b>	<b>\$1602.35</b>

*Table 1: Project costs estimation*



## Chapter 4. TECHNOLOGIES DESCRIPTION

### 4.1 CONTROLLER AND SENSOR UNIT

#### 4.1.1 PHOTON WI-FI IOT DEVICE

In every IoT project, a central controller is needed to manage each one of the different sensors and send the data, that has been collected, to the different analysis or visualization tools. In this project, this role is going to be adopted by the Photon Wi-Fi IoT device [7] that was developed by Particle, an Internet of Things platform.

The Photon device is part of the Wi-Fi hardware family developed by Particle and it combines a trustful and powerful microcontroller (SMT32 ARM Cortex M3) with a Wi-Fi chip (Cypress' industry-tested BCM43362) [8]. Moreover, the Photon could be powered by an on-board USB Micro B connector or via the VIN pin with a voltage that could be regulated between 3.6VDC and 5.5VDC

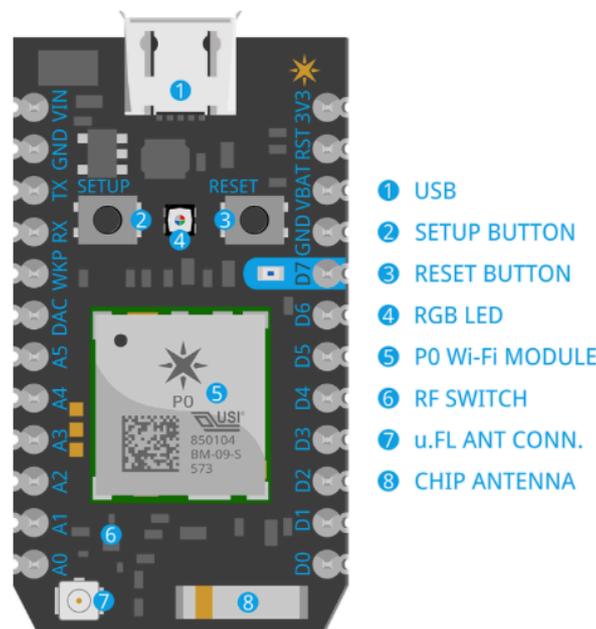


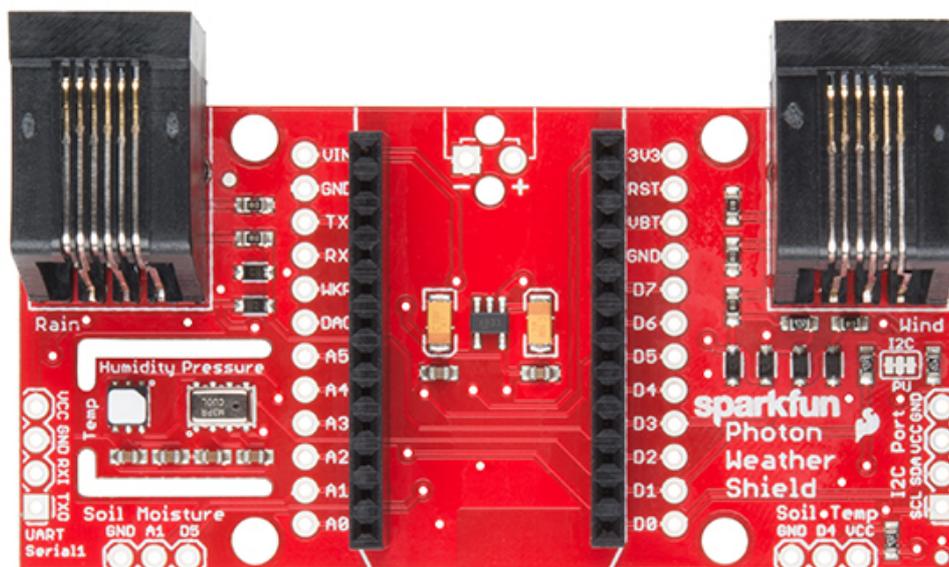
Figure 8: Particle Photon

#### 4.1.2 SPARKFUN PHOTON WEATHER SHIELD

Despite being the most important component of the IoT weather station, the Particle Photon is going to be set in a special board that allows the measure of several weather parameters and external weather sensors connections. This function is going to be held by the Sparkfun Photon weather shield (DEV-13674 ROHS) [9] developed by Sparkfun Electronics, an online electronic company that sells products and resources with the main purpose of making the world of electronics more accessible [10].

The Sparkfun Photon weather shield is able to measure several weather parameters and it gives the user the possibility of incorporating optional sensors. These optional sensors could be connected on two RJ11 connectors (for optional wind and rain sensors) or on a 3-pin soil moisture hookup.

Aside from enabling outside sensor connections, this board gives access to temperature, barometric pressure and relative humidity measures. This is possible due to the MLP3115A2 barometric pressure and the Si7021 temperature/humidity sensors that the board has integrated.



*Figure 9: Sparkfun Photon weather shield [9]*

### 4.1.3 RAINFALL AND WIND SENSORS

One of the external sensor inputs, that the Sparkfun Photon weather shield is going to receive, are a group of weather sensors that are able to measure wind speed, wind direction and rainfall rate, and send them to the Photon. In this weather station, this data is going to be obtained by a group of weather meters, that have been developed by Argent Data Systems and is also sold by Sparkfun Electronics.

The Sparkfun weather meters kit contains the three main weather measurement sensors: wind direction, wind speed and rainfall. The main characteristic of this sensors set is that it uses sealed magnetic reed switches and magnets instead of active electronics, so the sensors have to be powered to obtain any measurement, but they are easy to interpret [11]. Moreover, the kit includes RJ11 terminated cables to connect the sensors with the Sparkfun Photon weather shield, that also acts as a source of voltage.

Each sensor has its own way of collecting and read weather measurements [12]:

- The anemometer is a cup-type anemometer that measures wind speed by activating a contact as a magnet moves past a switch. Each contact activation means a wind speed of 2.4 Km/h (1.492 MPH).



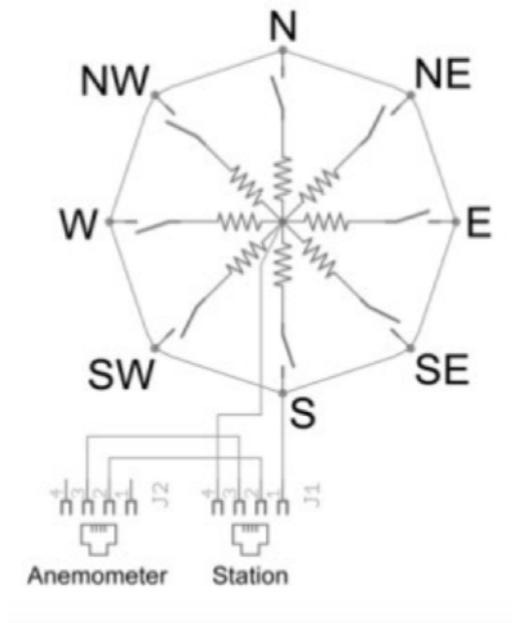
*Figure 10: Anemometer sensor [13]*

- The rainfall sensor is a self-emptying tipping bucket type that measures the amount of rain drop in a certain amount of time. Inside the bucket, there is a lever that each 0.011 inches (0.2794 mm) produces a movement that is recorded by a microcontroller interrupt input. The rain gauge is connected to the RJ11 cable.



*Figure 11: Rain Gauge Sensor [13]*

- The wind vane sensor is the most difficult to understand its measurement method. The sensor has 8 resistors that are connected to 8 switches (Figure 12), so, when the wind is blowing the sensor, the magnet could close two switches at a time, allowing up to 16 different positions. Then, the output voltage is measured, and its value determines the wind direction, once the output voltage has been converted with an analog to digital converter.



*Figure 12: Wind vane positions [12]*



*Figure 13: Wind vane sensor [13]*

Once that each sensor has been introduced, Argent Data Systems proposes a standard assembly process for these sensors that can be seen in Figure 14. On the one hand, the wind arm is going to be placed in the top of the metal mast with both wind sensors, and a short cable is going to connect both sensors. On the other hand, the rain gauge is going to be set on a lower position on the mast using an own plastic arm where it can be placed.

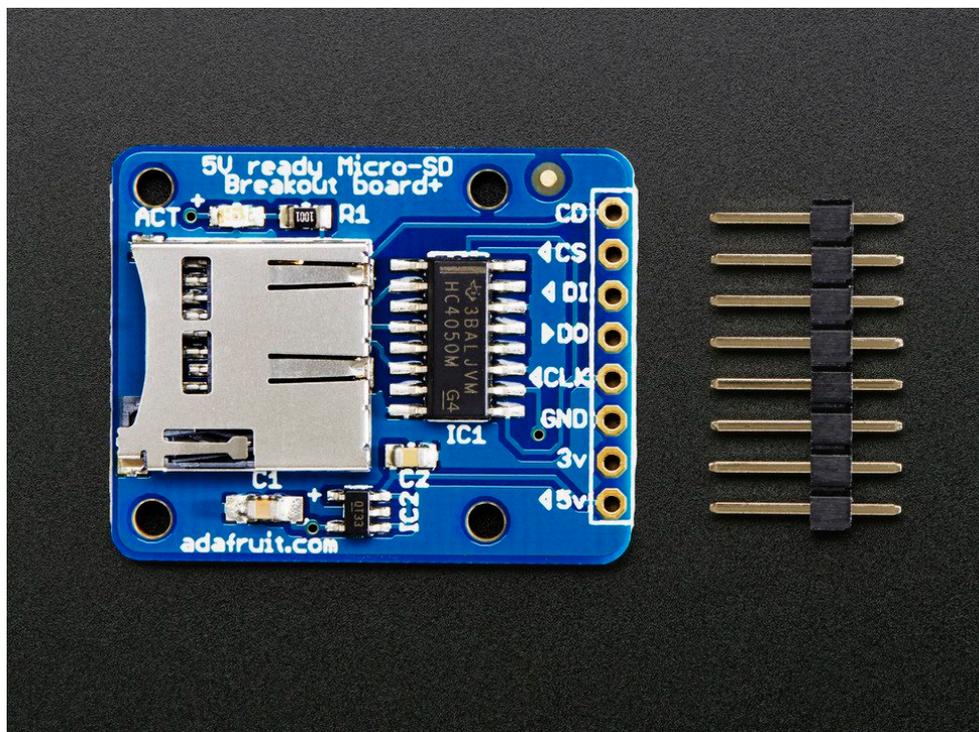


*Figure 14: Weather meters assembled [13]*

#### 4.1.4 MICROSD CARD BOARD

Despite the Photon is constantly collecting and sending live data to Weather Underground (see Weather Underground), Wi-Fi technology is really prone to drop occasionally, and that data will not be recorded anywhere by the IoT weather station. For this reason, as a solution, it has been thought to incorporate a 16 GB SD card, that is going to record all the collected data without any Wi-Fi dependence.

