University of Puerto Rico at Mayagüez

Mayagüez, Puerto Rico

Department of Electrical and Computer Engineering

WindTel: An Automated Wind Tunnel Redesign

A project proposal submitted as a partial requirement for the Embedded Systems Design course ICOM-4217

by

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For: Dr. Manuel Jiménez
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Abstract

Wind tunnels are used to study the aerodynamics of cars, boats, aircrafts and other objects by moving air through a chamber and analyzing its effects on the object. In 2013, a team of students from the ICOM-5217 course of the University of Puerto Rico at Mayagüez (UPRM) designed a system capable of taking measurements of force, pressure and velocity upon the object being studied using the wind tunnel at the Department of Civil Engineering, which is managed by Dr. Raúl Zapata. These measurements were then displayed on a Liquid Crystal Display (LCD), making these data visible for the users of the system. There was one limitation with their implementation: the software could only be accessed using an Android tablet. After a few years, the tablet software became obsolete and various hardware components were damaged, making the tunnel useless. Moreover, the hardware setup proved inadequate for proper maintenance or sustainability. This problem was compounded by a clunky user interface which did not do well to ensure that the system would not be damaged by user error. WindTel is proposed as an improvement upon this previous system and as a solution to the aforementioned problems. As its name suggests, this system will measure telemetry data and remotely send it to any device that contains the WindTel application. In addition, sustainability, extensibility, and modularity--both in terms of software and hardware--will be emphasized throughout the entire design process, such that the system will be of fruitful academic and industrial use well into the future.

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I. Introduction

A wind tunnel is system which can simulate the movement of air around and upon a solid object. In the wind tunnel, the engineer can control the conditions that affect the forces and motion of the solid object [1]. The behavior of the object varies depending on the aerodynamics characteristic of it. Scaled-down models of bigger real-life objects are tested inside the wind tunnel. These can include boats, cars, airplane, structure materials, solid composites, among others [2]. By measuring the object model forces, the engineer can determine the magnitude of the forces on the real, full-sized object.

Numerous institutions like the University of Puerto Rico at Mayagüez (UPRM), NASA, the University of Maryland-College Park, the University of Manchester and others, use wind tunnels. The Civil Engineering Department of UPRM has a wind tunnel that is used for research purposes and student project group tests [2]. In 2013, students from the ICOM 5217 course designed a system called Aerobal capable of taking measurements of force, pressure and speed of this wind tunnel. This information was displayed on a Liquid Crystal Display (LCD), making it visible to the users of the machine. Since the student group limited the only copy of the wind tunnel software to an Android tablet and the tablet data became unrecoverable due to a software update, the project fell apart, completely losing all automation functionality.

A proposed solution is to redesign the automation of the wind tunnel system by providing a reliable, sustainable, extensible and modular embedded system implementation named WindTel. A circuit containing resistors, capacitors, push-buttons, a microcontroller (MCU), a Wi-Fi communication module and other hardware components will function cooperatively to obtain the humidity and temperature information through sensors. The hardware components will be organized and compressed in a printed circuit board (PCB) and shielded with the MCU chosen for the application (Fig. 1). The process of obtaining data out of the wind tunnel will be done through an electronic system, which is a balance that is controlled by another MCU. The balance MCU is fed with amplified sensor signals that register the wind force direction and speed measurements over the object. The balance circuitry will also be converted into a PCB, reducing the component space and area. Both microcontrollers will send their respective collected information to a software application that will be made executable in any computer. The software application will be able to display all the sensor measurements in a variety of units such as the user desires, and wind tunnel operations will also be possible from this system.

