Aerobal: Progress Report #3 (Revision)

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Contents

1 System Block Diagram, version 3.

The system block diagram version 2 was redesigned to detail components selected for use in the implementation. After consulting professor Manuel Jimenez and director Raul Zapata, we determined components that will be used in the project and constructed with the following system block diagram:

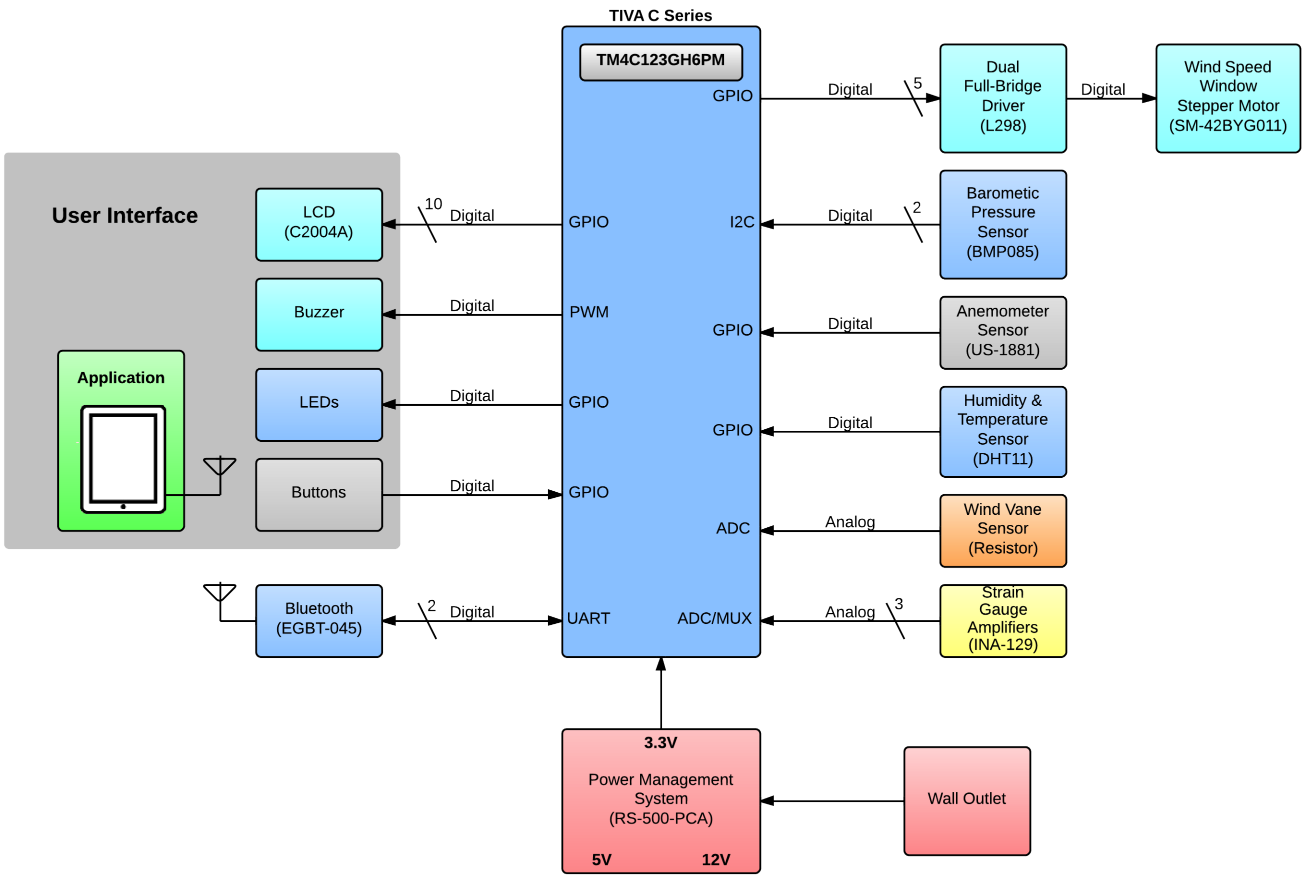
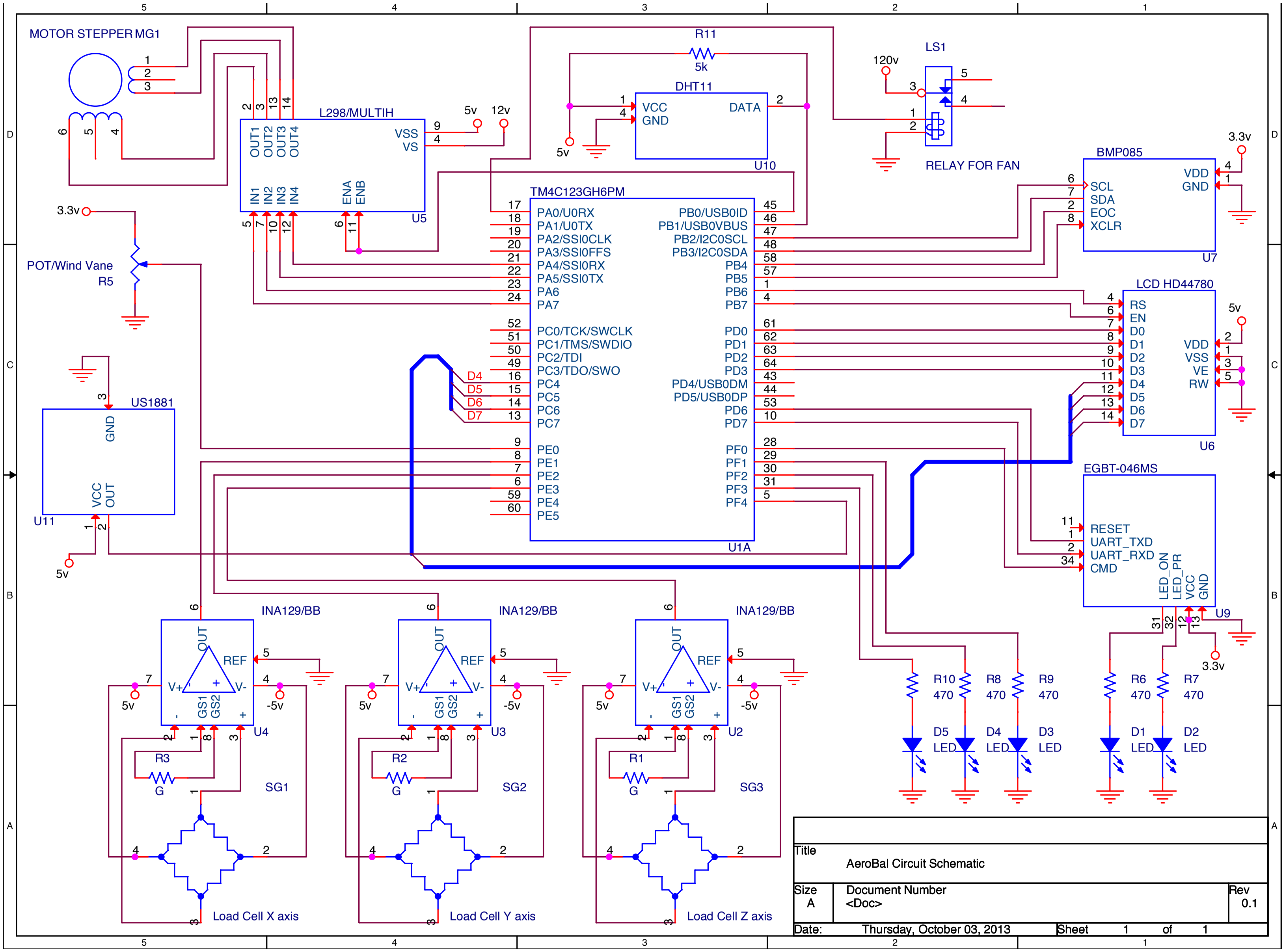


Figure 1: The third version of the AeroBal system block diagram.