The 16 GB SD card is going to be connected with the Photon through the MicroSD card board developed by the company Adafruit [14]. This card is linked with the Photon through the Serial Peripheral Interface (SPI), a synchronous serial data protocol used by microcontrollers to communicate quickly over short distances [15].



*Figure 15: MicroSD card board [14]*

#### **4.1.5 LITHIUM BATTERY**

As every electronic microcontroller, the Photon needs to be powered to be able to do its programmed function. For this reason, a 6Ah lithium ion battery [16] is going to be used to power the Photon. The battery of this project has been developed by the company Data Power Technology Limited and it has been sold by Sparkfun Electronic.

Specifically, it is a polymer li-ion rechargeable battery composed of a solid 3 cell pack, where each cell outputs a nominal 3.7V at 2Ah and they can be charged in parallel. Moreover, power is given through a 2-pin JST-PH connector with 2mm spacing between pins.



*Figure 16: Lithium Ion Battery [17]*

#### **4.1.6 SOLAR PANEL**

Due to the conditions of this project, it has been decided to use the solar power as the main source of energy to charge the battery and give to the station a high level of autonomy to operate without having to be charging the battery again and again. This is going to be possible through a 2W solar panel [18] sold by Sparkfun Electronic and that can be adapted and connected to the Sparkfun board.

This solar panel is able to power 2 watts with sun and it has a peak of power output around 6V at 378mA. Moreover, the panel uses monocrystalline high efficiency cells with a waterproof urethane coating, and it is UV resistant. Finally, the panel can be easily joined with the board because it comes with two different adapters, compatible with any of the Sparkfun development boards.



*Figure 17: Solar panel [18]*

## 4.2 SOFTWARE UNIT

### 4.2.1 PARTICLE BUILD

Particle is an Internet of Things platform, which its main purpose is to clean up the existing chaos on the IoT environment, where there have been found more than 450 separate IoT platforms [19]. The main difference from other IoT platforms is that the company offers everything from hardware to application programming interfaces (APIs) and software development kits (SDKs). Also, it connects all the devices in an IoT cloud.

Thus, hardware is coded in an online integrated development environment (IDE) named Particle Build, that allows software development and testing for Particle products. This environment has multiple functionalities as to flash the Particle product, to act as a software library or to save different software versions, that are really intuitive and can be done in an easy and quickly way.

In Figure 18, the Particle Build console interface can be appreciated and the different functionalities are visible at the left of the image.

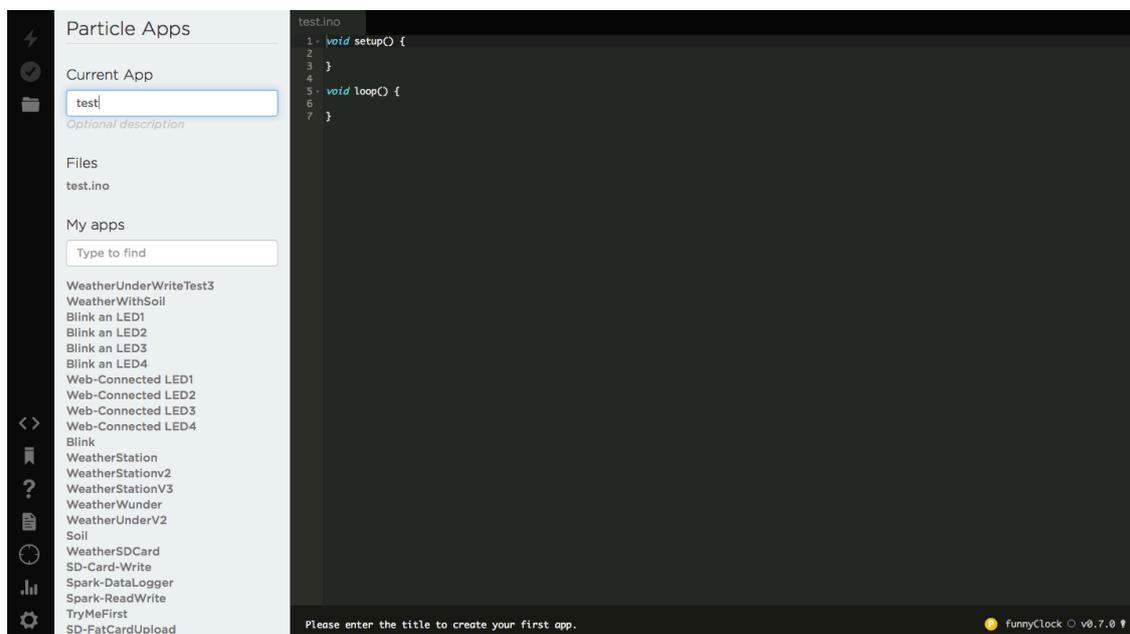
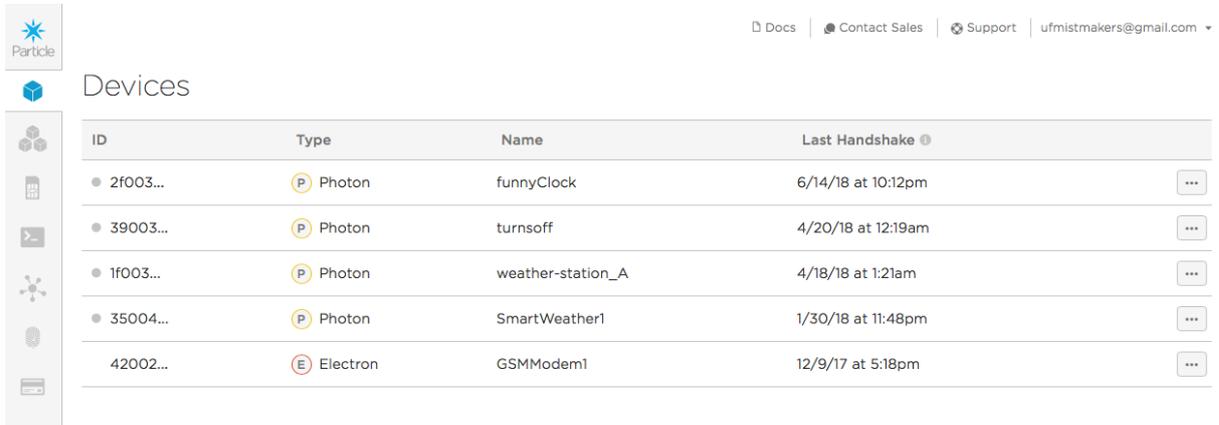


Figure 18: Particle Build console interface

Moreover, it is possible to have a register of each one of the Particle devices that you have owned, and the user is able to manage them through the Particle interfaces, as it can be seen in Figure 19.



ID	Type	Name	Last Handshake	
2f003...	Photon	funnyClock	6/14/18 at 10:12pm	...
39003...	Photon	turnsoff	4/20/18 at 12:19am	...
1f003...	Photon	weather-station_A	4/18/18 at 1:21am	...
35004...	Photon	SmartWeather1	1/30/18 at 11:48pm	...
42002...	Electron	GSMModem1	12/9/17 at 5:18pm	...

*Figure 19: Particle devices management interface*

#### **4.2.2 WEATHER UNDERGROUND**

Weather Underground is a company that its main purpose is to give public access to weather information. Since 1993, the weather underground community and meteorologists have created unique products to improve access to meaningful weather data from around the globe [20].

Nowadays, it is the Internet's first weather service and the company is always seeking from new ways of sharing data to more people. In fact, currently, the Weather Underground community has, just in the United States, almost 2,000 ASOS (Automated Surface Observation Systems) stations located at airports, over 250,000 personal weather station and over 26,000 weather stations of the MADIS (Meteorological Assimilation Data Ingest System) meteorological observation database [21].

To allow that public upload of weather data, there is a public API [22] that the company has for those software developers that want to use Weather Underground. There, developers can find the format that the code has to have in order to properly upload weather data to the website.

Moreover, once the data is uploaded into Weather Underground, the station can be monitored at real time from their interactive interface and WunderMap (Weather Underground Map). Also, there is an iPad and iPhone application where the user could follow every weather update and check every weather register from past days, months or year.