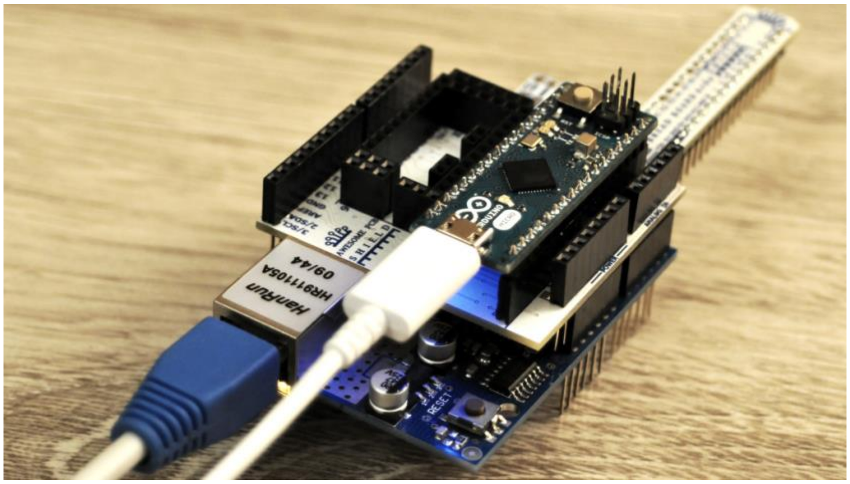

Image taken from AwesomePCB.com

Fig. 1: Example of a shielded PCB

II. System Conception

Global System View

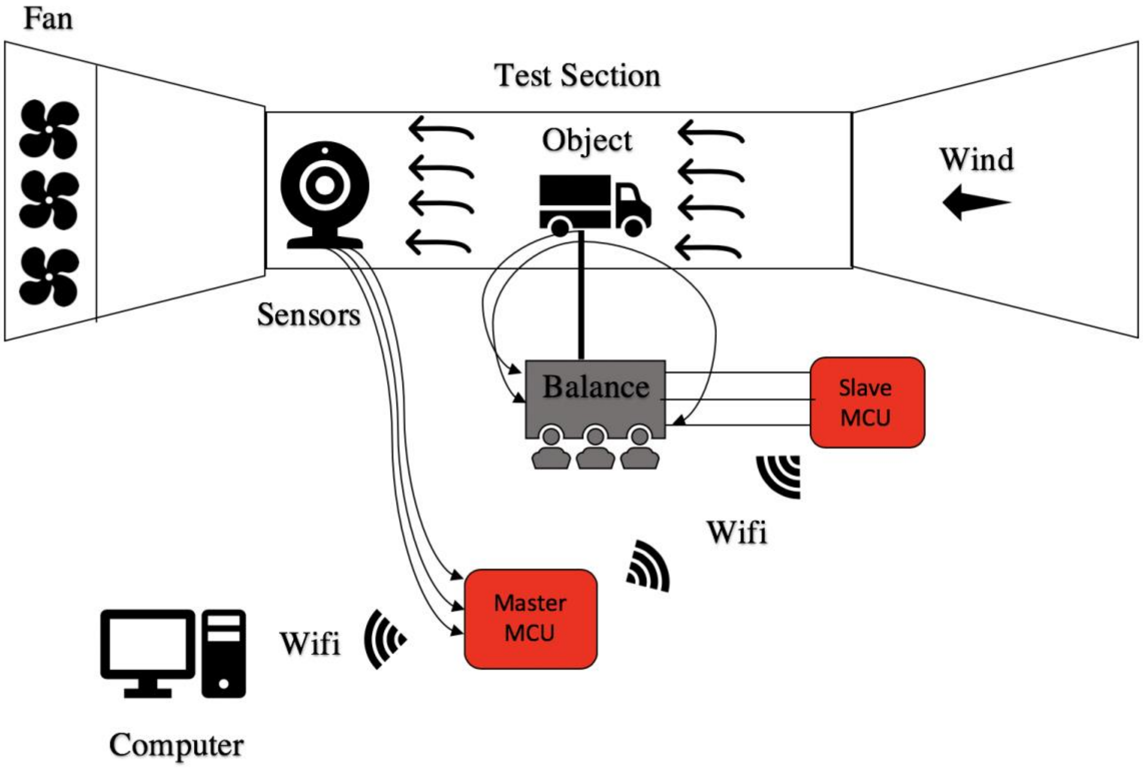

Fig. 2: Global System View of WindTel

User Interface-level

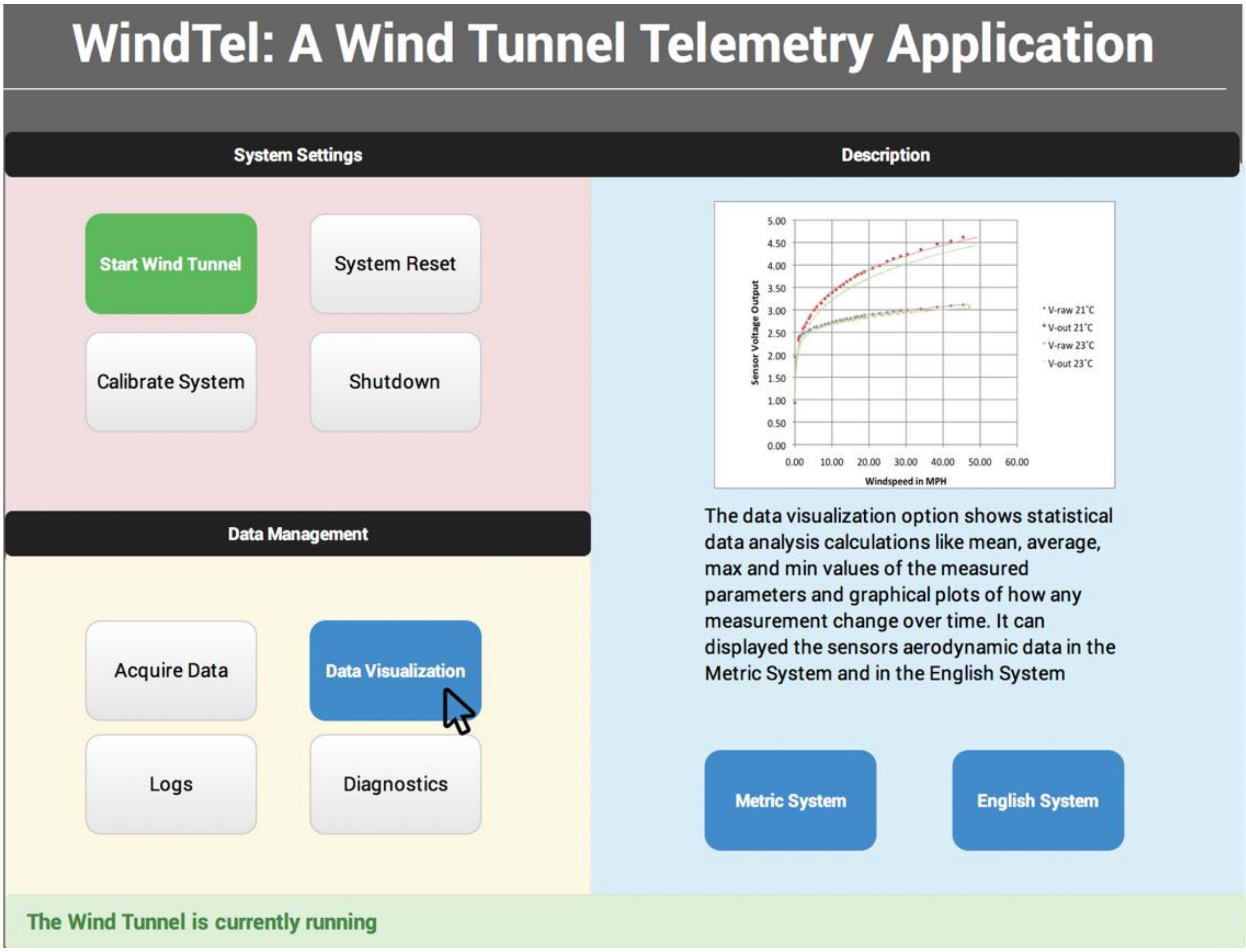

Fig. 3: WindTel software application GUI

III. System Architecture & Functionality