Schematic



MOTOR STEPPER MG1
L298/MULTIH
U5
OUT1 OUT2 OUT3 OUT4
IN1 IN2 IN3 IN4
ENA ENB
VSS
VS
5v
12v
3.3v
POT/Wind Vane
R5
US1881
U11
GND
VCC
OUT
R11
5k
DHT11
VCC
GND
DATA
U10
LS1
120v
RELAY FOR FAN
BMP085
VDD
GND
SCL
SDA
EOC
XCLR
U7
TM4C123GH6PM
U1A
PA0/U0RX
PA1/U0TX
PA2/SSI0CLK
PA3/SSI0FFS
PA4/SSI0RX
PA5/SSI0TX
PA6
PA7
PC0/TCK/SWCLK
PC1/TMS/SWDIO
PC2/TDI
PC3/TDO/SWO
PC4
PC5
PC6
PC7
PE0
PE1
PE2
PE3
PE4
PE5
PB0/USB0ID
PB1/USB0VBUS
PB2/I2C0SCL
PB3/I2C0SDA
PB4
PB5
PB6
PB7
PD0
PD1
PD2
PD3
PD4/USB0DM
PD5/USB0DP
PD6
PD7
PF0
PF1
PF2
PF3
PF4
D4
D5
D6
D7
LCD HD44780
RS
EN
D0
D1
D2
D3
D4
D5
D6
D7
VDD
VSS
VE
RW
U6
EGBT-046MS
RESET
UART_TXD
UART_RXD
CMD
LED_ON
LED_PR
VCC
GND
U9
INA129/BB
U4
U3
U2
OUT
REF
V+
V-
GS1
GS2
-5v
R1
R2
R3
G
SG1
SG2
SG3
Load Cell X axis
Load Cell Y axis
Load Cell Z axis
R10 470
R8 470
R9 470
R6 470
R7 470
D5 LED
D4 LED
D3 LED
D1 LED
D2 LED
Title
AeroBal Circuit Schematic
Size
A
Document Number
<Doc>
Rev
0.1
Date:
Thursday, October 03, 2013
Sheet
1
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1

2 Bill Of Materials

Listed below are the materials that were and will be used for both the electrical and mechanical components of the tunnel and balance.

Materials	**Vendor**	**Qty.**	**Price**	**Total Price**
Electrical Materials				
Micro Controller - Tiva Launchpad	Texas Instruments	1	12.99	12.99
Instrumentation Amplifier INA129	Digikey	3	09.18	27.54
Barometric Pressure Sensor BMP085	E-Bay	1	08.36	08.36
LCD 20x4 - HD44780	E-Bay	1	09.50	09.50
2 Channel Relay Module	E-Bay	1	04.74	04.74
Humidity and Pressure Sensor DHT11	E-Bay	1	03.25	03.25
Load Cell 22lbs	E-Bay	3	18.79	56.37
Bluetooth 2.0 Module - EGBT-046MS	E-Bay	1	10.78	10.78
Cables	E-Bay	1	06.80	06.80
Fan	E-Bay	1	40.65	40.65
PC Power Supply	E-Bay	1	21.00	21.00
Resistor Package	E-Bay	1	10.00	10.00
LED	Sparkfun	5	00.35	01.75
Mechanical Materials				
Wood and Tools	Home Depot	1	68.44	68.44
Thrust Bearings	DHGATE	4	07.93	31.72
Pillow Block Bearing 3/4”	E-Bay	1	09.18	09.18
Balance Materials (Pipes, Tools)	Home-Depot	1	55.56	55.56
Materials (Scres, Bolts, Drills)	El Palacio Hardware	1	42.50	42.50
				Total: **421.13**

3 Power Analysis

3.1 Power Supply Requirements

AeroBal will be a system that always stays in the same place. Therefore, we will use the voltage coming out of a regular power outlet as our main voltage source. In Puerto Rico, the voltage coming out of a standard wall outlet is 120V with a frequency of 60 Hz[**?**]. This would act as our *unregulated voltage source.*

120 Volts is excessive for the amount of peripherals we are going to use. Besides that, the recommended V_{DDRec} values of all of our components were are always one of the following three values: 3.3V, 5V, or 12V.

