AeroBal

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

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Abstract

Wind tunnels are used for research in various areas of science and engineering, such as wind and aerodynamics. The wind tunnel of the University of Puerto Rico, Mayagüez Campus is overly outdated, and recording data using it can be inconvenient due to old technologies used in it. We propose AeroBal, a system that would improve the current wind tunnel in an important way by adding sensors connected to a system that performs the procedure of obtaining the measurements automatically. 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.

Contents

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 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 and gyroscopes, 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.

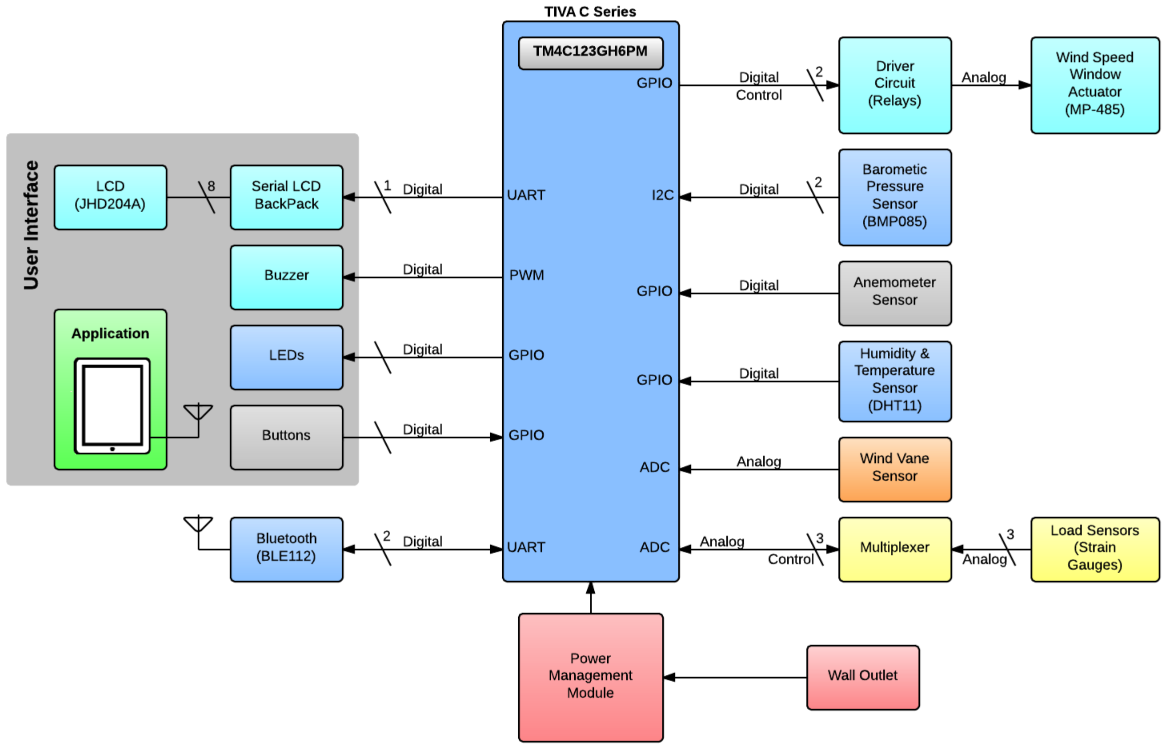

Figure 3: System Block Diagram (version 2)

3 Specifications

3.1 Requirements, Features and Limitations

1. The system must provide amount of force being applied to the object both in vertical and horizontal orientation when:

   - The object is not under aerodynamic effects to calibrate and establish reference (initial) values of force measurement.
   - The object is under aerodynamic effects to determine the actual force.

2. The system must provide an interface to start experiments and take measurements (LCD prompts and buttons for example).

3. The system must have a precision of at least the hundredths of pounds (0.01 lbs).

4. The system must be able to change between units (newtows, pounds) on the results provided.

5. 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.

6. 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.