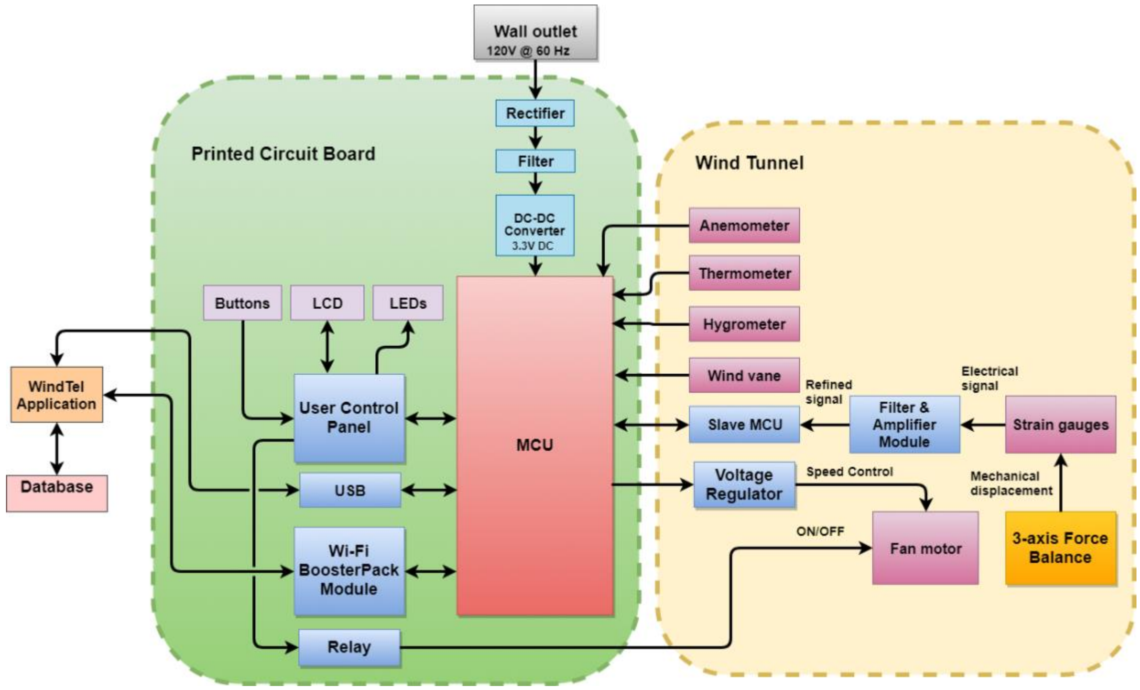

Fig. 4: System Architecture

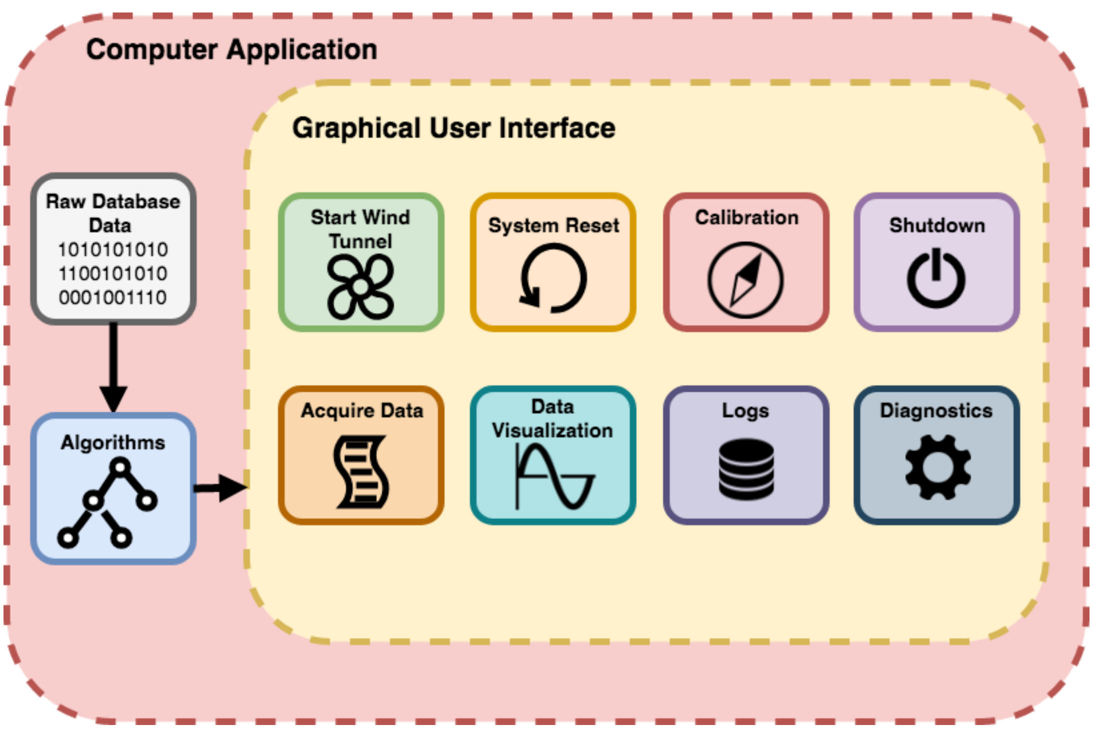

Fig. 5: System Architecture - Computer Application Detail

IV. Processor Selection

The WindTel system is expected to use a small memory size (lower than 128KB), to run at a low speed and to include I/O type peripherals, therefore, an MCU must be chosen for the application. The preliminary peripherals are shown in Fig. 6. The system will need at least four high precision Analog-to-Digital Converter (ADC), three Universal Asynchronous Receivers/Transmitters (UART), five error fault light-emitting diodes (LEDs) and a Wireless Local Area Network (WLAN) device. The three processor alternatives that were considered are: the TI MSP432P401R, TI TM4C123G and the TI MSP430F5418A.

