AeroBal

A project proposal submitted as a partial requirement of the Microprocessor Interfacing course ICOM-5217

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Contents

Abstract

Wind tunnels are used for research in various areas of science and engineering, such as wind and aerodynamics. The wind tunnel in the University of Puerto Rico, Mayaguez Campus is overly outdated, and recording data using it can be inconvenient. We propose AeroBal, a system that would improve the current wind tunnel in an important way. AeroBal would make recording data much simpler than it currently is, and could help make research easier in the future for constant users of the tunnel, such as mechanical and civil engineering students.

1 Introduction

Wind tunnels [1] are large tubes where an object is placed, and air is blown from powerful fans in a way that the air passes said object. The behavior of the object varies, depending on the aerodynamic characteristics of it. Therefore, we may say that wind tunnels are good tools to simulate the behavior of the objects in free flight. Some examples of objects that might be placed in wind tunnels are scaled-down versions of new airplane models, or cars with and without spoilers (in order to test how effective the spoilers are). Numerous institutions around the world use wind tunnels. Some examples are NASA, the University of Maryland [2], and the University of Southampton [3]. The Civil Engineering Department of the University of Puerto Rico, Mayaguez Campus [4] has a small wind tunnel used for research. In the past, this tunnel has been a central part of analyzing the aerodynamics of numerous projects, such as a Solar Car, ailerons, and tanks of storage for fluids. Unfortunately, this particular wind tunnel was constructed in 1983, and renewal of it has not been done. The conditions of the laboratory containing the wind tunnel can be considered of severely poor quality by todays standards. For example, two of the computers in the Wind Tunnel laboratory have 16 MB of onboard memory, and 424 MB of hard drive space. Another component of the tunnel which is in deplorable conditions is also one its main parts. This component is the mechanical balance that holds the model being analyzed. The balance of this particular tunnel is composed various steel bars connected together. These bars have halves of plastic milk bottles hanging from the bars. Figure 1 shows an image of the mechanical balance.

Figure 1: Current Mechanical Balance used in the wind tunnel.

Whenever an object is placed in the tunnel and the wind is blown, the balance is tilted. An example of the tilted balance can be seen in Figure 2. The direction of the tilt depends on the characteristics of the model being used. The data from the balance is obtained by pouring sand on whichever cup needs it in order to balance the device until it is close to 90 degrees, as it was from the start. After the desired angle has been achieved, the user takes the plastic cup and weights the poured sand. Calculations are then made using the measurement and then the process of getting the needed data can continue.

Figure 2: Mechanical Balance Tilted.

It is not hard to imagine how tedious and inconvenient the process of obtaining the data using the mechanical balance of this particular wind tunnel is. Science fair projects from recent years have tried to make solutions to improve the tediousness of the mentioned process, all of them to no avail. We propose an electronic system to renew the mechanical balance, having a microprocessor as a central point, in order to significantly improve wind tunnel as a whole. Our model would modernize the current tunnel in a meaningful way without having the economic implications of buying an entire new system.

2 System Block Diagram

The system will be reading data from the accelerometers, which will be used as tilt sensors, to know if the balance is positioned correctly for initial setup. Once in the correct position and the wind tunnel started, the system will then use the force sensors to read how much force is being applied to keep the object in its original position.

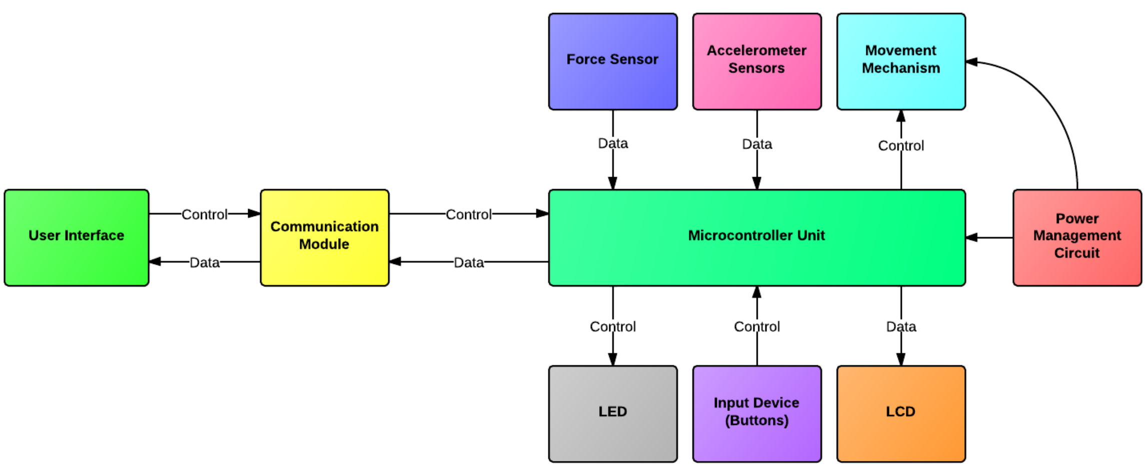

Figure 3: System Block Diagram (version 1)