Due to this problem, we though that it would be convenient to get a power supply that regulates the 120V AC from the outlet into the convenient values mentioned. After some research, we found a power supply that met our demands. This was the **Cooler Master eXtreme Power Plus 550-Watt ATX**, which comes at a cheap price and perfectly meets our voltage demands.

This power supply gives us seven different output voltages through Molex Power connectors. These are summarized in the following table.

Source	Voltage	Current
1	+3.3V	25A
2	+5V	25A
3	+12V 1	16A
4	+12V 1	16A
5	-12V	0.8A
6	-5V	0.8A
7	+5VSB	2.5A

3.1.1 Voltage

AeroBal uses a variety of peripherals that have different operating conditions. All of these will be presented in the following table.

	V_{DDRec}	V_{IH}	V_{IL}	V_{OH}	V_{OL}
MCU (TM4C123GH6PM)	3.3V	2.48V	1.16V	2.4V	0.4V
Wind Speed Window Actuator (SM-42BYG011)	12V	-	-	-	-
Barometric Pressure Sensor (BMP085)	3.3V	2.15V	0.66V	1.32V	0.3V
Humidity and Temperature Sensor (DHT11)	5V	-	-	-	-
Instrumentation Amplifiers (x6) (INA125)	12V	2V	0.8 V	1.4V	0.8 V
Bluetooth (JY-MCU)	3.3V	2V	0.66V	2.64V	0.66V
LCD (C2004A)	3.3V	2.25V	0.66V	2.5V	0.66V

The V_{DDRec} values of all of our components are either 3.3V, 5V, or 12V. The power supply that we chose gives us outputs for all three of these voltages. One of the main reasons we chose the chosen power supply was because of how convenient it would be to have a cheap power supply that gave us the exact voltages we needed for all of our components.

It is also worth mentioning that there will be two extra components not in the list. They are not in the list because we will make them ourselves, so there are no data sheets for them.

These components are:

- **Anemometer Sensor**
- **Wind Vane Sensor**

These components will be designed to work with an V_{DDRec} value of 3.3V for the wind vanea and a V_{DDRec} value of 5V for the anemometer. Thus, the final number of components in each one of the three used output power connectors will be:

The number of components per connector are:

- **+12V connector** - 2 Components
- **+5V connector** - 2 Component
- **+3.3V connector** - 5 Components.

3.1.2 Current

The following table summarizes the values of the currents of each one of our components. Although a 4mA pin current seems a little high, it is an accurate number according to page 1353 of the TM4C123GH6PM datasheet, *Recommended Operating Conditions* section. The current might vary depending on how much current it is driving. However, when in deep sleep mode, the current might get as low as 0.28 mA. This is according to page 1390 of the datasheet, section *Current Consumption*.

	I_{In}	I_{Out}	I_{Leak}
MCU (TM4C123GH6PM)	4mA	4mA	1μA
Wind Speed Window Actuator (SM-42BYG011)	330 mA	-	-
Barometric Pressure Sensor (BMP085)	7.7 mA	1.5 mA	5 μA
Humidity and Temperature Sensor (DHT11)	2.5 mA	1mA	150 μA
Instrumentation Amplifiers (x6) (INA125)	6 mA	700μA	2 nA
Bluetooth (JY-MCU)	40 mA	-	-
LCD (C2004A)	150μA	50μA	1μA

There are plenty of I_{In} values for our components. Luckily, our power supply has a wide and comfortable amount of current in each output. This was another of the top reasons why we chose this supply source.