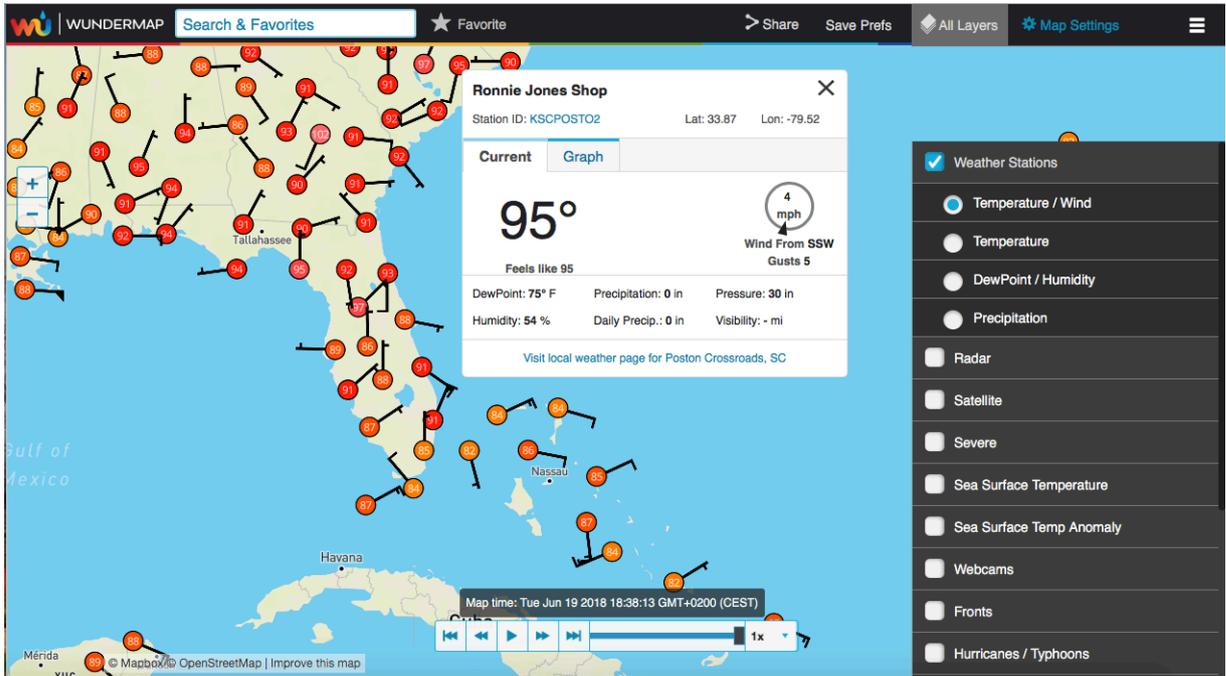


Figure 20: WunderMap Interface

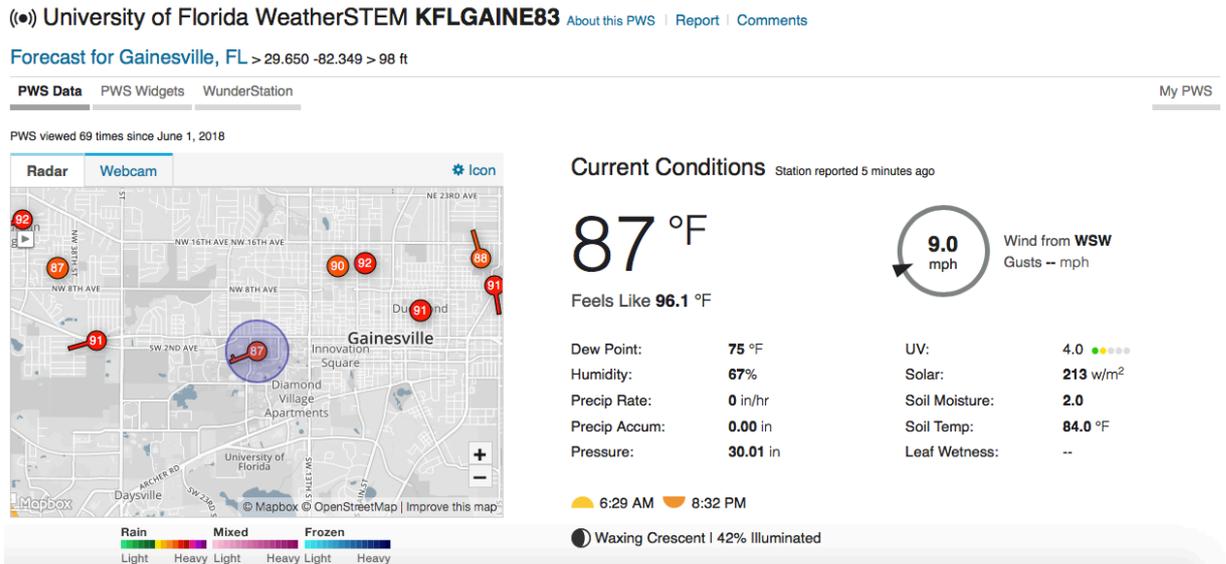


Figure 21: Standard weather station interface at Gainesville, Florida



## Chapter 5. DEVELOPED SYSTEM

### 5.1 GENERAL DESCRIPTION

Before getting thoroughly into the most technical aspects of the station, a general project view is needed to be able to understand those technical functionalities. The station itself is divided into multiple units that have different tasks and coordinate together to obtain and to process all the data.

The weather station can be divided into five tasks it has to perform:

- Weather station readings. The different sensor units, that have been mention in the previous chapter (see Technologies description), are the ones in charge of this task. While the Sparkfun Photon weather shield is the one that obtains temperature, humidity and pressure data, the weather meters are in charge of obtaining wind speed & direction and rainfall measurements.
- Algorithm definitions. Despite the sensors are programmed to give data in an understandable way, it is needed to define some algorithms to interpret this data and to send it with the correct format to each one of the output sources.
- Power self-autonomy. The solar panel and the lithium battery are in charge of giving self-charging autonomy to the station. While the solar panel charges the battery and powers the station, when the solar goes off the battery runs the station.
- Wi-Fi Internet communication. The Photon has the capability of wireless communicating through Wi-Fi technology and send the measurements final value to the output source.

- Data output. The final values are going to be sent to two main output sources. On the one hand, the SD card board is going to directly receive data from the Photon and it has to be able to store all that data in an output file that researchers could analyze. On the other hand, data is going to be send to Weather Underground, in the format that his API expects, through the Photon wireless function.

The main challenge of this project is to coordinate the Photon to receive and interpret data from every source and to make it capable of store this data into a local file and, also, send it to an Internet web interface that is able to show real-time results.

## **5.2 DESIGN CONCEPT REVIEW**

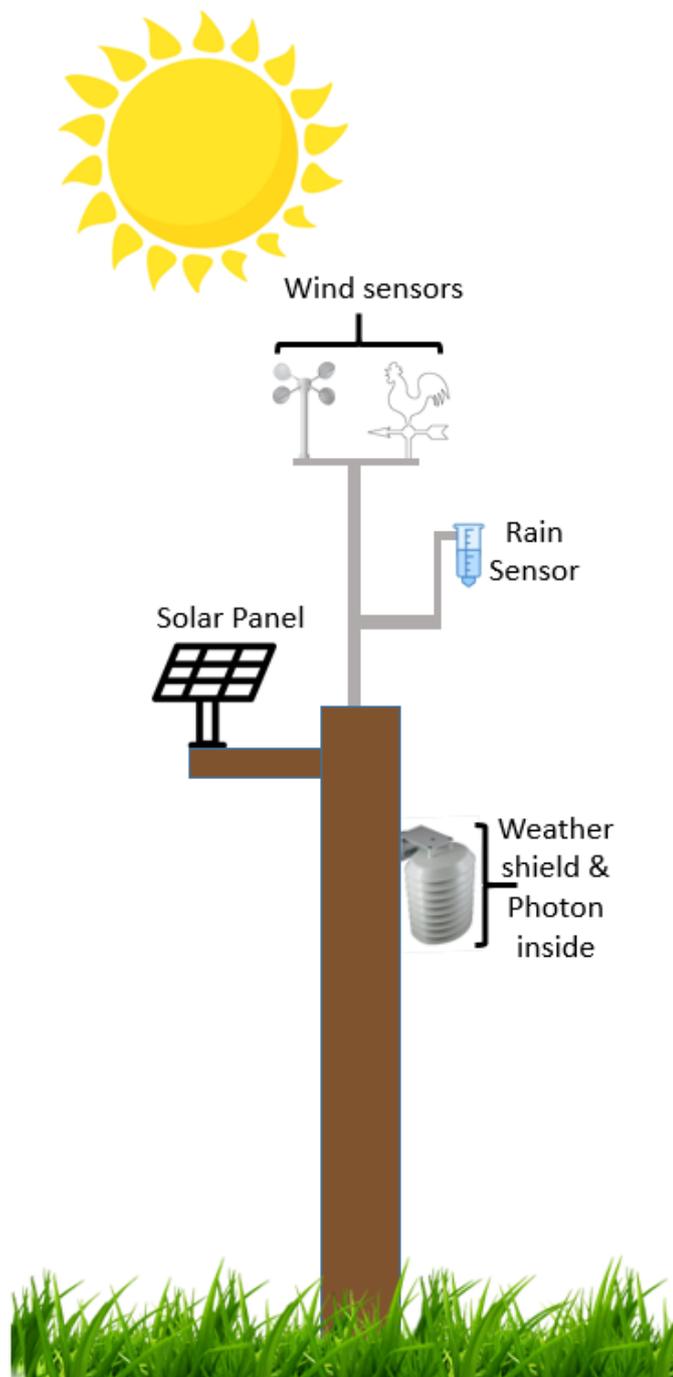
The weather station is going to be designed in such way that each sensor could be set in a position that is going to optimize their respective data collection. The station parts are going to be in a wooden post, that is going to have several spots to locate each one of the parts.

First, the Photon is going to be hosted inside a small plastic box accompanied by the Sparkfun Photon weather shield, the lithium battery and the microSD card board. Moreover, this plastic box is going to be located, at the bottom of the post, inside a waterproof enclosure, as it can be appreciated in Figure 22, that is going to protect the Photon and the sensitive elements that the station has.