7. The system must connect to multiple sensors that read the environmental data of the wind tunnel, such as humidity, temperature, and pressure, and provide this data.

8. The system must be able to read and control the wind speed of the tunnel.

3.2 Hardware and Software Requirements

Hardware:

1. Strain Gauges - The strain gauges will be used to measure the forces being applied to the object. This data will be transferred to the microcontroller.

2. Communications Module - The communications module will be used to send data to a remote user interface for data logging purposes.

3. LCD - The LCD will be used to display data and user feedback as well as a menu to the user for setup.

4. LED - The LEDs will be used to display system status.

5. Buttons - The buttons will be used for user input in the menus provided through the LED and for control.

6. A minimized version of the wind tunnel for testing. This tunnel will be useful as a testbench for the project to not interfere in the actual system.

7. A mechanical system tied to the strain gauges that measures the amount of force applied. This mechanical system must move freely in the horizontal and vertical directions as minimum requirement. It must provide a minimally-obstructive extension that is inserted into the wind tunnel in order to provide a base for the object while interfering as little as possible with the aerodynamic measurements.

8. A circuit that controls the actuator that controls the windows that change the wind speed of the tunnel.

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

1. Store calibration values when the wind tunnel is off to use as reference (static values) and then substract them from actual or dynamic values when the wind tunnel is on to provide the correct measurement of force.

2. Store strain gauge sensor data on user input.

3. Compute statistical values of the results.

4. Calculate aerodynamic parameters based on stored data.
5. Communicate with user interface to display results.
6. Check status of the system to follow operating conditions (wind speed).
7. Display users the current procedure state of the system and available options.
8. Prompt users to continue other procedure states with the appropiate message.
9. Store and apply configuration parameters of experiment (wind speed, units, etc.).
10. Provide the control signal to change the wind speed of the tunnel when configuration is changed.
11. Display status of the sensors that read environmental data.

3.3 Components

Communications

The system will communicate with an application running on a tablet device that reads, interprets and displays the result. This communications interface is wireless using a Bluetooth module to achieve this communication.

User Interface

The system will incorporate a user interface in hardware and software. 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. For hardware, the system will display through a wired interface to an LCD the results of the experiment. For software, the system will communicate with a remote UI (tablet interface), through wireless communication using Bluetooth, which will read the values to display the tabular and graph form of the results.

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

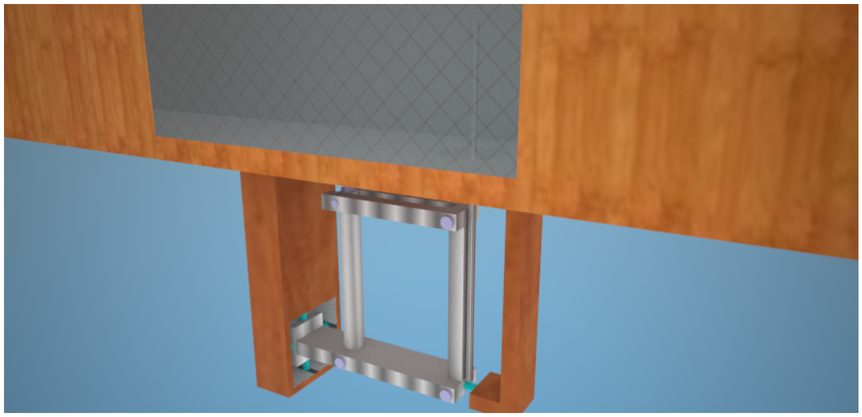

Figure 4: Global System View of the proposed solution (tentative)

The wind tunnel balance system will be a system that will be able to calibrate itself for initial use using the strain sensor components which do not require the system to move like the actual system. This will provide a reference value from which the system will then calculate the difference to obtain the actual result. These actual results are used for two stages of the system: the setup stage and the experiment phase. For the setup phase, the experimenter needs to determine using the wind tunnel the aerodynamic properties of the base that will be used to place the object for which we want to determine the same properties. In the experiment phase, the object is placed in the base, and at this time, the system knows the aerodynamic properties of the base. Once the properties are obtained with both the object and the base, all the system has to do is a difference of the values obtained in the setup phase and the experiment phase.