The analysis of whether the current provided is enough for our components is as follows:

- **+12V connector**(Capacity: 16A):

  This connector will have seven components. The sum of I_{In} if these components is:

  $$\sum_{i=1}^{7} c_i = 4mA + (6)(6mA) = 60mA.$$

  $$60mA < 16A$$

- **+5V connector** (Capacity: 25A):

  This connector will only have one component, and it's value is greatly below our capacity:

  $$2.5mA << 25A$$

- **+3.3V connector** (Capacity: 25 A):

  This connector will have six components. Two of them will be made by ourselves, so we don't know yet how much current they will need. The ones we do know are the following:

  $$\sum_{i=1}^{4} c_i = 4mA + 7.7mA + 40mA + 150uA = 51.9mA$$

  $$51.9mA << 25A$$

  Although we are not considering the two remaining components, we are sure that the remaining current capacity of the connector will be more than enough to supply them without any problem.

  NOTE: Although 6 instrumental amplifiers were listed, we are studying a way of using only 3 instead. This would decrease the needed current out of the +12V connector.

3.1.3 Driving Capability

The value V_{IH} of the GPIO pins of our MCU is 2.4V. This means that all the if components interfaced to are working as loads would need to have a V_{IH} lower than 2.4V. This condition is met, given that the component closes to 2.4V is the LCD, which has a value V_{IH} of 2.25V.

The value of V_{OL} of the GPIO pins of our MCU is 0.4V. This means that all the components interfaced to it working as loads would need to have an V_{OL} above of 0.4V. This condition as also met, as the component with the lowest value of V_{OL} in the other components is 0.66V.

3.1.4 Maximum Pin Current

The maximum current of the GPIO pins of our MCU depend on which juncture they are in, and their position in the board. To show the values of each, they will be presented in two tables. The first one describes where in the board they are located. The second shows the max current value per position in the board:

Side	GPIO's
Left	PB[6-7], PC[4-7], PD7, PE[0-3], PF4
Bottom	PA[0-7], PF[0-3]
Right	PB[0-3], PD[4-5]
Top	PB[4-5], PC[0-3], PD[0-3,6], PE[4-5]

Side	I_{MAX}
Left	30 mA
Bottom	35 mA
Right	40 mA
Top	40 mA

3.2 Voltage Compatibility

None of our components require alternating current (AC) Voltage to work. Given that we will use power supply that converts the AC voltage off the outlet into DC voltage, the output DC voltage should suffice for all peripherals. Thus, we should not have any compatibility issues regarding voltages between source and peripherals.

3.3 Thermal Analysis

On thermal analysis we need to determine the maximum power dissipation the chip can handle. Using function 8.11 from the book:

$$P_{diss(max)} = (T_{J(max)} - T_A)/\theta_{JA}$$

According to the datasheets:

$$T_{J(max)} = 96C$$

$$T_A = 25C$$

$$\theta_{JA} = 54.8C/W$$

$$P_{diss(max)} = (96C - 25C)/54.8 = 1.2956W$$

Hence, 2.28 W is the maximum power dissipation of the microprocessor.

The current required by the processor while running at full speed 80MHz with V_{DD} = 3.3V and ambient temperature 25C is 45.1mA. The current required from GPIO components is 51.9mA in total. The total current is then

$$I_{DD(avg)} + \sum_{allpins} c_i = 45.1mA + 51.9mA = 97mA$$

Multiply by voltage level V_{DD} = 3.3V:

$$P_{diss} = 3.3V * 97mA = 320mW < P_{diss(max)} = 1.2956W$$

Therefore our system complies with the thermal limitations of the chip and it is safe to use for the application.

3.4 Power Supply Capacity

For our project, we chose Cooler Master eXtreme Power Plus 550-Watt ATX as our power supply. The main characteristics of our power supply were shown at the start of the Power Analysis. As a reminder, they are as follows:

Source	Voltage	Current
1	+3.3V	25A
2	+5V	25A
3	+12V 1	16A
4	+12V 1	16A
5	-12V	0.8A
6	-5V	0.8A
7	+5VSB	2.5A

There are various reasons why we chose this power supply. Some of these are:

- **Convenience** - All of our interfaced components use voltage sources of either 3.3V, 5V or 12V. This power supply gives us all three.