3 Specifications

3.1 Requirements, Features and Limitations

1. The system must provide equilibrium to the balance when two conditions are met:
    - The system is/is not under aerodynamic effects.
    - The system has/does not have the object attached to it.
2. The system must be able to measure the force being applied to return the balance to equilibrium.
3. The system must be able to measure the tilt in 2 axes.
4. The system must have a precision to at least the hundredths of pounds (0.01 lbs).
5. The system must be able to change between units (newtows, pounds).
6. The system must show the measurement of force in a simple GUI, the measurement of the coefficient of drag and coefficient of force, and show the average and variance of data.
7. A limitation is that due to turbulence, the instant forces being measured might not provide consistent results. Hence the measurements must be averaged and the variance of data must be provided.

3.2 Hardware and Software Requirements

Hardware:

1. Microcontroller - The microcontroller will be used to process data, control the mechanics, and manage the communication with the communications module.
2. Force Sensors - The force sensors will be used to measure the forces being applied to the balance. This data will be transferred to the microcontroller.
3. Accelerometers - The accelerometer will be used to keep track of the position in which the balance is through the experiment. They will be used as tilt sensors.
4. Communications Module - The communications module will be used to send data to a remote user interface for data logging purposes.
5. LCD - The LCD will be used to display data and user feedback as well as a menu to the user for setup.
6. LED - The LEDs will be used to display system status.
7. Buttons - The buttons will be used for user input in the menus provided through the LED and for control.

8. User Interface - A computer interface will be provided to visualize data collected via communications module.

9. Power Management Circuit - The power management circuit will be used to provide the necessary power to every component on the system to their required levels.

10. Movement Mechanism - The movement mechanism will be used to control the position of the balance.

Software: Various functions must be developed. They must, at a minimum, perform the following tasks:

1. Track balance position.

2. Track force sensor data.

3. Stores sensor data.

4. Controls movement mechanism based on force sensor data and balance position.

5. Calculates aerodynamic parameters based on logged data.

6. Communicate with user interface.

7. User Interface for LCD screen.

3.3 Components

Communications

The system will communicate with an application and/or device that reads, interprets and displays the result. This interface may be wired, wireless or a storage device.

User Interface

The system will incorporate an user interface in hardware and/or software basis. This UI will allow the user to initiate data reading and storage. While reading and when stopped, the UI will show the user the data in tabular and graph form, and display statistical information.

Control Scheme

The system must control all the components that contribute to keeping the system in equilibrium. This must happen whether it is under the aerodynamic test or not. The system will also provide manual control to the balance orientation or tilt.

Microprocessor-Based

The microprocessor is a necessary component due to the need of providing control as a function of the sensor readings to maintain equilibrium in the system. The microprocessor is also in charge of displaying the information read from the sensors (force) to the user interface (hardware and/or) and to provide control from user input (hardware and/or software). In software UI, the microprocessor is also in charge of managing the communication from the physical system.

4 System Conception

4.1 Global System View

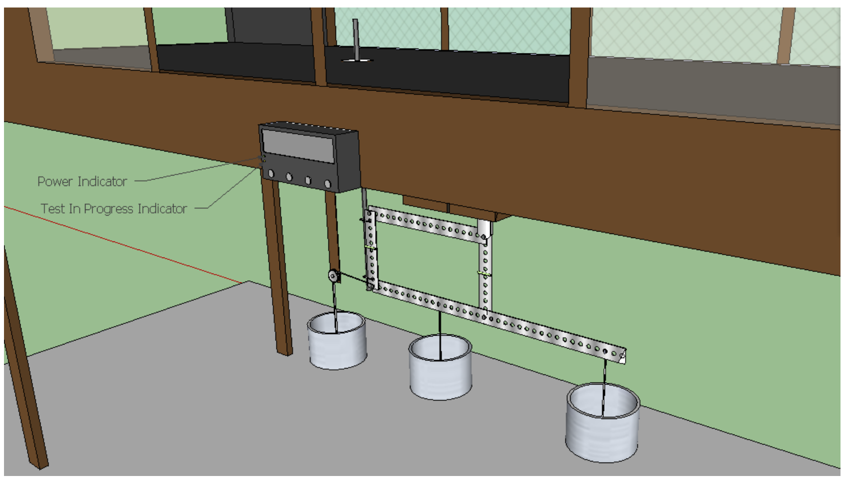

Figure 4: Global System View of the proposed solution (tentative)

The wind tunnel balance system will be a system that will be able to calibrate itself for initial use, balance itself during measurements, and report measurement of wind drag force and wind lift force to the user in a quick and easy manner reducing the time it takes to complete experiments and increasing accuracy by providing ways to determine unstable readings due to turbulence. Using the system involves five stages, detailed below.