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 onn user input. The UI will also provide the user with the ability to control the system. Two proposed user interfaces are to be implemented: 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 interface that displays the configuration options, the control options, the data being captured if the experiment is running, and the data for previous experiments.Using the information read, measurements can be stored on a database, experiment and statistical computations can automatically be performed from, these measurements and graphs can be provided. A mockup is shown in figure 5.

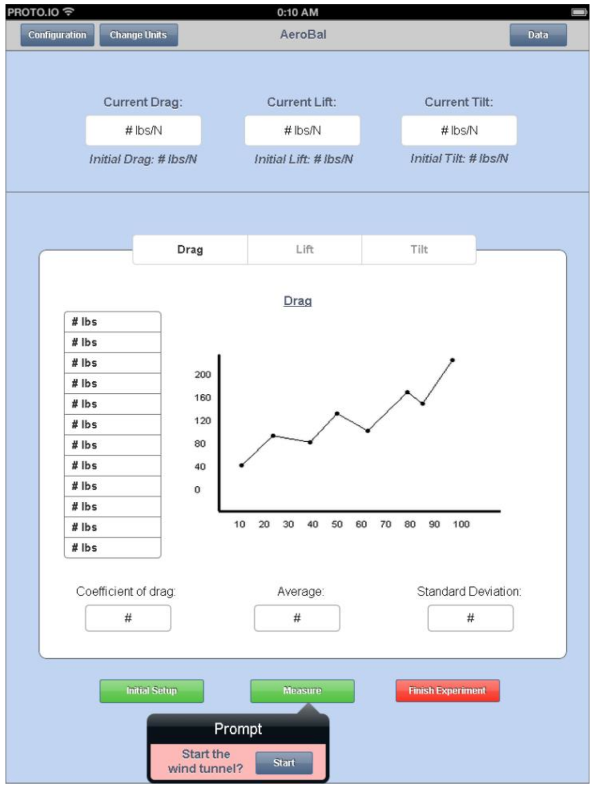

Figure 5: UI Mockup

Computations that can be performed are for the coefficient of drag and lift which are calculated using the forces obtained from the strain gauges. This user interface will be updated periodically to display the status of the system, and the configuration settings allow the user to setup the desired wind speed as well as the desired units.

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 setup of the system (Initial Setup), and the measurement of the drag and lift forces of the experiment (Measure).

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. The UI will provide control over the initial setup phase, the experiment phase, and the configuration. The measurements will be stored as it is done in the software UI to provide an average and a variance. To achieve this, the hardware UI will then feature a menu controllable by buttons on the LCD.

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 strain gauge sensors it measures the forces exerted by the object and obtains necessary data without actually moving. It replaces an old and very manual system using sand as weights which must be balanced by hand 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. Different implementations exist ranging from optical systems to reduce friction [5] to static systems measuring force [6] like the one being implemented. Commercial wind tunnel vendors may include their own version for their 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 a similar rod balancing system 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 a static mechanical system that requires no movement and this is an improvement over the current design. It requires no intervention from the user contrary to the present one. In the present one, should the mechanical component of the object fail while performing the experiment it can damage the components or cause damage to the experimenter. Since no manual intervention is required in the proposed system, an improvement is provided in terms of safety.