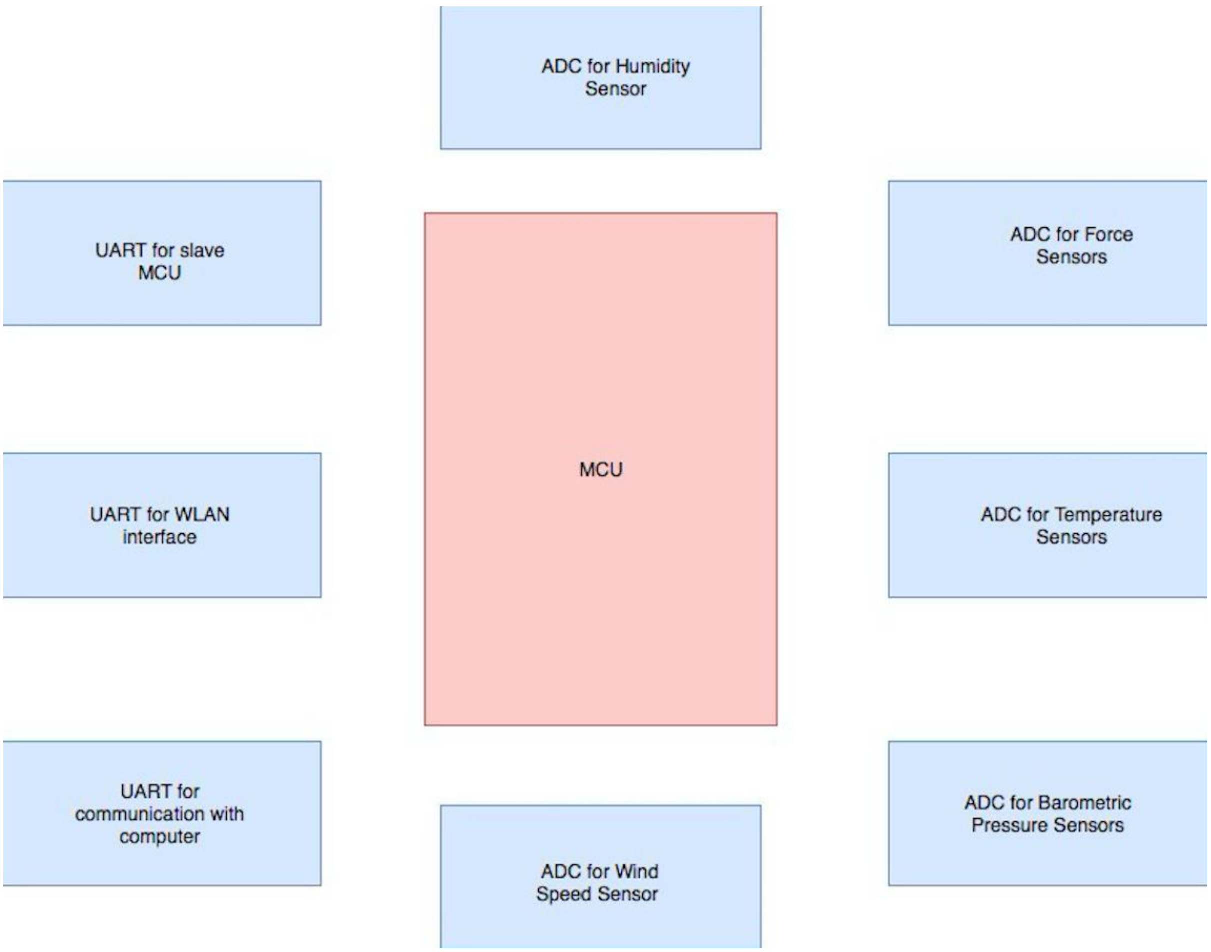

Fig. 6: Peripherals for the WindTel system

TI MSP432P401R (MCU selected for the project)

The MSP432P401R has a 48MHz ARM 32-bit Cortex-M4F Central Processing Unit (CPU) with 256KB Flash and 64KB RAM memory (Fig. 7). It has a high-precision 16-bit 24 channels ADC which enables high resolution of analog data taken from the outside world. In addition, it has an ultra-low-power mode that can be enabled using software. Another feature is that it includes four programmable serial communication modules which can be used to transfer data using UART, SPI and/or I2C protocols. More information can be found in [7]. Because of its high-resolution ADC, this MCU was chosen to reduce the error of the telemetry in the wind tunnel. The MCU is also compatible with Bluetooth modules and Wi-fi wireless connectivity which will facilitate interfacing with the WLAN peripheral. It can be programmed using Integrated Development Environments (IDEs) such as IAR Embedded Workbench and Code Composer Studio. Finally, a Launchpad kit is available in Texas Instruments, Inc. website for $12.99.

Courtesy of Texas Instruments, Inc.

Fig. 7: TI MSP432P401R Launchpad

TI TM4C123G

The TM4C123G, member of the Tiva C Series family of MCUs, has an 80MHz 32-bit ARM Cortex-M4-based microcontrollers CPU with 256KB Flash, 32KB SRAM and a 2KB EEPROM (Fig. 8). It has a 12-bit 12-channel ADC with single-ended and differential-input configurations and an on-chip internal temperature sensor. In addition, it has 8 UART, 6 I2C and 4 SPI ports which can be used for serial communication with the other external devices. More information can be found in [8]. This MCU was also considered because of the resolution of the ADC, the memory size and the number of serial communication modules which makes it suitable for the application. It can be programmed with IDEs such as IAR Embedded Workbench and Code Composer Studio. As the MSP432P401R, the TM4C123G comes in a Launchpad kit for $12.99.

Courtesy of Texas Instruments, Inc.

Fig. 8: Tiva C Series Launchpad

TI MSP430F5418A

The MSP430F5418A is a 16-bit ultra-low power microcontroller with a 25MHz Reduced Instruction Set Computing (RISC) architecture and a memory of 128KB and a 16KB RAM (Fig. 9). The MCU has a 12-bit 16-channel ADC and four universal serial communication interfaces which can be programmed to use has UART, SPI and I2C protocol ports. More information can be found in [9]. Although the memory size is limited compared to the other alternatives, the resolution of the ADC and the number of communication ports makes this MCU a good option. The main disadvantage is that it does not come in a development kit or in a Launchpad kit which makes its usage more difficult. The cost of the MCU is $4.63.

Courtesy of Texas Instruments, Inc.

Fig. 9: The TI MSP430F5418A MCU

V. Specifications

A. Hardware Requirements

The project requires a hardware component that is capable of making measurements inside the wind tunnel of parameters such as: the forces acting upon the test model, temperature, humidity, wind speed, and wind direction. Moreover, the stated design goals of sustainability and modularity impose additional hardware requirements.