Otherwise, the rain and wind weather meters are going to be in different positions at the top of the station, so they could perform their measurements in an optimal way. The wind sensors are going to be in the highest position and they are going to be fixed to a metal pole that came with the sensors when they were bought. Besides, the rain gauge is going to be set in another metal pole, but in a lower position than those wind sensors.

Finally, the solar panel is also going to be set in a high position to take advantage of those sun rays that are going to hit the station every day. Moreover, the panel direction is going to depend on the sunrise and its direction.

In Figure 22, the station design concept can be appreciated in a more clarifying way and it is possible to get used to the station aspect.



*Figure 22: Weather station design concept*

### **5.3 SCHEMATIC DESIGN**

Once that the physical design concept has been clarified, it is necessary to know about a deeper and more technical design to have a general idea about each module and sensor connections, so a schematic design is presented to understand better the station inwards.

The main module is going to be the Photon, and, thanks to the Sparkfun weather shield board, every sensor or module is going to be connected to it. Moreover, it is going to be connected to ground and powered by the solar panel and the lithium battery.

Furthermore, each sensor or board has its own configuration with different resistances, diodes or capacitors. These configurations have been designed by each module company and they are already prepared to be connected to the Sparkfun board.

The add-in modules that have been used in this project are wind, humidity & temperature, rain and pressure sensors, a SD card board and a serial, that is going to be used for testing purposes of reception and transmission.

On the next page, Figure 23 represents the weather station schematic design, so it is possible to appreciate to which Photon pin is each input/output connected.

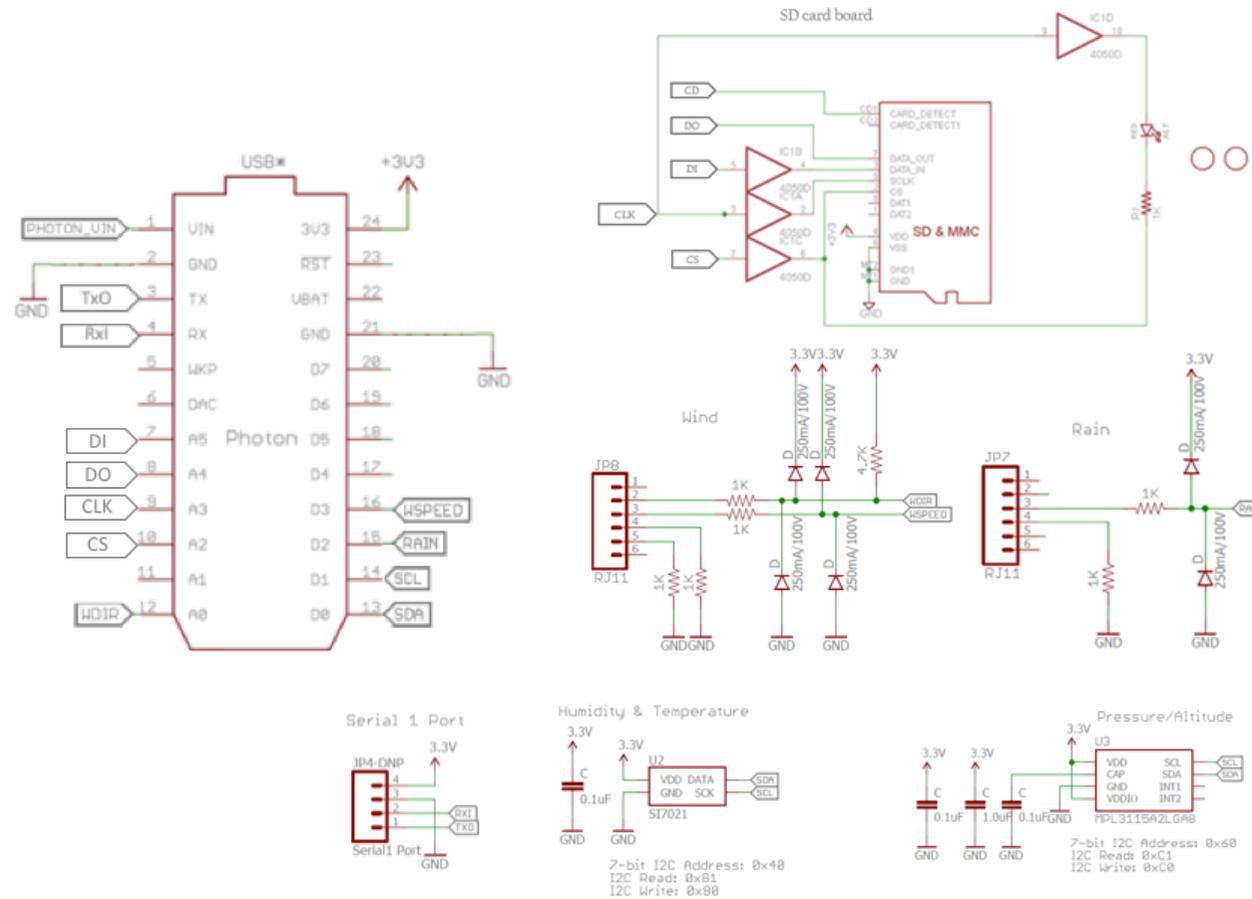


Figure 23: Weather station schematic design

## 5.4 SOFTWARE IMPLEMENTATION

The most important part, to enable an optimal weather station performance, is to properly code the Photon and its connections, so the station could obtain and manage all the data from the sensors and send it to the different outputs. In this section, some code parts are going to be shown to explain those parts that have been fundamental to have the station properly performing.

### 5.4.1 STATION SET UP

Firstly, the Photon inputs were configured, so it could know where to obtain each weather measurement. Normally, each one of the sensors or boards are going to be connected to different Photon pins, except from the humidity, temperature and pressure sensors that come integrated in the Sparkfun Photon weather shield board and they have own functions that the Photon could use to obtain data from them (SDA and SCL inputs).

As it can be appreciated in Table 2, each module is connected to a different Photon pin.

<i>Input</i>	<i>Photon pin</i>
Wind Speed (WSPEED)	D3
Wind Direction (WDIR)	A0
Rain Gauge (RAIN)	D2
Weather shield board sensor (SDA)	D0
Weather shield board sensor (SCL)	D1
SD Card board input (DI)	A5
SD Card board output (DO)	A4

SD Card board clock (CLK)	A3
SD Card board chip select (CS)	A2
Serial receiver (RXI)	RX
Serial Transmitter (TXO)	TX

*Table 2: Photon pin configuration*

Accordingly, this configuration has to be coded in terms of software, so the Photon could know where each module is connected and treat them properly. The Photon inputs could be divided into two main types, the internal ones (temperature, humidity and pressure), that come integrated in the Sparkfun weather shield board, and the external ones (wind & rain sensors and SD card board).

On the one hand, the internal ones are going to be configured with an already developed library named *Sparkfun\_Photon\_Weather\_Shield\_Library.h* that have been done to treat those sensors that come integrated in the Sparkfun board. Moreover, its initialization its done in a simple way that to a class named *Weather*, that has been named *sensor* on this project. In Figure 24, the initialization of this class can be appreciated.

```
//Initialize the I2C sensors and ping them
sensor.begin();
sensor.setModeBarometer();//Set to Barometer Mode
//These are additional MPL3115A2 functions the MUST be called for the sensor to work.
sensor.setOversampleRate(7); // Set Oversample rate
sensor.enableEventFlags(); //Necessary register calls to enable temp, baro and alt
```

*Figure 24: Sparkfun board sensors initialization*

On the other hand, the external ones are going to be set up in a different way. First, wind and rain sensor pins are going to be defined in several global variables at the top of the program, so they could be changed easily, if necessary. Moreover, while wind speed and rain detections are going to be treated with several interruptions every time that the sensor moves,

the wind direction sensor is going to be read directly each time the station wants to obtain its data, as it could be appreciated in section Wind direction measurement.

```
pinMode(WSPPEED, INPUT_PULLUP); // input from wind meters windspeed sensor
pinMode(RAIN, INPUT_PULLUP); // input from wind meters rain gauge sensor

attachInterrupt(RAIN, rainIRQ, FALLING);
attachInterrupt(WSPPEED, wspeedIRQ, FALLING);
```

*Figure 25: Wind speed and rain sensor initialization*

Additionally, the SD card board supports SPI (Serial Peripheral Interface) technology, so it is going to be configured with a default configuration and is going to use the class *SdFatLibSpi* to read/write from the SD card.

```
#elif SPI_CONFIGURATION == 2
// Primary SPI with Arduino SPI library style byte I/O.
// SCK => A3, MISO => A4, MOSI => A5, SS => A2 (default)
SdFatLibSpi sd;
const uint8_t chipSelect = SS;
```

*Figure 26: SD card board SPI configuration.*

## 5.4.2 WEATHER MEASUREMENTS

Once the Photon pin scheme has been configured, the data collection of each one of the weather measurements has to be coded. In this section, it is going to be explained the way data is managed once it has been obtained from the different sensors.

### 5.4.2.1 Humidity, temperature, pressure and dew point measures

The sensors that came integrated with the Sparkfun weather shield board are the ones that are going to be explained in first place. As it has been mentioned in the previous section, the Photon have own functions to obtain data from these sensors due to a library developed by Sparkfun.

The easiest ones to obtain are the relativity humidity measures from the Si7021 due to a function *getRH()* that directly gets these measures in the format that is expected by the weather station outputs.