- **Price** - The price of our power supply without any discount is $59.99. Online, the supply can be obtained at $19.99 using discounts. We consider this to be a completely acceptable value for the power supply of our system.

- **Efficiency** - According to our power supply's website, it is 70% better efficiency-wise at typical load operation.
- **Risk Free** - We initially considered doing our own power supply for *Aerobal*. However, once we discovered this power supply we thought that maybe it was better to buy one that was already made and worked instead of taking the risk of wasting more time trying to build a power supply. This is something we have never done before, and we prefer focusing in the interfacing aspects of the projects in order to make sure it is ready in time.

4 Timing Analysis

4.1 Minimum Pulse Width

The minimum pulse width for a system is obtained by determining the component which works with the fastest frequency. This determines the constraints for the processor in terms of clock speed and frequency division. For the Aerobal system, the components that require interface with a specific/given frequency are:

- BMP-085 - Barometric Pressure Sensor
- US-1881 - Hall-Effect Sensor for Fan Anemometer
- EGBT-045 - Bluetooth Module
- C2004A - LCD HD44780 Based
- DHT11 - Humidity and Temperature Sensor

4.1.1 BMP085 - Barometric Pressure Sensor

The Barometric Pressure Sensor uses as its fastest interface the I^2C. The maximum speed it attains is 3.4Mhz. The minimum pulse witdh would be 0.29us.

$$MaximumFrequency : I^2C@3.4Mhz$$

$$MinimumPulseWidth = 1/(3.4MHz) = \ 0.29us$$

To configure the clocking for this peripheral (I2C) one does only need to set its timer period in the registers. There are four available speeds: Standard (100Kbps), Fast (400Kbps), Fast-plus (1Mbps) and High Speed (3.33Mhz per second). Since the Tiva provides the clocking (or acts as the master), this speed is set by the MCU. As mentioned above, the BMP085 can withstand any of these modes in the configuration. Since the amount of data read from the BMP085 is small (5 registers per computation) this would leave us with ((100K/8)/5) = 2.5K reads per second of all data required at the lowest frequency.

4.1.2 US-1881 - Hall-Effect Sensor for Fan Anemometer

A fan will be used to work as an anemometer for the system. The fan only requires the blades to spin to be detected by a sensor that is contained within them. This sensor sends two pulses per rotation. Hence the rotation at which the anemometer turns determines the working frequency of the component.

Rotation speed in fan datasheets = 4500 rpm @ 2 pulses per revolution
= 9000 pulses per minute
= 9000ppm/60 = 150pps max. = 150Hz Maximum Frequency

$$MinimumPulseWidth = 1/(150Hz) = 6.67ms$$

A timer here is used to keep track of time per pulse. This can be done by setting a timer that runs on a millisecond basis (1kHz), such that we can calculate the deltas in time between pulses.

4.1.3 EGBT-045 - Bluetooth Module

To achieve UART Communication the clock of the MCU is set to 8, 16, 32, and 64 times higher than the baud rate.This module can be configure to read a baud rate of 921600 although 9600 is the default.

However, the Tiva MCU does not have documented Baud Rate error table but has a Performance Limitation table that details the attainable and successful baud-rate communication using 9600 bps to 115200 bps. The minimum frequency specified for which the maximum baud is successful is 20 Mhz. Therefore the only way we can use the highest baud is we configure the MCU to work at 20 MHz.

Using the default, we can achieve communication although the worst-case configuration is demostrated here.

$$AcceptableBaud : 9600bps$$

Tiva configuration for 9600bps requires 8Mhz

$$MinimumPulseWidth : (1/8MHz) = 125ns$$

$$Worst - CaseBaud : 115200bps$$

Tiva configuration for 115200bps requires 20Mhz

$$MinimumPulseWidth : (1/20MHz) = 50ns$$

Due to the limitation of the Baud Rate error table, the error that the clock causes on the baud rate cannot be shown here.