1. A Wireless Local Area Network (WLAN) device for Wi-Fi Communication.

2. Light Emitting Diodes (LEDs) for indicating error faults in the circuit.

3. PCBs so that the circuit takes less space and to obtain a fixed circuitry.

4. MSP432P401R high-precision ADC LaunchPad™ Development Kit.

5. LCD and push-buttons to operate the circuit in the development phase and provide an alternative way of debugging the system.

6. Sensors to measure force, temperature, humidity, wind speed, wind direction.

B. Software Requirements

The software component must be capable of performing algorithms on raw data measurements. It should also be capable of producing data visualizations.

1. A desktop or personal computer with C programming compiler and Code Composer Studio IDE.

2. PgAdmin 4 and PostgreSQL software for creating and establishing a database.

3. R open source programming language for creating the plots for the data visualization of the wind tunnel.

4. RStudio IDE software application for developing R scripts.

C. Communication Requirements

The system must allow for inter-component communication. Hardware sensors performing data measurements inside the wind tunnel environment must be able to relay this information to the master MCU. Furthermore, all environment data and associated experiment metadata (such as date and time of experiments) must then be transmitted to a database server through the IoT interface. A USB port will also be utilized to allow for direct data transfer with a desktop PC or device of choice.

D. User Interface

The wind tunnel user will interact with the WindTel implementation through the use of a software application in a desktop or personal computer. The application will be developed in the C programming language. It will display a menu with several options: start wind tunnel operation, system calibration, data acquired, system reset and shutdown. The start wind tunnel operation will turn-on the wind tunnel and start acquiring the aerodynamic measurements. The system calibration option will communicate with the slave MCU and set the mechanical balance in a calibration status were an object of 0.01lbs will be placed inside the chamber so that the system will have a precision of at least hundredth pounds [2]. The data acquired option will display the pressure, the humidity, the temperature, the wind speed and the forces exerted on an object in all x, y, z directions. It will display a submenu giving the option to change the measurements units from the Metric System to the Imperial System and vice versa. The data visualization option shows statistical data analysis calculations like mean, average, max and min values of the measured parameters and graphical plots of how any measurement change over time. The diagnostic option shows the status of the wind tunnel, latest update, calibration information and last perform experiment. The Logs option display the information of all the experiments inside the WindTel database and provide the user the ability to perform the data visualization option on any past log. The system reset option will delete all data stored from past experiments and take the system to its initial state letting the calibration values in memory intact. The shutdown operation will stop the data acquiring process, save the experimental data in a database and turn-off the power of the wind tunnel.

E. Control Scheme Requirements

The wind tunnel wind speed is controlled by a fan. WindTel will include a closed-loop control system for the fan. A Proportional-Integral (PI) controller will be designed to maintain, increase or decrease the wind speed of the tunnel. The PI controller characteristics will be defined using the MSP432P401R and its peripherals (ADCs).

F. Microprocessor-based Requirements

The WindTel project requires a microprocessor-based implementation since there is a need to monitor multiple distinct aerodynamic measurements inside the wind tunnel throw sensors and it needs to obtain the status information of a mechanical balance control system. Three strain gauges measure the forces being applied to a test model inside the wind tunnel in the x, y, and z coordinates. These strain gauges are mounted on a balance which provides an extension that serves as a base for the test model, interfering as little as possible with the aerodynamic measurements [2]. The sensor signals of the strain gauges are amplified through analog circuitry and are connected to a mechanical balance system constructed by the Aerobal group. A slave MCU will receive the mechanical balance signals, perform aerodynamic computations of the forces, and send the results to the master MCU. The master MCU will send all its monitored data to a software application in a computer via Wi-Fi communication to a local database. The master-slave MCU communication and the computer communication will be done through Wi-Fi.

VI. Market Description

There are several companies and universities that have a wind tunnel, some more sophisticated than others, that are used to analyze different characteristics of the air. One university that has one of the best wind tunnels is the University of Maryland-College Park. We are taking their wind tunnel, which they named it Glenn L. Martin, as our reference point to develop our project.

Glenn L. Martin wind tunnel specifications of [5,6] state the following:

1. The tunnel will be a closed loop solid wall
2. The test section is 7'9" high, 11' wide, and 13' long
3. The maximum speed is 230 mph with upgrades in planning to bring the maximum speed to 330 mph.
4. Primary instrumentation provides capability to measure six component forces on test articles ranging from aircraft to ground vehicles, marine vehicles, building components, etc.
5. Instrumentation includes pressure transducers, temperature transducers, flow sensors, and specialized software for experiment automation, data gathering, and data presentation.
6. Advanced computation capabilities for rapid data presentation and rapid comparison of results of measurements, analyses, and computational simulations
7. User will be able to plan an experiment to achieve a specified set of objectives
8. User will receive a test report of the experiment

As for the costs, they don't specify their expenses towards making the Glenn L. Martin wind tunnel. They charge $950.00 per occupancy hour of time using it since they are having for research and project purposes, where we can then state that with that they must have sufficient funding for maintenance for the tunnel, hardware and software components, among others, as well as for the employees in charge of doing so.