1. Balancing the system without the object.
2. Activate the wind tunnel to determine the initial drag and lift for the base.
3. Balancing the system with the object.
4. Activate the wind tunnel to determine the drag and lift for the base and the object.
5. Calculate the real drag and lift for the object and deliver the results.

At system startup the user will have a button to auto calibrate the system prior to use, in which the system will make sure, by using the accelerometers, that the balance is in right position to begin its use. The user should then proceed to start the wind tunnel to obtain the values for the drag and lift of the base in which the object will be placed. Once this is done, the system will keep these values recorded so that the user can place the object in the base. These initial values are also displayed in the LCDs of the system. The system can then be balanced again with the object, and the wind tunnel started to begin the experiment. The system can then using the initial values compute the difference in the initial and final drag and lift forces to determine the true forces acting only on the object and not the base.

Aerodynamic properties determined by the system are the drag and lift forces acting on the object. Additionally, formulas can be applied using these forces to determine the coefficients of drag and lift which help with computations done when scaling objects that are minimized. This can all be provided using the UI of the system hardware (LCD) as well the application UI (on software).

4.2 User Interface Level

The system UI proposed will provide users the convenience of reading the current measurements and logging this information in intervals of time. The UI will also provide the user with the ability to control the system. Two proposed user interfaces are presented: the software UI using a personal computer, and the hardware UI using LCDs and LEDs.

For the software UI, the user will be presented with an organized manner of the drag and lift forces read from the system. Using the information read, measurements can be stored, computations can automatically be performed, and graphs can be provided. An mockup is shown in figures 5, 6 and 7.