4.1.4 2004A - LCD: HD44780 Based

The specifications inidicate that the MCU must correspond/conform to a 2Mhz bus interface. This means the frequency for interfacing is 2Mhz. It can be slower than this however.

$$Maximumfrequency : 2MHz$$

$$MinimumPulseWidth : 1/(2Mhz) = 0.5us$$

4.1.5 DHT11 - Humidity and Temperature Sensor

The communication with the sensor requires a provided digital algorithm to read the data from it. The algorithm specifies signals that must be sent for a period of time.

- 18ms Start Signal ACK

- 20-40us MCU Pull Up Voltage ACK
  - 80 us low-v-level response signal.
  - 80 us high-v-level preparation signal.
    - 50 us low-v-level means start bit transmit.
    - 26-28 us high-v-level is 0.
    - 70 us high-v-level is 1.
    - 50 us low-v-level means end.

Hence, the minimum pulse width needed would be:

$$MinimumPulseWidth = 20us$$

$$MaximumFrequency = 1/(20us) = 50KHz$$

4.2 Real-Time Clocks

This system requires the use of a real-time clock to be able to keep track of time in human units since calculations are made that use units of time (seconds), for example, the speed of the wind. which is measured in either kilometers per second or miles per second.

The Tiva Contains an internal real-time clock which can be used in software for this purpose.

4.3 Baud-Error

Due to the limitation of the Baud Rate error table not being available for the Tiva (substituted by UART Performance Limitation), the error that the clock causes on the baud rate cannot be shown here.

4.4 Baud-Rate Selection

The default configuration of the Bluetooth module will be used since this one is sufficient for tranferring small amounts of data (bytes). The data to transfer is not big in size, but only measurements taken from the sensors of of the system.

4.5 System Clock Selection

Hence the **worst-case** minimum pulse width is:

$$50ns$$

Source: Tiva w/ Bluetooth Module @ 115.2 Kbps Baud requires 20 Mhz Frequency.
Processor must have a minimum frequency of:

$$20Mhz < 80Mhz = TivaFrequency$$

A **functional** minimum pulse width:
Source: Tiva w/ Bluetooth Module @ 9.6 Kbps Baud requires 8 Mhz Frequency.
This forces the processor to have a minimum frequency of:

$$8Mhz < 80Mhz = TivaFrequency$$

Tiva gives us the benefit of having up to 80 Mhz to work with. Hence the clock can be lowered to about 25Mhz without affecting the communication and minimum pulse width requirement and still satistying the worst-case requirements.

5 Software Plan

5.1 Pseudo-code

General System Outline

Describes the general procedure the system follows.

```
WHILE TRUE
    Display Prompt to Start Setup
    Wait for Confirm Signal
    Execute Calibrate System Procedure
    Display Prompt to Set Objet and Set Wind Tunnel Settings
    Wait for Confirm Signal
    Execute Wind Speed Check Procedure
    WHILE finish signal has not been received
        IF store button is pressed
            Store Values from Sensors
        ENDIF
    ENDWHILE
    Perform Mean Calculations of Forces
    Display Results onto Tablet/LCD
ENDWHILE
```

Calibrate System

Calibrates the system with the initial values the strain sensor convey to use as initial reference point.

```
Display Prompt to Setup and Start
Wait for Confirm Signal
Store First Calibration Values
Prompt to Configure Wind Tunnel Before Starting Fan
Wait for Confirm Signal
Enable Wind Tunnel Fan
Execute Wind Speed Check Procedure
Store Second Calibration Values
Display Prompt to Disable Wind Tunnel Fan
Wait for Confirm Signal
Disable Wind Tunnel Fan
Display Prompt to Place Object
Wait for Confirm Signal
Store Last Calibration Values
```

Bluetooth Communication
Procedure for pairing, control, and transfer of data through the bluetooth module.

```
Configure Bluetooth Settings
Wait for Pair Request
WHILE TRUE
    Send Data to Paired Device
    Process Received Data
    IF Command Data was received
        Execute Command that was received
    ENDIF
ENDWHILE
```