We can see that the Glenn L. Martin wind tunnel is very similar to the wind tunnel that we're going to work with since they're both used for research purposes and have more or less the same type of measurements desired upon the object being analyzed. In our case, we're limited in several aspects such as: the velocity of the wind tunnel to which the maximum value does not exceed 50 mph versus 230 mph, the accuracy of the measurements may be slightly off to the nominal or correct value, the quality of the wind tunnel in general, among others.

Even though we have some limitations with our wind tunnel, we can still be able to overcome some of them and be able to develop an application where no matter what wind tunnel you are using (i.e: Glenn L. Martin wind tunnel, NASA's wind tunnel or any other) you will be able to configure it to your liking and use it with your wind tunnel for the data acquisition. This is our goal with WindTel and we hope to be able to achieve it successfully.

VII. Design Constraints

Sustainability

One of the motivating factors in our choice of project is the fact that the previous wind tunnel automation system that was serving Dr. Raúl Zapata's wind tunnel quickly fell into a state of disrepair and disfunction. Without the maintenance skill or documentation to support such a maintenance effort, all of the previous efforts to automate the wind tunnel were soon in vain. An explicit design goal for the project we are proposing is ease of maintenance and sustainability. Our wind tunnel automation system must provide an interface as well as documentation that will enable its continued maintenance well into the future.

To that end, we are designing our system to have a simple interface that will maximize modularity as well as upgradeability and extensibility. A user's/debugging guide will be developed with the purpose of restoring the WindTel system in case of malfunctioning sensor, loss of software or other abnormality. By emphasizing modularity at both the software level and the hardware level, we are ensuring that our wind tunnel automation system is sustainable and will satisfy Dr. Raúl Zapata's needs for years to come.

Safety

The wind tunnel is located in the first floor of the Civil Engineering building at UPRM in room CI-07. Most of the circuitry in the WindTel implementation will be weld to a PCB that will place at the top of an MCU. The MCU will be stored in a special sealed case with the purpose of excluding the device from any human interaction. Safety procedures and instructions on how to operate the device will be included in the user's guide. Accessibility to the wind tunnel as well to the WindTel product must be granted with the authority of Dr. Raúl Zapata.

As a safety requirement any researcher or project group that is going to use the WindTel implementation must first read the user's guide to learn how to execute properly the WindTel application software. The user's guide must be stored inside room CI-07 in a container and must be given to the user by Dr. Zapata only.