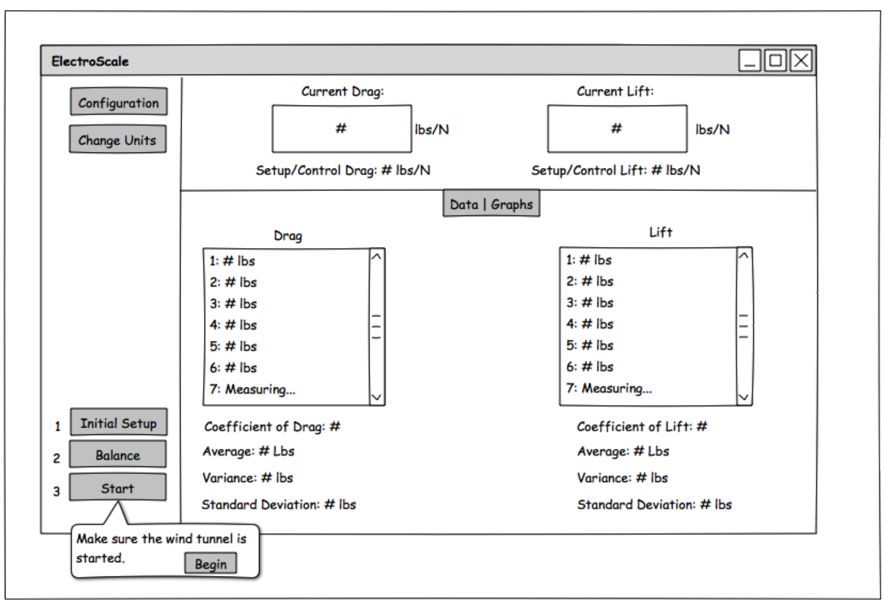

Figure 5: UI Mockup

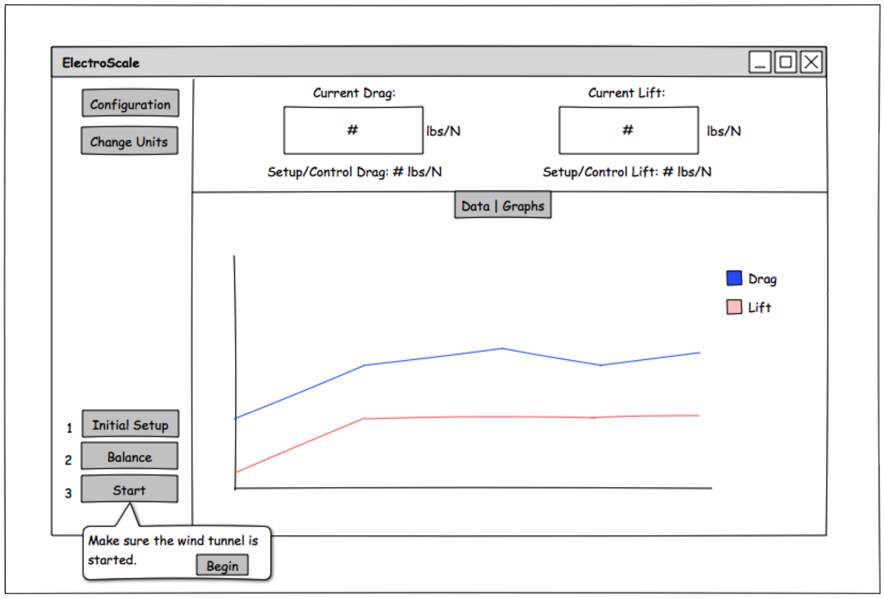

Figure 6: UI Mockup

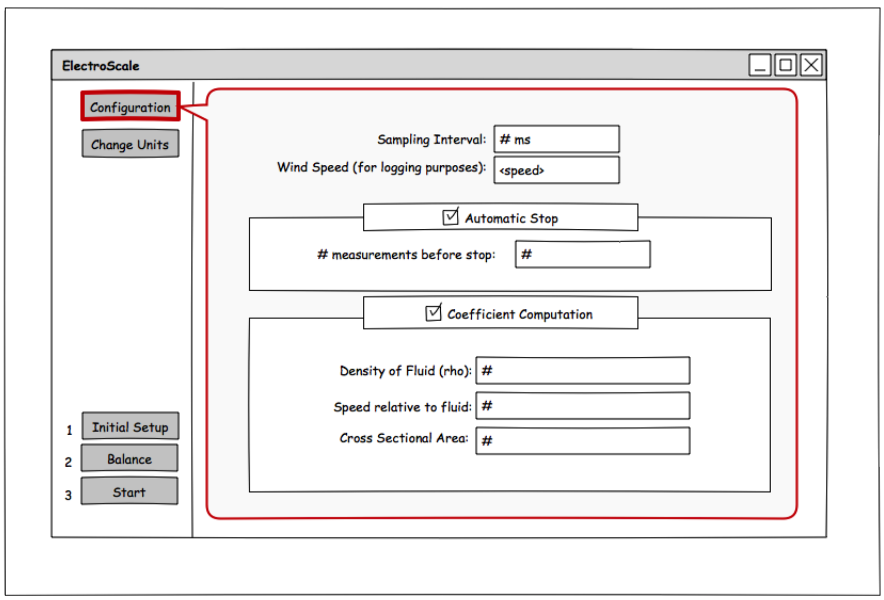

Figure 7: UI Mockup

Computations that can be performed are for the coefficient of drag and lift which are calculated using the forces and other parameters provided by the user for which the interface provides input. Using the measurements stored, the UI can then provide other statistical measurements such as average and variance. This user interface will be updated periodically to display the status of the system, and the configuration settings allow the user to setup the sampling interval as well as the number of measurements before automatically stopping the experiment. Additional to providing the display of information, the UI will provide the user with software control of the system. The UI will have buttons that will be analogous to the hardware buttons given to the system. These buttons will provide control over the initial balancing of the system, the initial setup of the system and the measurement of the drag and lift of the system. The Initial Setup button will clear all of the measurements collected so far and will set the initial forces acting on the base. The Balance button will just put the balance ready for use by balancing the weight of the object or base. The Start button will start the measurements using the initial setup parameters to display the drag and the lift on the application as well as the other factors calculated.

For the hardware, UI and LCD panel will be provided which will display the current drag and lift forces acting on the object placed in the system. These measurements can then be stored as it is done in the software UI to provide an average and a variance. This will be displayed on the LCDs with a chosen frequency or sampling interval and to achieve this, the hardware UI will then feature a menu controllable by buttons on the LCD. Three buttons will be available as in the UI to control the initial setup, the balance and the start of the experiment.

5 Market Description

The proposed system is designed to enhance balancing systems used in wind tunnels, and thus has a targeted market of organizations or individuals who want to enhance the precision or data collection on their wind tunnels. The system is a fixed system which must be installed on the wind tunnel itself and powered electrically. By using sensors, it balances the object in the wind tunnel quickly and measures the forces necessary to achieve the calibrated position, saving a significant amount of setup time. It replaces an old and very manual system using sand as weights which must then be weighed on a scale to know the amount and adds human error, affecting precision.

There is currently no general commercial solution for a self built wind tunnel like this. Since wind tunnels are built in different ways with different sizes and power available, the systems used for measurements can be different and in turn are developed by the makers of the wind tunnel. Commercial wind tunnel vendors may include their own version for their own wind tunnels which may not be adaptable or cost efficient for self-made wind tunnels. This makes our project useful for any wind tunnel which uses the same rod balancing system for for measurements on the object inside, which would enhance precision and the speed of data collection.