In terms of pressure measurement, the function *readPressure()* gives the MPL3115A2 sensor reading of pressure in Pascals, but as Wunderground expects this measure in inches of Mercury (inHg), this conversion has to be made.

$$\text{Pressure in inHg} = \text{Pressure in Pascals} * 0,0002953$$

*Equation 1: Conversion from Pascals to inHg*

Moreover, for calculating the temperature, both sensors give a reading of temperature so and average of both sensors temperature is done to obtain a more accurate value. In case of the Si7021 sensor, temperature is obtain with the function *getTemp()*, and, in case of the MPL3115A2 sensor, it is obtained with the *readBaroTemp()* function. Furthermore, temperature in United States is expected in Fahrenheit instead of Celsius, so this conversion also has to be done.

$$\text{Output temperature} = \frac{\text{Si7021 temp reading} + \text{MPL3115A2 temp reading}}{2}$$

*Equation 2: Average temperature reading from both sensors*

$$\text{Temperature in F} = \left( \frac{9}{5} * \text{Temperature in Celsius} \right) + 32$$

*Equation 3: Conversion from Celsius to Fahrenheit*

Last but not least, the dew point is the lowest temperature to which the water vapor starts to be condensed to form liquid water. It has been coded a function to calculate each dew point and the calculation has been done as Equation 4 states, obtaining the dew point in Celsius and having to convert it to Fahrenheit later.

$$\text{Dew Point (Celsius)} = \text{Temperature (Celsius)} + 35 * \log \left( \frac{\text{Relative Humidity}}{100} \right)$$

*Equation 4: Dew Point calculation*

In Figure 27, the code developed to calculate all these parameters is shown.

```
// Measure Relative Humidity from the HTU21D or Si7021
humidity = sensor.getRHC();

// Measure Temperature from the HTU21D or Si7021
humTempC = sensor.getTempC();
humTempF = (humTempC * 9)/5 + 32;

//Measure the Barometer temperature in F from the MPL3115A2
baroTempC = sensor.readBaroTempC();
baroTempF = (baroTempC * 9)/5 + 32; //convert the temperature to F

//Measure Pressure from the MPL3115A2
pascals = sensor.readPressure();
inches = pascals * 0.0002953; // Calc for converting Pa to inHg (Wunderground expects inHg)

//Average the temperature reading from both sensors
tempC=(humTempC+baroTempC)/2;
tempF=(humTempF+baroTempF)/2;

//Calculate Dew Point
dewptC = dewPoint(tempC, humidity);
dewptF = (dewptC * 9.0)/ 5.0 + 32.0;
```

*Figure 27: Relative humidity, pressure, temperature and dew point code*

#### **5.4.2.2 Rain rate measurement**

The rain sensor mainly works due to an interrupt input that closes each time that water falls on top of it. In terms of code, this has been treated as an event each time the interrupt is closed, so each closure means an additional 0.011 inches of rain.

$$\text{Daily rain rate (inches)} = (\# \text{ of Interrupt closures}) * 0,011$$

*Equation 5: Rain rate calculation*

Moreover, time management has been included in the program to treat wind and rain sensor events and to avoid glitches that could be produced by the same closure keeping active for a space of time. In this case, the program counts 10 ms between the time the interrupt has recently been activated and the last time rain was recorded, and if these milliseconds has passed and the interrupt is activated again, another 0,011 inches of rain are added.

```
void rainIRQ()
// Count rain gauge bucket tips as they occur
// Activated by the magnet and reed switch in the rain gauge, attached to input D2
{
  raintime = millis(); // grab current time
  raininterval = raintime - rainlast; // calculate interval between this and last event

  if (raininterval > 10) // ignore switch-bounce glitches less than 10mS after initial edge
  {
    dailyrainin += 0.011; //Each dump is 0.011" of water
    rainHour[minutes] += 0.011; //Increase this minute's amount of rain
    rainlast = raintime; // set up for next event
  }
}
```

*Figure 28: Daily rain rate calculation code*

Finally, to calculate the amount of rain that has been detected an hour and send it to Wunderground, the previous event shown in Figure 28 is saving the rain each minute in an array and, then, every component is added in a unique parameter, as it can be appreciated in Figure 29.

$$\text{Rainfall rate for an hour} = \sum_{i=1}^{60} \text{rainHour}(i)$$

*Equation 6: Rainfall rate for an hour calculation*

```
//Total rainfall for the day is calculated within the interrupt
//Calculate amount of rainfall for the last 60 minutes
rainin = 0;
for(int i = 0 ; i < 60 ; i++)
  rainin += rainHour[i];
```

*Figure 29: Amount of rainfall for an hour calculation code*

### 5.4.2.3 Wind speed measurement

The wind speed sensor works in a similar way to the rain one, with an interrupt that each time that is activated, an event is launched in the program to manage the interruption. The way wind speed is calculated can be appreciated in Equation 7.

$$\text{Wind speed (mph)} = \frac{\text{\# of wind clicks}}{\text{seconds from last wind check}} * 1,492$$

*Equation 7: Wind speed calculation*

In this case, each time the activation is detected, a variable adds a wind click to the current number of previous clicks.

```
void wspeedIRQ()
// Activated by the magnet in the anemometer (2 ticks per rotation), attached to input D3
{
  if (millis() - lastWindIRQ > 10) // Ignore switch-bounce glitches less than 10ms
  {
    lastWindIRQ = millis(); //Grab the current time
    windClicks++; //There is 1.492MPH for each click per second.
  }
}
```

*Figure 30: Wind speed interruption management code*

Then, when the weather station wants to know the current wind speed, it calls a function that returns wind speed in miles per hour (mph) converting wind clicks, using the time that has passed from the last wind check.

```
float get_wind_speed()
{
  float deltaTime = millis() - lastWindCheck; //Obtain ms from last wind check
  deltaTime /= 1000.0; //Convert to seconds
  float windSpeed = (float)windClicks / deltaTime;
  windClicks = 0; //Reset and start watching for new wind
  lastWindCheck = millis();
  windSpeed *= 1.492; //Clicks each second * 1.492 = speed in mph
  return(windSpeed);
}
```

*Figure 31: Wind clicks conversion code*

Last but not least, this weather station also takes into account several wind gusts that could occur through a day, so this has also been coded in the Photon program to send it to the different outputs. The way of calculating these wind gusts is to compare the speed of the gust with the common speed that the station is normally detecting, so if the speed detected is higher than normal, it is a wind gust.

```
//Check to see if this is a gust for the day
if(currentSpeed > windgustmph)
{
  windgustmph = currentSpeed;
  windgustdir = currentDirection;
}
```

*Figure 32: Wind gusts detection code*

#### **5.4.2.4 Wind direction measurement**

Wind direction is going to be managed as its datasheet states, an analog read is going to be made from the sensor each time the station wants to know current weather data. The analog read is going to give a value that is going to be compared to know where wind is coming from. This comparison can be found in Table 3.

<i>Analog read interval</i>	<i>Direction</i>
2270 - 2290	North
3220 - 3299	Northeast
3890 - 3999	East
3780 - 3850	Southeast
3570 - 3650	South
2790 - 2850	Southwest

1580 - 1610	West
1930 - 1950	Northwest

*Table 3: Sensor analog read - wind direction equivalence*

This equivalence has been coded in the station program, so the function that obtain wind direction is going to return a value that means a specific direction. Moreover, for Wunderground, each one of these positions are going to be converted to another number that Wunderground accepts as a specific position in its API.

```
int get_wind_direction()
{
    unsigned int adc;

    adc = analogRead(WDIR); // get the current reading from the sensor

    if(adc > 2270 && adc < 2290) return (0); //North
    if(adc > 3220 && adc < 3299) return (1); //NE
    if(adc > 3890 && adc < 3999) return (2); //East
    if(adc > 3780 && adc < 3850) return (3); //SE

    if(adc > 3570 && adc < 3650) return (4); //South
    if(adc > 2790 && adc < 2850) return (5); //SW
    if(adc > 1580 && adc < 1610) return (6); //West
    if(adc > 1930 && adc < 1950) return (7); //NW

    return (-1); // error, disconnected?
}
```

*Figure 33: Wind direction management code*

### 5.4.3 OUTPUTS MANAGEMENT

Once data has been collected and prepared to be sent, it is necessary to code the send of this data to the two main outputs that the station has, Weather underground and the SD card. In this section, these outputs connections are going to be explained and the format in which data is sent to each one of them.

### 5.4.3.1 Weather Underground connection

Weather Underground has a specific format of receiving data, so it could properly show this data on the weather station personal web page. Therefore, the Photon is going to be connected to this specific web page and is going to send this data in the proper format.

Firstly, some variables that allow connection to Weather Underground have been created in the Photon program. These variables include the server that is going to support the connection, the name of the Wunderground page, the ID and password that this weather station has, the current time where the information is being sent and the type of software that is sending the information, so Wunderground can know that it is a Photon sending the data.

Then, if the connection has been successful, each one of the weather parameters that have been calculated previously is going to be send to Weather Underground in the format that it expects. In Figure 34, the part of the program that send data to Weather Underground can be appreciated, so this can be seen in a more clarifying way.

```
if (client.connect(SERVER, 80)) {
  Serial.println("Connected");
  client.print(WEBPAGE);
  client.print("ID=");
  client.print(ID);
  client.print("&PASSWORD=");
  client.print(PASSWORD);
  client.print("&dateutc=now");
  client.print("&tempf=");
  client.print(tempF);
  client.print("&dewptf=");
  client.print(dewptF);
  client.print("&windspeedmph=");
  client.print(windspeedmph);
  client.print("&windgustmph=");
  client.print(windgustmph);
  client.print("&winddir=");
  client.print(winddir);
  client.print("&rainin=");
  client.print(rainin);
  client.print("&dailyrainin=");
  client.print(dailyrainin);
  client.print("&humidity=");
  client.print(humidity);
  client.print("&baromin=");
  client.print(inches);
  client.print("&soilmoisture=");
  client.print(soilMoistureValue);
  client.print("&softwaretype=Particle-Photon&action=updateraw&realtime=1&rtfreq=120");
  client.print("Accept: text/html\r\n");
  client.print("Host: ");
  client.print(SERVER);
  client.print("\r\n\r\n");
}
```

Figure 34: Wunderground connection code





## **Chapter 6. RESULTS ANALYSIS**

Usually, the best way to check the success of a project is to verify if the output results are as they were initially expected. As it has been mentioned, this weather station has two different main outputs, Weather underground, as the remote output, and a 16 GB SD card, acting as a local output to minimize the station Wi-Fi dependence. In this chapter, either the local or the remote output is going to be analyzed to prove the weather station performance.