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:

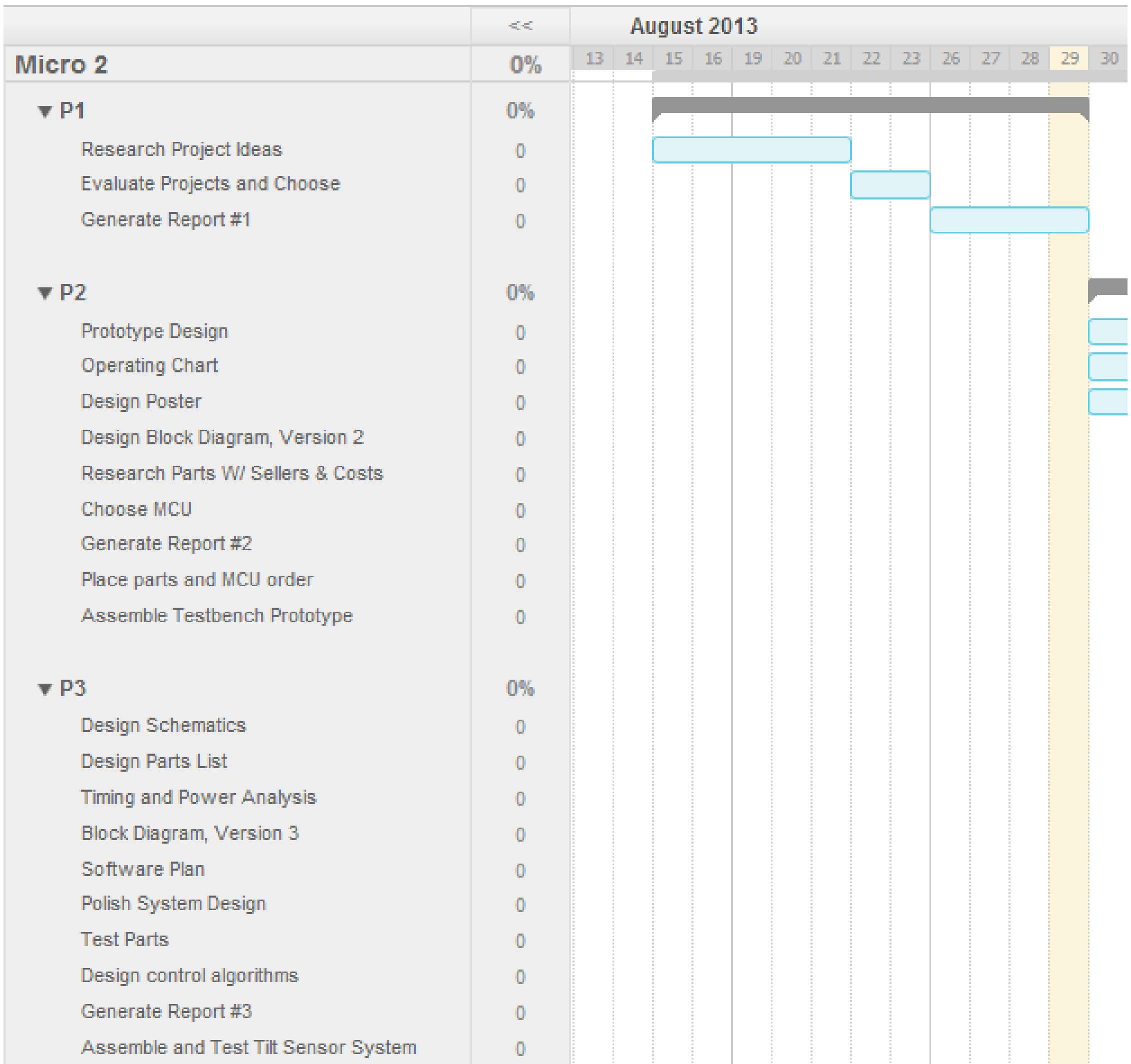

Figure 6: Project Time Table (August)