6 Design Criteria

6.1 System Precision and Range

The system needs to be precise in the measurements performed while running the aerodynamic experiments against the objects as they can vary in weight in different orders. According to the director, Dr. Raul Zapata, the measurement precision performed in the current version of the scale is in the order of hundreds of pounds (approximately 0.02 pounds or 10 grams). This could be over a range of 0 to 15-20 pounds.

6.2 System Safety

The system will be used in an environment for testing aerodynamics, particularly in the wind tunnel located in the Civil Engineering building at the University of Puerto Rico at Mayaguez. The location of the current system is below the tunnel and it is attached to it (bolted). The current proposed design of the system involves using motors along with strings to perform the same function. Unless this design is changed later in the project phases, the design requires some form of casing or black boxing for some of these strings of the projects so as to prevent harm to humans in the testing area. This is for prevention purposes since the intention of the design will be for the experimenter to not have to intervene physically with the system.

7 Project Time Table

The following pictures present the Gantt chart contructed to serve as a guide for the scheduling of the tasks to be completed in the project. The date range of the project development is from August 15, 2013 to December 3. The pictures are presented by month:

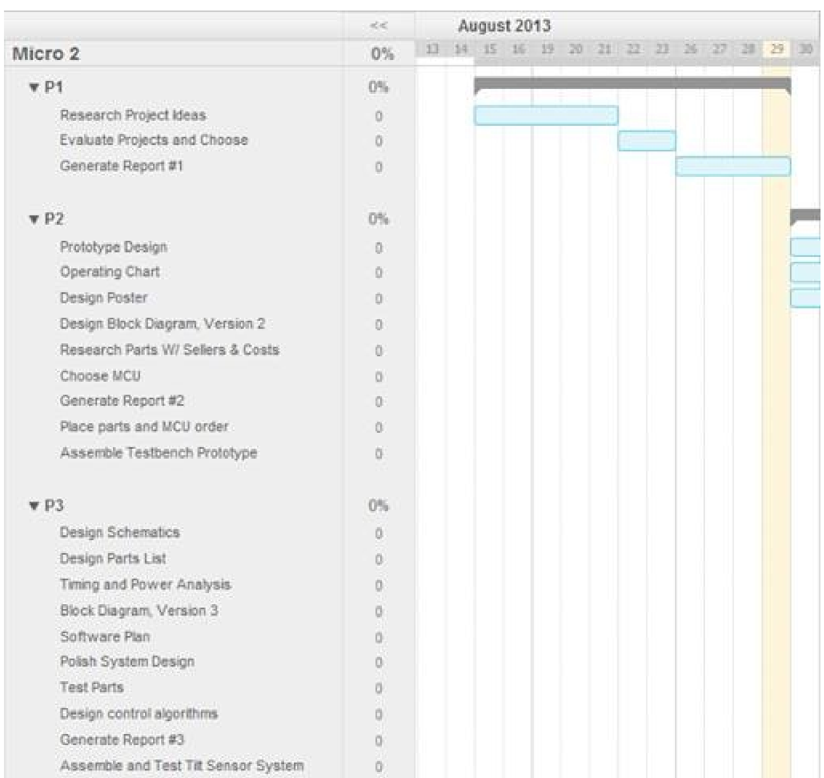

Figure 8: Project Time Table (August)