### **6.1 WEATHER UNDERGROUND**

On the one hand, this weather station is going to be constantly updating and uploading data into Weather Underground via Wi-Fi, so it will be possible to see real-time weather conditions and to record each weather measure in each space of time. This data record will be able to be consulted every time in the Weather Underground station interface in a quickly and intuitive way.

Although the station is not already set in a fixed place to have it working every day, there have been done several tests in a mosquito cage field that University of Florida has for weather investigations at Gainesville, Florida. These tests have been done in different days and some interesting and valuable results have been obtained from these days and they have been visible at Weather Underground.

#### **6.1.1 CURRENT CONDITIONS AND SUMMARY UPDATE**

When entering at this personal station page in Weather Underground, the first aspect that would be able to find is a current conditions summary that is going to show real-time results, so the station current measures can be appreciated there.

In Figure 36, the current conditions that the station reported on June 8<sup>th</sup>, 2018 at 10:00 am can be appreciated. The station reported a temperature of 71.6 °F (22 °C), a dew point of 64

°F (17,7 °C), a humidity of 80%, no rain, no wind unless some wind gusts that hit the station and a pressure of 30,14 inches of mercury.

These results make sense due to that Gainesville, Florida has a semi-tropical climate and temperatures and humidity are especially high there in June, despite that these measures have been taken at 10 o'clock in the morning. Moreover, it can be appreciated that the map shows some lightly rains, but the sensor has sent a precipitation rate of 0 inch/hour. This is because the rain sensor, that has been used for this station, take a time to detect light rain due to it does not have the required strong to activate the pull-up/pull-down piece that the sensor uses to count rain inches. Nevertheless, this was monitored during that day and, later, it was finally detected.

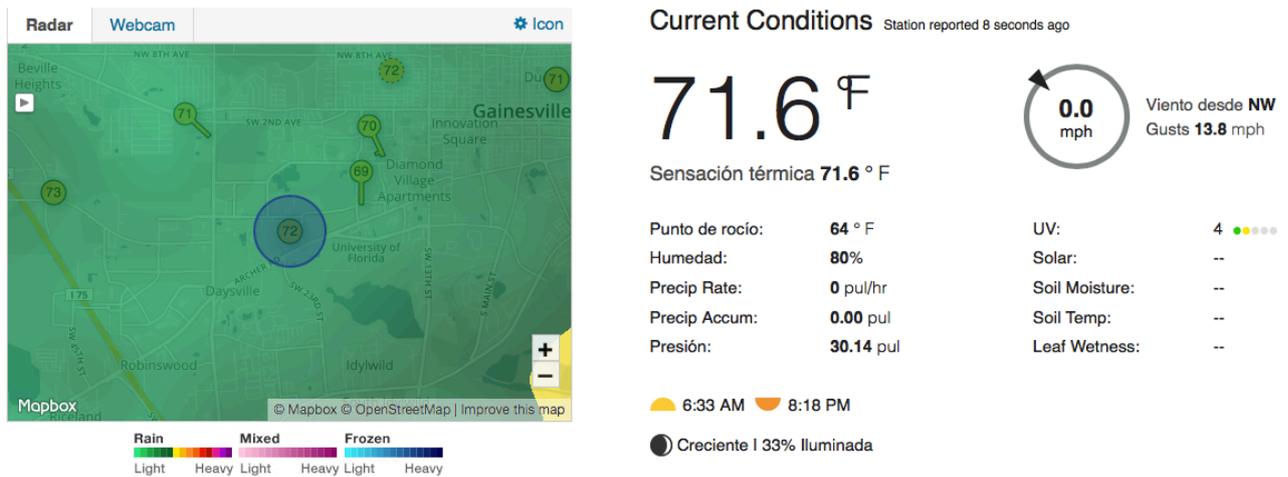


Figure 36: Current conditions of the station at Wunderground on June 8<sup>th</sup>, 2018

Furthermore, this page is constantly updating a day summary to have an idea of the daily measures that the weather station is obtaining. Later, on June 9<sup>th</sup>, 2018, a screenshot of this summary was taken (Figure 37) to check if the collected data was reasonable according to the weather conditions that Gainesville presented on June 8<sup>th</sup>.

Effectively, the results made sense with the weather that Gainesville had on that day, because it was a hot day in Florida and temperatures varied from 95,1 °F (35 °C) to 67,2 °F (19,2 °C) in the night. Moreover, humidity reached a 90% peak, which is common in Florida by that time of the year, and the lightly rains that Gainesville was suffering in the morning of June 8<sup>th</sup> were recorded with a high precipitation rate of 0.02 inches.

Nevertheless, wind measures are not accurate because by June 8<sup>th</sup>, the wind sensors were suffering some code adjustment to test them, but these sensors had worked properly in previous tests and good wind results can be found in section Wind results of this memorandum.

**Summary**  
**June 8, 2018**

	High	Low	Average		High	Low	Average
Temperature	95.1 °F	67.2 °F	81.1 °F	Wind Speed	7 mph	--	0 mph
Dew Point	77.1 °F	62.6 °F	70.1 °F	Wind Gust	0 mph	--	--
Humidity	90%	47%	68%	Wind Direction	--	--	North
Precipitation	0.02 in	--	--	Pressure	30.04 in	29.94 in	--

*Figure 37: Weather summary on June 8<sup>th</sup>, 2018 at Wunderground*

### 6.1.2 TEMPERATURE RESULTS

At the same personal weather station web site at Weather Underground, it is possible to visualize several graphs about the evolution of the different station measures through a day, week, month or year. In this case, several sample graphs have been taken from the web page that the station has worked properly in the different days that it has been tested.

In Figure 38, the evolution of the daily temperature on June 8<sup>th</sup>, 2018 at the mosquito cage field in University of Florida is presented. In the graph, it is possible to appreciate that the temperature has suffered the common evolution of a summer day in Florida with temperatures near 75 °F (24 °C) at night and extremely high temperatures at midday until 4 pm.



Figure 38: Temperature evolution on July 8<sup>th</sup>, 2018

### 6.1.3 WIND RESULTS

In terms of wind measures, there are two graphs that could be appreciated at this webpage. These results were taken on a test done by May 15<sup>th</sup>, 2018 and they represent the evolution of this day, because on June 8<sup>th</sup> the wind sensors were suffering code changes and the results were not so accurate at these ones.

The first graph is the wind speed and the detection of several wind gusts through the day. In Figure 39, it can be noticed that the wind speed sensor has properly detected wind speed changes, having a wind peak of 4.2 mph (6,76 km/h). Moreover, the different wind gusts, that have hit the station during the day, have been registered.

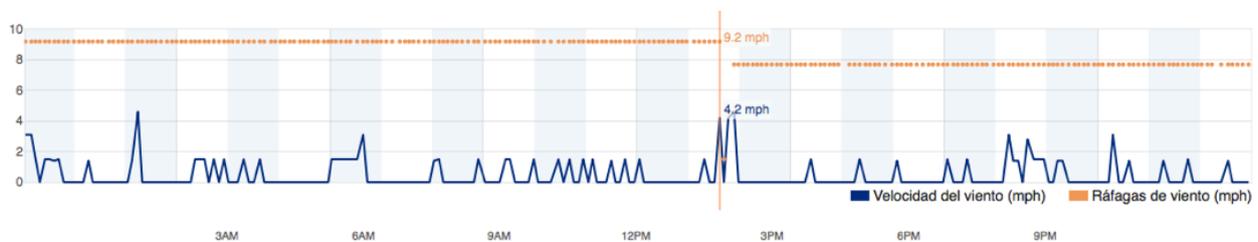


Figure 39: Wind speed evolution on May 15<sup>th</sup>, 2018

In the second graph (Figure 40), it can be appreciated the wind direction that the station registered on May 15<sup>th</sup>, 2018 and it clearly seems that the wind came from a North-West direction on that day, although there were several moments that the wind slightly changed its direction.

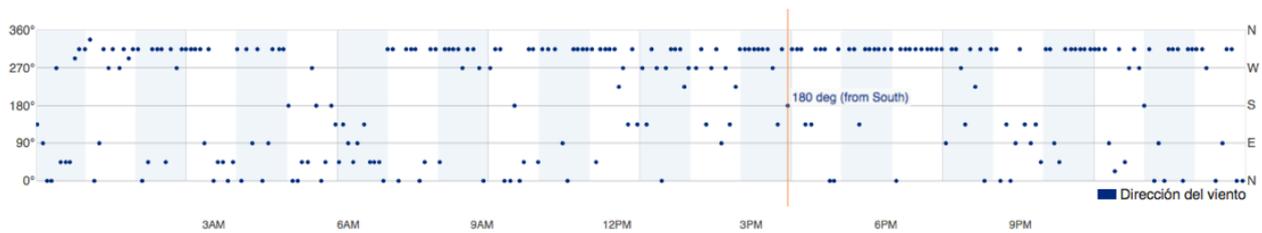


Figure 40: Wind direction evolution on May 15<sup>th</sup>, 2018

#### 6.1.4 RAIN RESULTS

The rain sensor has been the most difficult one to test on natural conditions because it has to rain to obtain any results. Fortunately, on July 6<sup>th</sup> and July 7<sup>th</sup>, 2018, several rains hit Gainesville, Florida and the sensor correctly detected those rains.

In Figure 41, it can be appreciated that a typical summer storm was suffered in Gainesville around 8 pm, while there were some precipitations accumulated from July 6<sup>th</sup>. As it can be seen, this storm lasted around 2 hours until 10 pm and a peak of 0.53 inches of rain were registered.