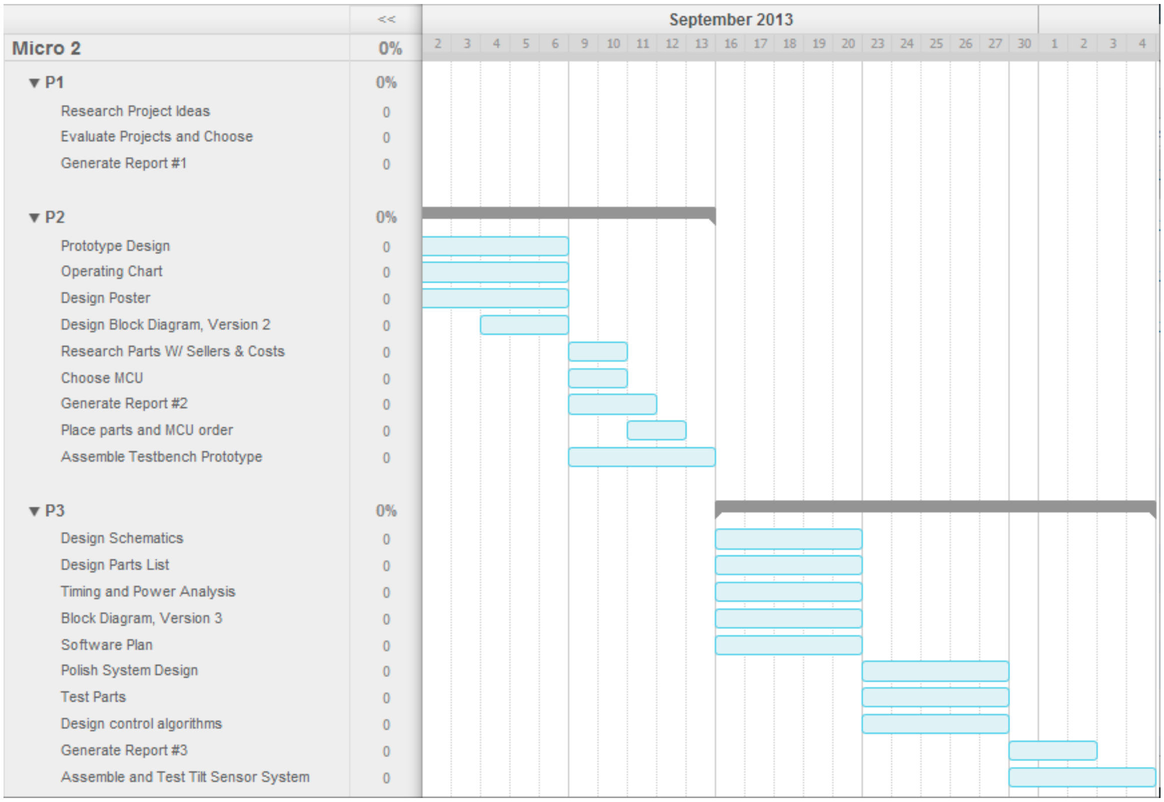

Figure 7: Project Time Table (September)