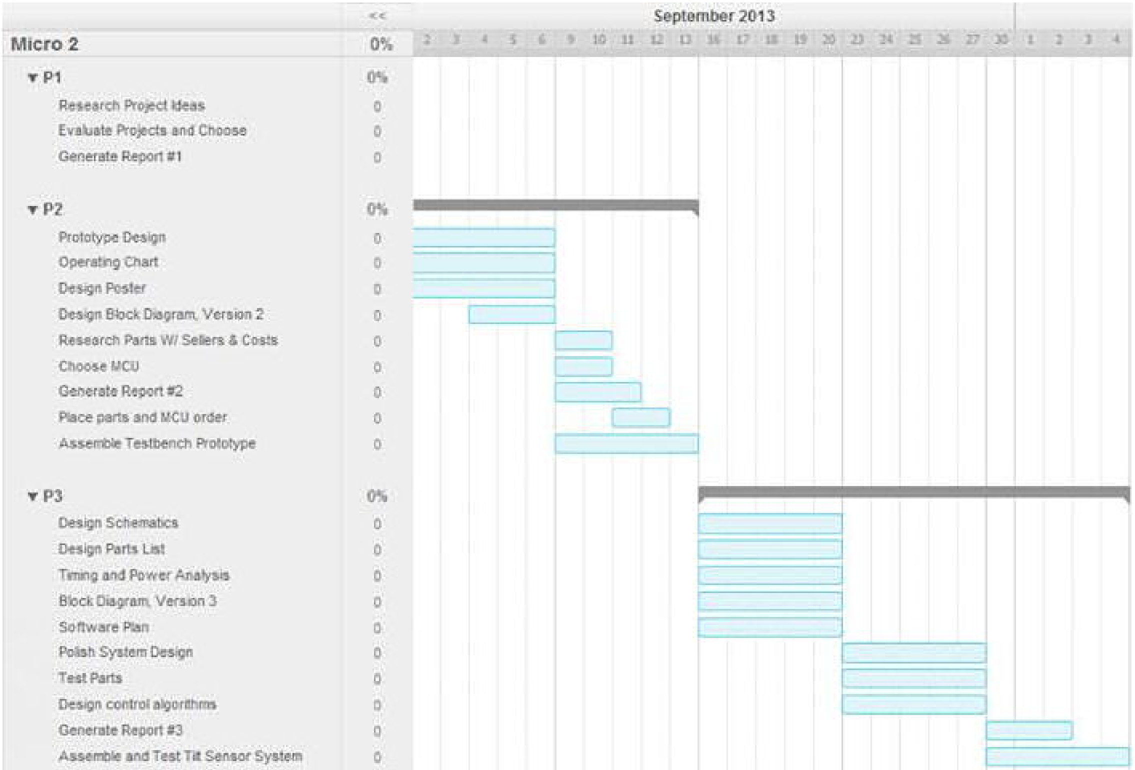

Figure 9: Project Time Table (September)

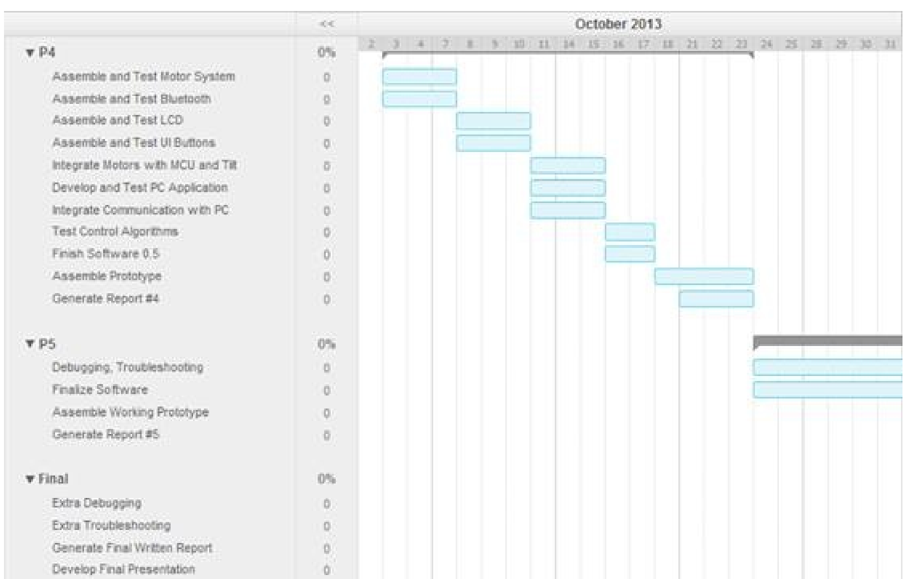

Figure 10: Project Time Table (October)

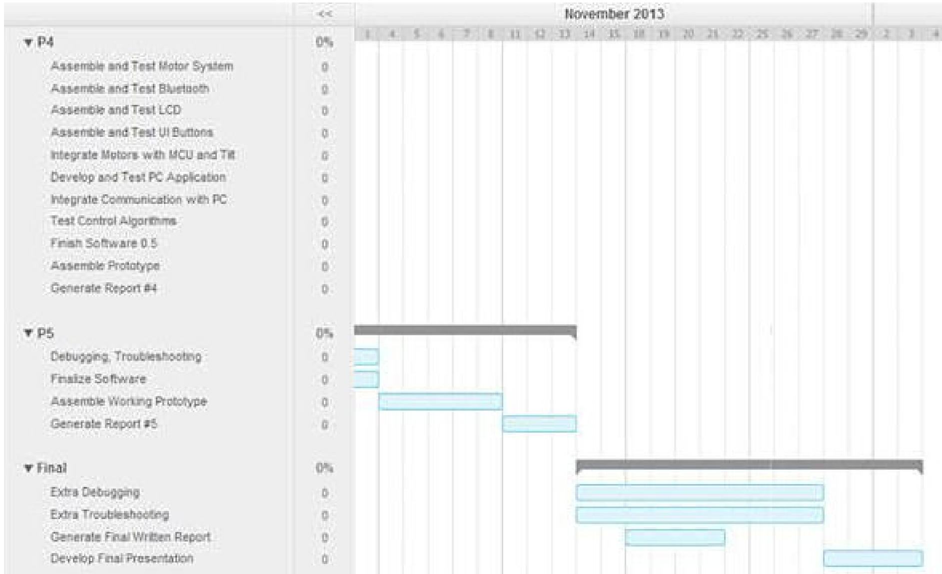

Figure 11: Project Time Table (November and December)