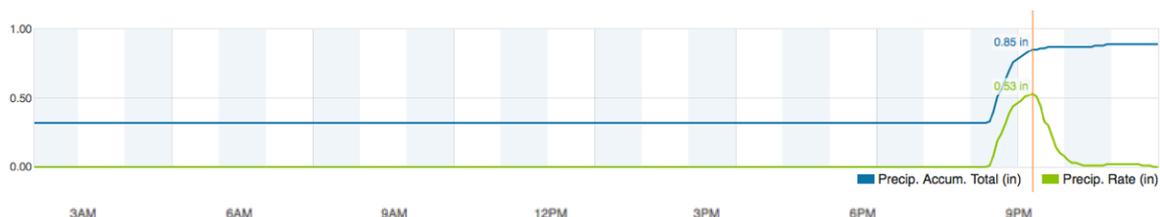


Figure 41: Precipitation evolution on June 7<sup>th</sup>, 2018

### 6.1.5 PRESSURE RESULTS

The final graph, that can be found at this personal station web page, is the evolution of the atmospheric pressure that the station is registering. Obviously, this pressure is going to be very constant, but it could be useful to detect any anomaly in the weather conditions if it suffers a drastic change.

In Figure 42, the pressure evolution through July 8<sup>th</sup>, 2018 can be appreciated with an average pressure of 30 inches of mercury. These results make sense with the atmospheric conditions at Florida because, under normal atmospheric conditions, the common pressure at sea level is about 29.92 inches of mercury and Florida is a state that has water in almost each of its border with not so many mountains or elevations.



Figure 42: Pressure evolution on July 8<sup>th</sup>, 2018

### 6.1.6 WEATHER HISTORY TABLE

Last but not least, another feature, that this website has, is the possibility of look to a weather history table with every minute, hour, week or monthly update that the station has done. This table enables the possibility of analyzing weather changes or anomalies in each space of time.

In Figure 43, it can be seen the evolution that weather had on the morning of July 8<sup>th</sup>, 2018 and it makes sense with the data that has been analyzed on previous sections. As it has been mentioned, wind data is not working properly on these days because, on these testing days, wind sensors were suffering code changes.

**Weather History Table**  
**June 8, 2018**

Time	Temperature	Dew Point	Humidity	Wind	Speed	Gust	Pressure	Precip. Rate.	Precip. Accum.
12:04 AM	77.4 °F	69.2 °F	75 %	North	0 mph	0 mph	29.97 in	0 in	0.89 in
12:09 AM	77.4 °F	69.2 °F	75 %	North	0 mph	0 mph	29.97 in	0 in	0.89 in
12:14 AM	77.4 °F	69.1 °F	75 %	North	0 mph	0 mph	29.97 in	0 in	0.89 in
12:19 AM	77.4 °F	69.1 °F	75 %	North	0 mph	0 mph	29.97 in	0 in	0.89 in
12:24 AM	77.4 °F	69.1 °F	75 %	North	0 mph	0 mph	29.96 in	0 in	0.89 in
12:29 AM	77.4 °F	69 °F	75 %	North	0 mph	0 mph	29.96 in	0 in	0.89 in
12:34 AM	77.4 °F	69 °F	75 %	North	0 mph	0 mph	29.96 in	0 in	0.89 in
12:39 AM	77.4 °F	69 °F	75 %	North	0 mph	0 mph	29.96 in	0 in	0.89 in
12:44 AM	77.4 °F	69 °F	75 %	North	0 mph	0 mph	29.96 in	0 in	0.89 in
12:49 AM	77.4 °F	69 °F	75 %	North	0 mph	0 mph	29.95 in	0 in	0.89 in
12:54 AM	77.4 °F	68.9 °F	75 %	North	0 mph	0 mph	29.95 in	0 in	0.89 in
12:59 AM	77.4 °F	69 °F	75 %	North	0 mph	0 mph	29.95 in	0 in	0.89 in
1:04 AM	77.4 °F	69 °F	75 %	North	0 mph	0 mph	29.95 in	0 in	0.89 in
1:09 AM	77.3 °F	68.8 °F	74 %	North	0 mph	0 mph	29.95 in	0 in	0.89 in
1:14 AM	77.2 °F	68.6 °F	74 %	North	0 mph	0 mph	29.95 in	0 in	0.89 in
1:19 AM	77.1 °F	68.5 °F	74 %	North	0 mph	0 mph	29.95 in	0 in	0.89 in
1:24 AM	77.1 °F	68.6 °F	75 %	North	0 mph	0 mph	29.95 in	0 in	0.89 in
1:29 AM	77.1 °F	68.8 °F	75 %	North	0 mph	0 mph	29.96 in	0 in	0.89 in

*Figure 43: Weather history table on June 8<sup>th</sup>, 2018*

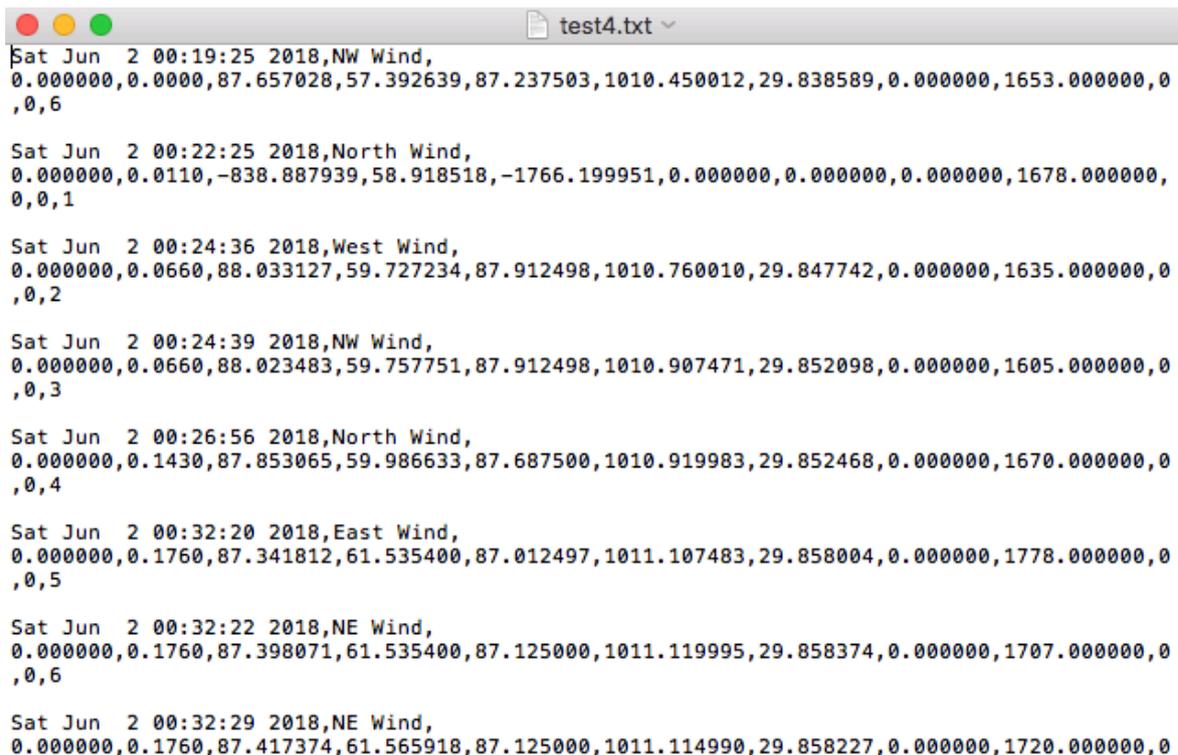
## 6.2 SD CARD OUTPUT

On the other hand, data is also going to be sent to a SD card that is going to save each data input in a text file, so it can be analyzed in case that Wi-Fi presents any type of failure. In this section, a screenshot of an output text file (Figure 44) is presented to demonstrate that the Photon is correctly sending data to the SD card, and this one is properly recording each received instance.

It can be appreciated that data has been saved with the format that was programmed and that each instance can be correctly differentiated from the previous one. If data is analyzed, the weather parameters seems to have been obtained and calculated correctly with the normal conditions of a summer day at Gainesville, Florida. Nevertheless, wind parameters are not working properly on this sample because, by the date that the text file is stating, wind sensors

were under code testing, but it has been showed in the previous section that these sensors have been working properly before starting to improve them.

Finally, one of the last parameters that appears in each instance is a soil moisture value because, by June 2<sup>nd</sup>, 2018, some tests on this new sensor have been already done to integrate it soon with the weather station.



```
test4.txt
Sat Jun 2 00:19:25 2018,NW Wind,
0.000000,0.0000,87.657028,57.392639,87.237503,1010.450012,29.838589,0.000000,1653.000000,0
,0,6

Sat Jun 2 00:22:25 2018,North Wind,
0.000000,0.0110,-838.887939,58.918518,-1766.199951,0.000000,0.000000,0.000000,1678.000000,
0,0,1

Sat Jun 2 00:24:36 2018,West Wind,
0.000000,0.0660,88.033127,59.727234,87.912498,1010.760010,29.847742,0.000000,1635.000000,0
,0,2

Sat Jun 2 00:24:39 2018,NW Wind,
0.000000,0.0660,88.023483,59.757751,87.912498,1010.907471,29.852098,0.000000,1605.000000,0
,0,3

Sat Jun 2 00:26:56 2018,North Wind,
0.000000,0.1430,87.853065,59.986633,87.687500,1010.919983,29.852468,0.000000,1670.000000,0
,0,4

Sat Jun 2 00:32:20 2018,East Wind,
0.000000,0.1760,87.341812,61.535400,87.012497,1011.107483,29.858004,0.000000,1778.000000,0
,0,5

Sat Jun 2 00:32:22 2018,NE Wind,
0.000000,0.1760,87.398071,61.535400,87.125000,1011.119995,29.858374,0.000000,1707.000000,0
,0,6

Sat Jun 2 00:32:29 2018,NE Wind,
0.000000,0.1760,87.417374,61.565918,87.125000,1011.114990,29.858227,0.000000,1720.000000,0
```

Figure 44: SD card text file sample

## **Chapter 7. CONCLUSIONS AND FUTURE APPROACH**

### **7.1 CONCLUSIONS**

Nowadays, Haiti's poor technological development, and its few capabilities to obtain accurate weather data measures, has derived in searching modern and low-cost projects to make the country more capable of self-development. One of these fields, that need a technological push, is weather measurement to predict the common natural disasters, that usually devastate Haiti, or to be able to optimally manage agriculture in the country.