VIII. Project Time Table

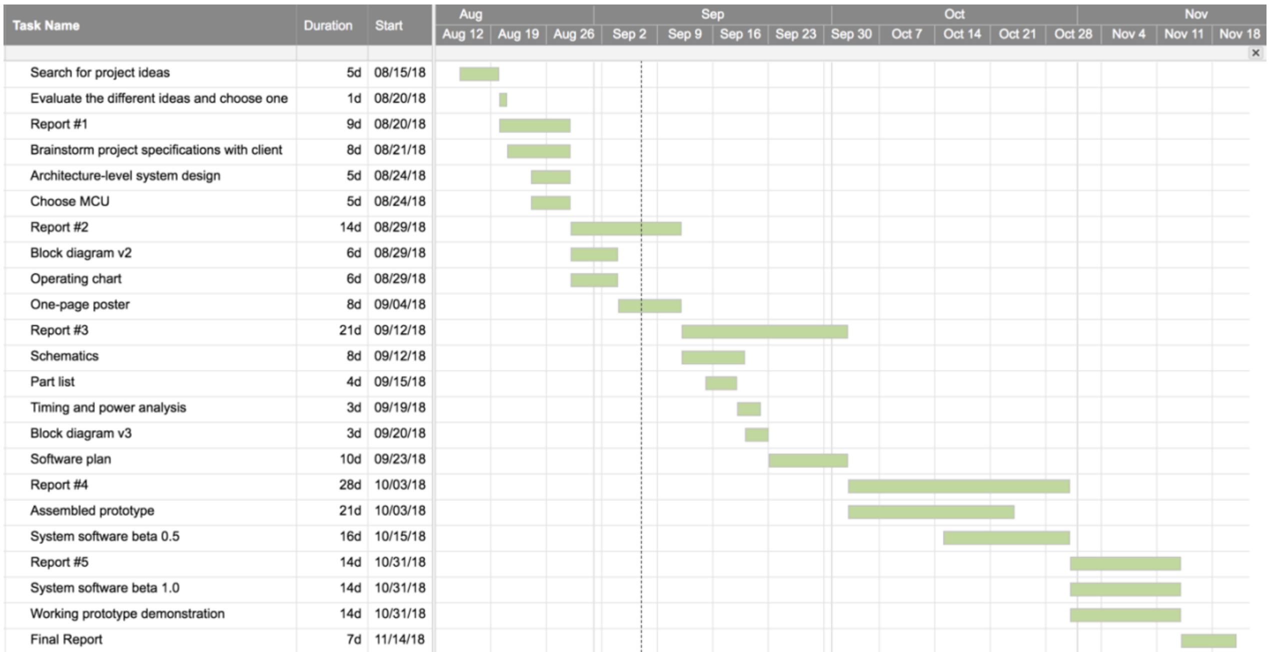

Fig. 10: WindTel Gantt Chart

IX. Expert Opinion

Our client Dr. Raúl Zapata from the Civil Engineering department gave us a background story of the wind tunnel and of the previous group that created the balance and the software to operate the tunnel. He mentioned that they made a great job, but they failed on making the software reliable and redundant in terms of being able to use it elsewhere besides the Android tablet that they used to make tests, as well as make the circuit easier to understand in case of future component failure so they can be easily distinguished and replaced with the correct ones.

We took his advice to create the problem statement and therefore, work on this project to create the software application that he highly desires for the wind tunnel. Besides making this reliable and redundant, he also wants the application to perform the aerodynamic calculations that the previous system performed as well as new features.

Dr. Raúl Zapata - Client
Civil Engineering Department
787-464-3045

X. References

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[9] "MSP430F5418A 16-Bit Ultra-Low-Power Microcontroller, 128KB Flash, 16KB RAM, 12 Bit ADC, 2 USCIs, 32-bit HW Multi | TI.com", *Ti.com*, 2018. [Online]. Available: http://www.ti.com/product/MSP430F5418A/support. [Accessed: 28- Aug- 2018].

XI. Appendices

A. Work Distribution Table

Task Description	Luis	Nelson	Misael	Kahlil
Search for project ideas	X	X		
Evaluate the different ideas and choose one				X
Report #1	X	X	X	X
Brainstorm project specifications with client	X			
Architecture-level system design			X	
Choose MCU		X		
Report #2	X	X	X	X
Block diagram v2			X	
Operating chart				X
One-page poster		X		
Report #3	X	X	X	X
Schematics			X	
Part list	X			
Timing and power analysis		X		
Block diagram v3			X	
Software plan				X
Report #4	X	X	X	X
Assembled prototype		X	X	
System software beta 0.5	X			
Report #5	X	X	X	X
System software beta 1.0	X			X
Working prototype demonstration		X	X	
Final Report	X	X	X	X

B. Project Journal

The Journey Begins to the famous Micro 2. An Embedded System Design Course Blog

Hearing rumors of how tough is the Embedded System Design course of the Electrical and Computer Engineering Department (ECE) of UPRM we form a project group the semester before the course started. The group members are composed of Luis O. Vega Maisonet, Nelson G. Rodriguez Ortiz, Kahlil J. Fonseca Garcia and Misael Valentín Feliciano.

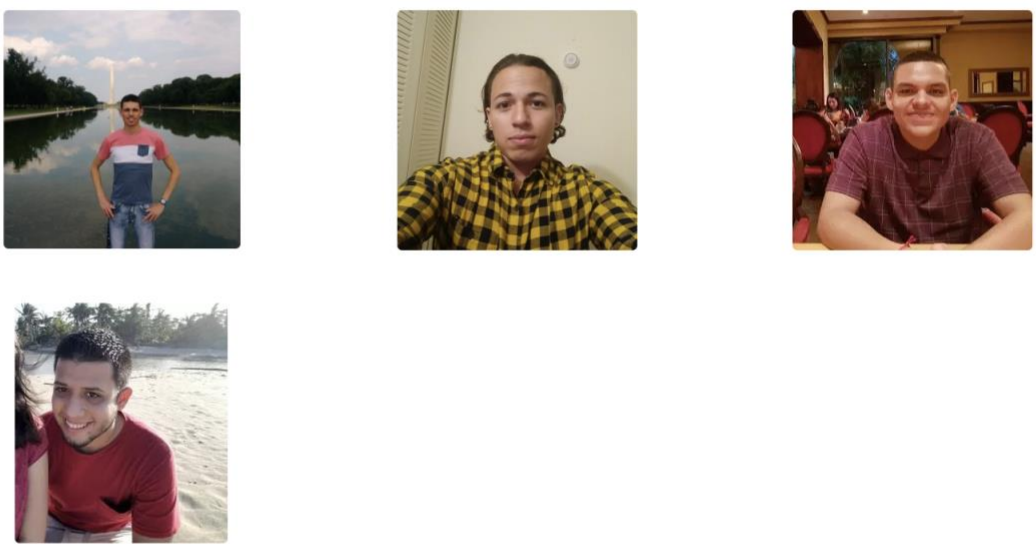

Fig. 11: Project Blog Image

Our project journal, in which we will document our weekly progress, can be found at the URL below: https://gonewiththewindtunnel.wordpress.com/