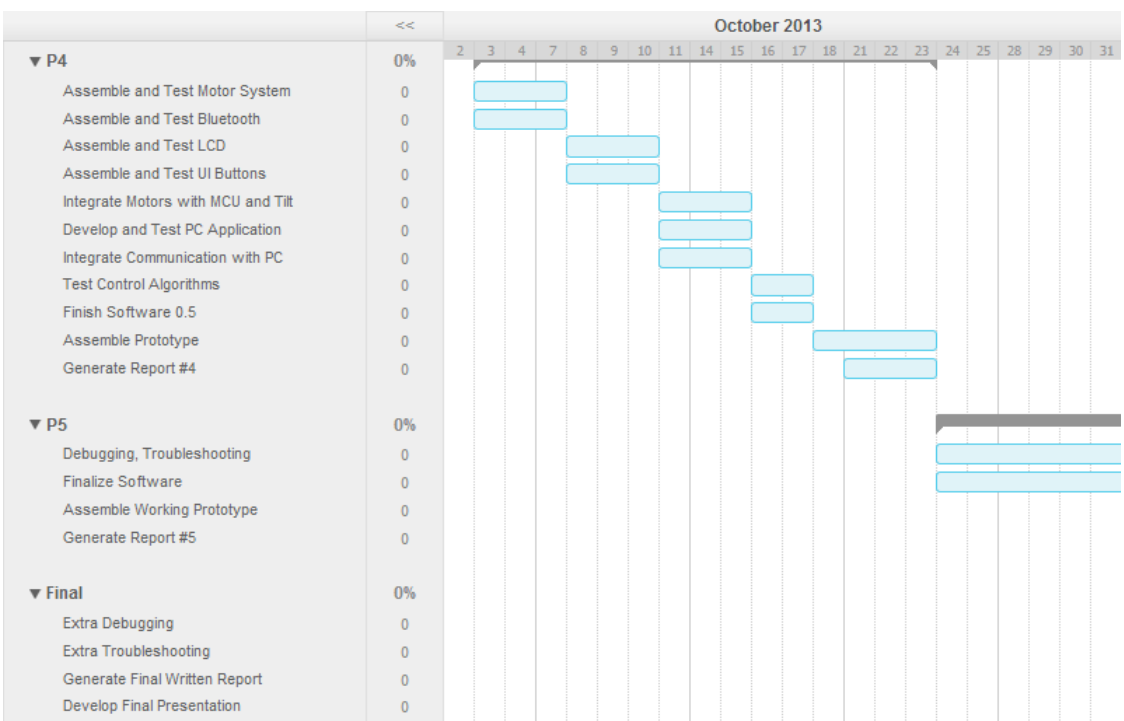

Figure 8: Project Time Table (October)

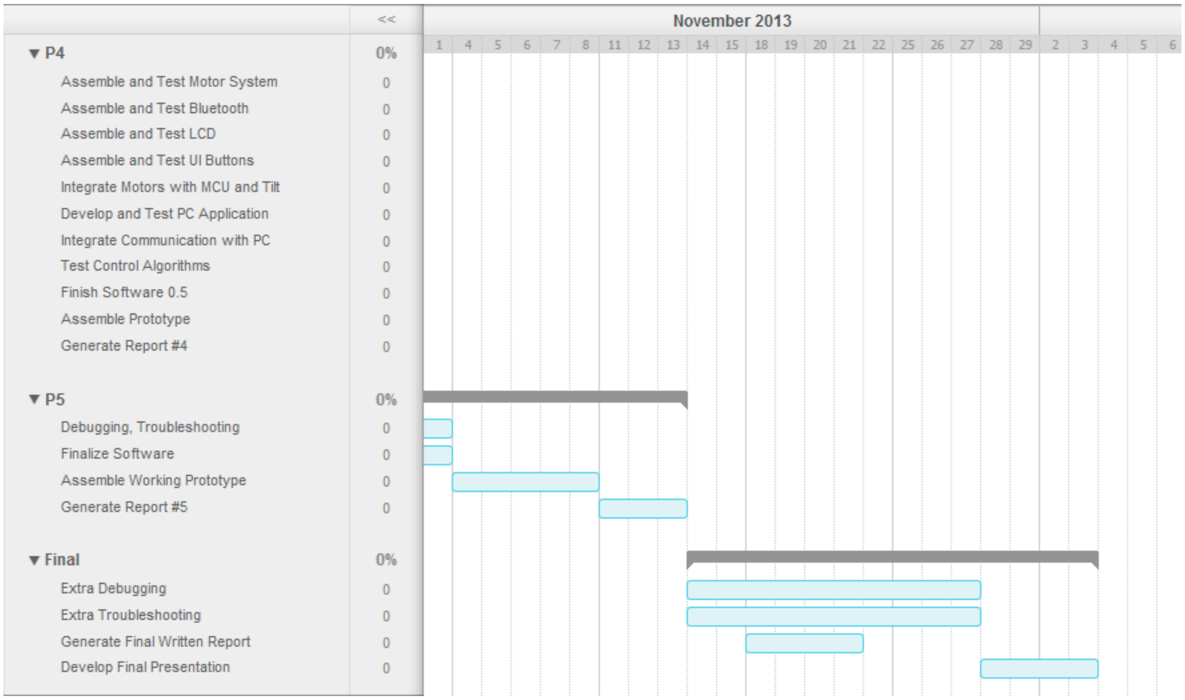

Figure 9: Project Time Table (November and December)

8 Expert Opinion

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

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.)