8 Expert Opinion

ELECTRONIC BALANCE FOR EVALUATION OF AERODYNAMIC FORCES ACTING ON MODELS TESTED AT THE WIND TUNNEL LABORATORY

The main application user for this project will be the students, faculty and general public that come to perform research work at the Wind Tunnel Laboratory of the Department of Civil Engineering and Surveying. The Supervisor of this facility and direct contact for technical expertise of the current project is Associate Director of the Department of Civil Engineering, Dr. Raul E. Zapata-Lopez.

Dr. Zapata presented us with the idea of working on the automation of one of the current measurement devices of the laboratory. A mechanical balance system is used to measure aerodynamic (drag and lift) forces acting on objects or scaled models that are aerodynamically tested in a wind tunnel facility that the department developed many years ago. Using the momentum concepts (moment = force * distance), the aerodynamic forces acting on a given model are measured by seeking to balance the aerodynamic force by another force acting in opposite direction at a given distance from a pivot point. That force is obtained by pouring dry and loose sand into a bucket until the balance system is leveled to the original position before the aerodynamic forced started to act over the model. Because the drag force acts horizontally and the lift force acts on the vertical axis, the balance system works in those two directions. The equilibrium position is reached when all arms of the balance systems are leveled which are verified by the use of bubble levels. The sand is then collected and weighted on an external balance. The process is repeated three to five times or until the statistics of collected data is reasonable to explain the aerodynamic model behavior. The operation of this mechanical system is working effort intensive and requires at least two persons to perform as expected.

The proposed project seeks to transform that mechanical scale which requires manual interaction, sand and moving parts to be substituted by an automated system that will make the repetitive process of the tests easier to handle.

The current scale was built by Dr. Zapata who as a result knows all the factors in building the scale that could affect the experiment. To be able to replicate the behavior in an automated manner we will be contacting him to provide us with technical specifications of what the system must achieve, and at the end will decide if the chosen design complies with the specifications. As stated by the laboratory supervisor:

"If possible, I would like to see the construction of an electronic scale that replaces the current mechanical scale in two directions. I am available to discuss any technical specification about the scale as well as any theoretical information. This project would enable us to run tests faster and more effectively. One of the main factors that the current project can help us is time effort reduction since the amount of time used for running the experiments is extensive. Another factor is the expected consistency of the collected data will keep and most probably improve the precision of the collected data.

For any issues or questions Dr. Zapata can be contacted by email at raul.zapata@upr.edu and at the telephone number 787-265-3815 or 787-832-4040 (ext. 3815, 3434, 3559 at Dept. office and ext. 3376 at Wind Tunnel Lab.)

Raul E. Zapata Lopez, PhD, PE, RPA Civil Engineering Wind Tunnel Lab Supervisor and Associate Director of the Department of Civil Engineering

Dr. Eduardo Ortiz-Rivera (Professor of the University of Puerto Rico, Mayagez Campus), had the following comments:

1. - An important characteristic of the system should be to use two accelerometers and compare values of both, in order to get the best precision possible. A gyroscope should be considered as well.

2. - Bluetooth or some other of wireless communication to an external device has to be a part of the project. If the idea is to make the researcher have a more convenient system, then having to bend down to collect the data through something like an SD Card should be evaded.

3. - Value of the device should be considered; if it is low enough, then it could be marketable.

4. - The system currently used should not be thrown away. Although it is not convenient to use, it is reliable in the sense that it can always be used in case our system malfunctions, plus it does not need electricity to work.

References

[1] http://www.nasa.gov/audience/forstudents/k-4/stories/what-are-windtunnels-k4.html

[2] http://windvane.umd.edu/

[3] http://www.southampton.ac.uk/windtunnels

[4] http://ingenieria.uprm.edu/inci/mod/page/view.php?id=33

9 Appendices

9.1 Work Distribution Table

	Jesus	Anthony	Juan	Jean
Search for Topic	✗	✗	✗	✗
Define Specifications	✗	✗	✗	✗
Introduction				✗
Abstract				✗
System Architecture			✗	
System Conception		✗		
Design Criteria		✗		
Define Hardware and Software Aspects	✗	✗	✗	✗
Block Diagram		✗		
Graphical Aspects		✗	✗	
Expert Opinion		✗		✗
MCU Selection	✗	✗	✗	✗
Project Journal				✗
Cost Analysis	✗	✗	✗	✗
Proofread				✗
Project Time Table	✗			✗
Work Distribution Table	✗			✗
Parts Selection	✗	✗	✗	✗
Market Description	✗			
Design	✗	✗	✗	✗
Proposal and Reports	✗	✗	✗	✗
Testbench Prototype			✗	✗
Tilt Sensor	✗	✗		
Control System				✗
User Interface - Computer	✗	✗		
User Interface - Micro			✗	✗
Communication Protocol	✗			✗
Soldering			✗	✗
Motor Systems			✗	✗
LCD		✗	✗	
User Interface Buttons	✗			✗
Implement Control System				✗
Motor/Control System Integration		✗		✗
Communication Integration	✗		✗	