These needs derived, among others, in the project that has been explained in this memorandum, the development of a low-cost Internet-connected modular weather station, so Haitians could use this modern and cheap technology to obtain a huge quantity of weather information and to serve as a basis for future prediction algorithms. Now, eight months after the project beginning, the weather station is almost ready for its implementation at Haiti and project objectives have been mainly accomplished.

Firstly, the different weather station modules have been properly analyzed and tested to obtain optimal weather readings from them. Each unit has been firstly tested by their own and, then, several tests have been done inside a mosquito cage, on a University of Florida field, with all the modules assembled together as a unique station. It can be said that the most part of these tests have been successful, and they have help to fix small bugs that, now, are under observation.

Moreover, each sensor had different ways of obtaining data and it has to be manipulated after its collection to have some readable weather results. These several ways have been properly code in the controller (Particle photon) program and they have been documented in this memorandum to understand them easily. After visualizing output results, it is noticeable that each sensor is obtaining and converting data in its proper way and they are recording real time weather conditions.

Furthermore, the weather station has been successfully provided with a self-autonomy power system due to a solar panel and a rechargeable lithium battery that have been integrated with it. This takes out the need for having to be plugging in the station the whole time and it provides freedom to the set-up place for the station, so it will be possible to locate it in more optimal places. Also, the Photon has given the wireless capacity that was necessary on the station to avoid the use of electrical wires that could highly limit the project.

In terms of station design, a modular station model has been successfully designed and it has been correctly assembled and tested to avoid miscommunications between modules and to be able to present a unique solution to Haitians, so they could implement the station in a quick and easy way.

Finally, data has been outputted to two main sources with readable and optimal results. These results have served to demonstrate that each unit has worked properly on, at least, some of the tests that have been done to the station. On the one hand, data has been sent to a personal weather station web page at Weather Underground and, now, this data is able to be visualized at this website. On the other hand, data has been recorded in a SD card to avoid the station Wi-Fi dependence, so any data will not be lost. Both output have successfully showed a valid result that have demonstrate a correct station performance, although some units need some code changes to work in a more optimal way.

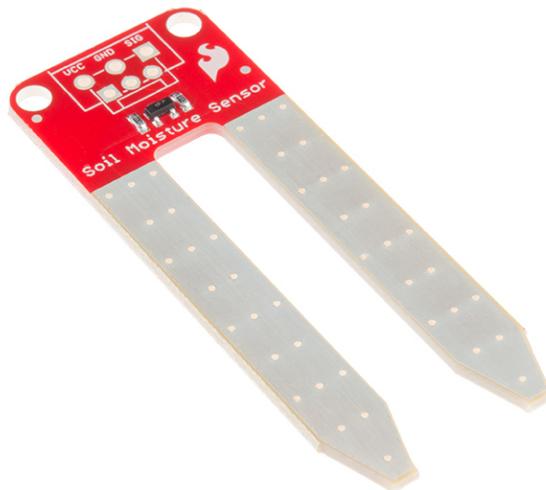
This project has given an enormous impulse to implement IoT solutions in developing countries, such as Haiti. It has been demonstrated that these solutions are not only valid for developed countries, and that they could serve as a basis for a country self-development, if they are implemented in a nonprofit way. Moreover, a valid modular weather solution has been successfully designed and it will be ready to be implemented at Haiti in the next few months, so Haitians could use it as an easy-to-use weather tool to manage agriculture, among others.

## **7.2 FUTURE APPROACH**

### **7.2.1 SOIL MOISTURE SENSOR INTEGRATION**

There are several future improvements that have been thought for this IoT weather station. These improvements vary from adding more data sources to acquiring more modern hardware units or optimizing the way the station has been coded to make it more understandable for Haitians, so they could work in their own station improvements.

First, there have been done some tests with a soil moisture sensor but there has not been enough time to incorporate it in this version of the station and more testing is needed to be done. The sensor that was chosen to provide this soil moisture data is the Sparkfun Soil Moisture Sensor (SEN-1322 ROHS) developed by Sparkfun Electronics and that is prepared to connect with the Sparkfun Weather Shield board.



*Figure 45: Soil moisture sensor*

### **7.2.2 IMPLEMENTATION AT HAITI**

Moreover, this station has been designed to be implemented at Haiti and to enable Haitians to use it as a tool for obtaining weather data and to be able to have more opportunities to face natural disasters and manage agriculture in their country.

By the time this memorandum has been written, there has not been enough time to fully tune up every station feature. Nevertheless, it is planned to have a final version station at Haiti before the end of 2018, so Haitians could start to get used to it. Obviously, more improvements will be integrated to this final version in future steps, as it can be appreciated in the following sections of this memorandum.

### **7.2.3 IOT UPGRADES**

Furthermore, in terms of IoT upgrades, technological units are always being improved to optimize the way they perform their daily functions. For that reason, it is an important task to be up-to-date when being part of a technological project and, despite this weather station works well with the component used, new advances should be integrated into the project to avoid having an obsolete station.

One IoT improvement alternative could be to get profit of modern weather stations solutions that the market is launching. The weather sensors, that have been used in this station, give good and reliable measures and they have a good quality-price relationship, but new solutions are arising into the market and the need of being up-to-date is essential to have a profitable market solution.

Having said that, Netatmo, an IoT company [23], has launched a modern weather station model that is more accurate and easy to work with than the one used on this project, so to incorporate it into the project is a real alternative for the following project steps. Moreover, Netatmo has an own App to store the weather results, it is possible to see real-time data on this App in an easy way and it gives you the possibility to integrate easily with the well-known Internet-connected Amazon solution, Alexa.

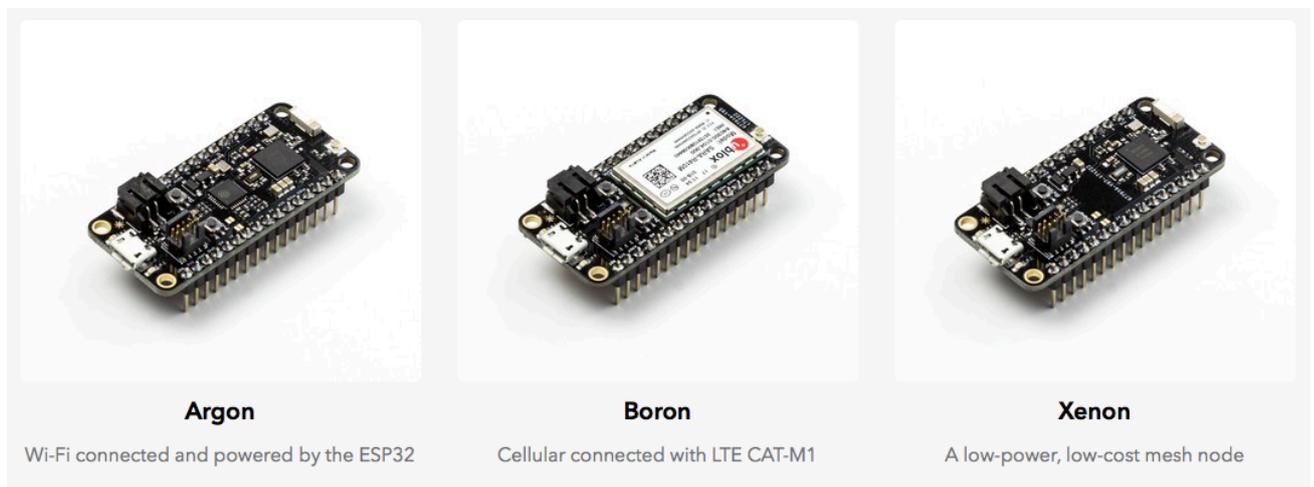
In Figure 46, the Netatmo station modules aspect could be appreciated.



*Figure 46: Netatmo station module and wind & rain units [24]*

Other IoT improvement alternative could be to look for any upgrades at the IoT company that has been used for the project, Particle. In fact, the Photon has a new successor due to Particle has just launched its third-generation hardware development kits (Argon, Boron and Xenon), introducing the new concept of Particle Mesh [25]. This new idea is a mesh networking technology that has been designed to connect those spaces between Wi-Fi and cellular deployments, creating low-cost, secure and ultra-reliable local networks.

On this mesh network, a small amount of the devices is connected to the Internet, acting as gateways for the rest of the devices in the network. This device creates a local wireless network that the rest of the devices join to help collecting sensor data and communicating between Particle devices. Also, mesh networking ensures that each message is been delivered to each receiver and it helps to solve the most common problems that IoT solutions usually have, with a technology that gives the project new capacities as high network reliability, local communications, low cost hardware and low power consumption.



*Figure 47: Particle third generation hardware development kit. [30]*

#### 7.2.4 CODE OPTIMIZATION

Last but not least, it is always important to have an optimized code in a technological project, so it is easier to understand by future researchers and the functions will be performed faster. For the weather station software code, several objectives have been planned to optimize the station performance:

- Optimize the overall control loop.
- Multi-threading the code to avoid lockup.
- Power reduction strategies to obtain a more power saving solution.
- Making the SD card read and write via particle variables.
- Finish the soil moisture code.

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