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] NASA.gov (2010) What are wind tunnels? [Online] http://www.nasa.gov/audience/forstudents/k-4/stories/what-are-wind-tunnels-k4.html

[2] University of Maryland AeroSpace Engineering (2010), Glenn L Martin Wind Tunnel [Online] http://windvane.umd.edu/

[3] University of Southhampton (2013) University of Southhampton Wind Tunnels [Online], http://www.southampton.ac.uk/windtunnels

[4] Departamento de Ingenieria Civil y Agrimensura, (2013) Laboratorio de Tunel de Viento, [Online], http://ingenieria.uprm.edu/inci/mod/page/view.php?id=33

[5] Tufts University, Tufts Wind Tunnel Project, [Online], http://www.ceeo.tufts.edu/robolabatceeo/College/windtunnel/dnld/WT_webpages.pdf

[6] Interactive Instruments, Jet Stream 500, [Online], http://www.interactiveinstruments.com/educationalproducts/jetstream/i

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

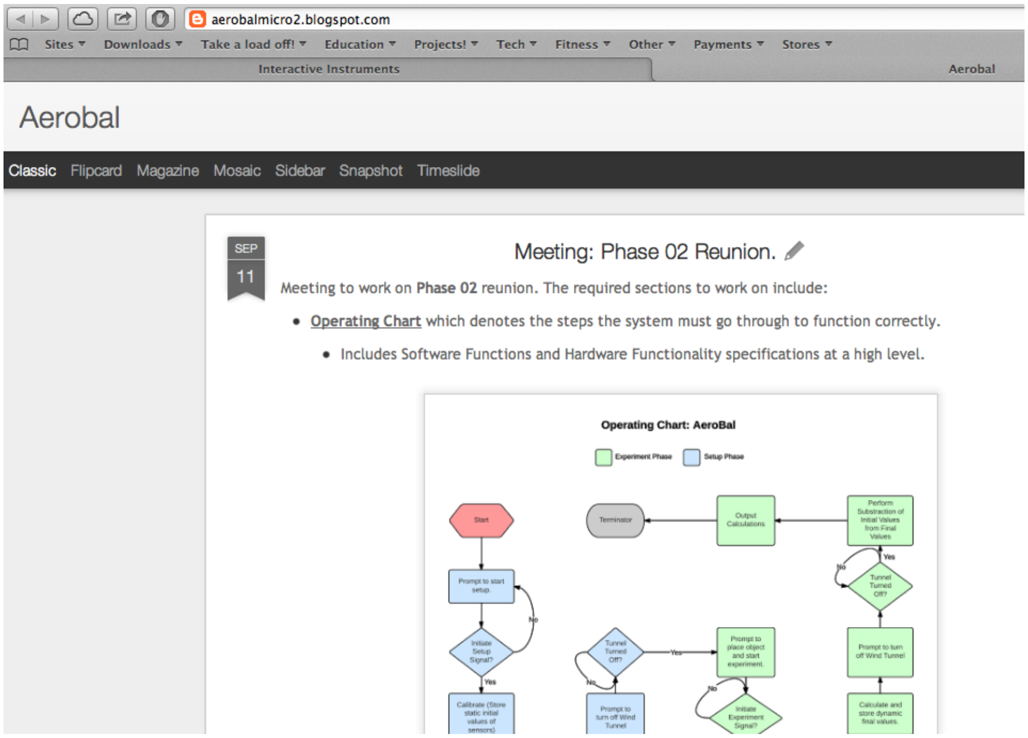

Figure 10: WebBlog

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://aerobalmicro2.blogspot.com/`