9.2 Project Journal

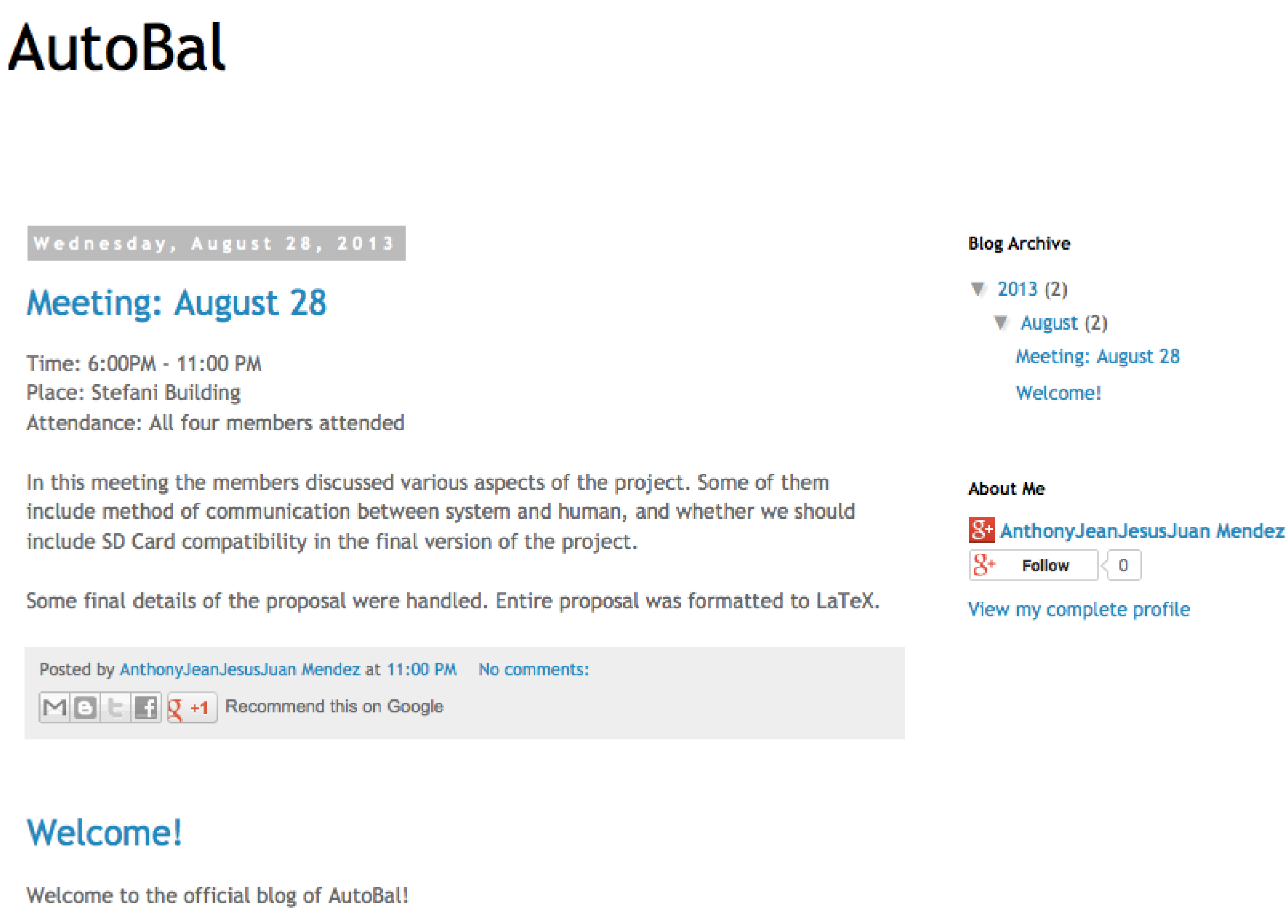

Figure 12: WebBlog

A journal has been created to keep track of the work done in the project per session. The date, time, place, member attendance and summary of work will be posted in a blog created online. The blog web address is: `http://autobalmicro2.blogspot.com/`