Wind Speed Checker
Procedure for calibration of the desired speed of the system.

```
WHILE Speed value isnt acceptable (within value + threshold)
    Verify Wind Speed Value from Anemometer
ENDWHILE
Initiate Counter
WHILE counter < counter limit
    Verify Wind Speed
    IF Wind Speed has not gone over or under threshold
        Increase Counter
    ELSE
        Restart Procedure
    ENDIF
ENDWHILE
```

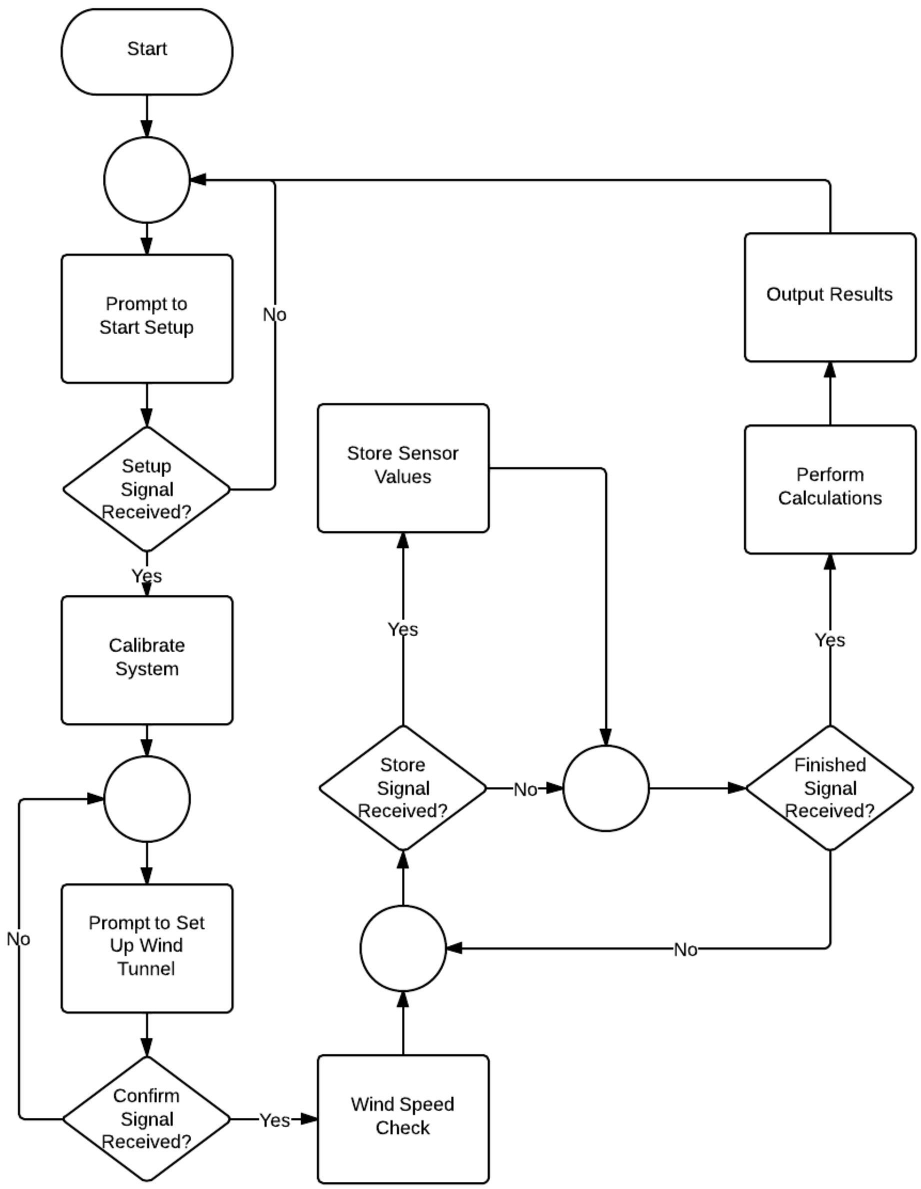

Figure 2: The general/main system procedure flowchart.

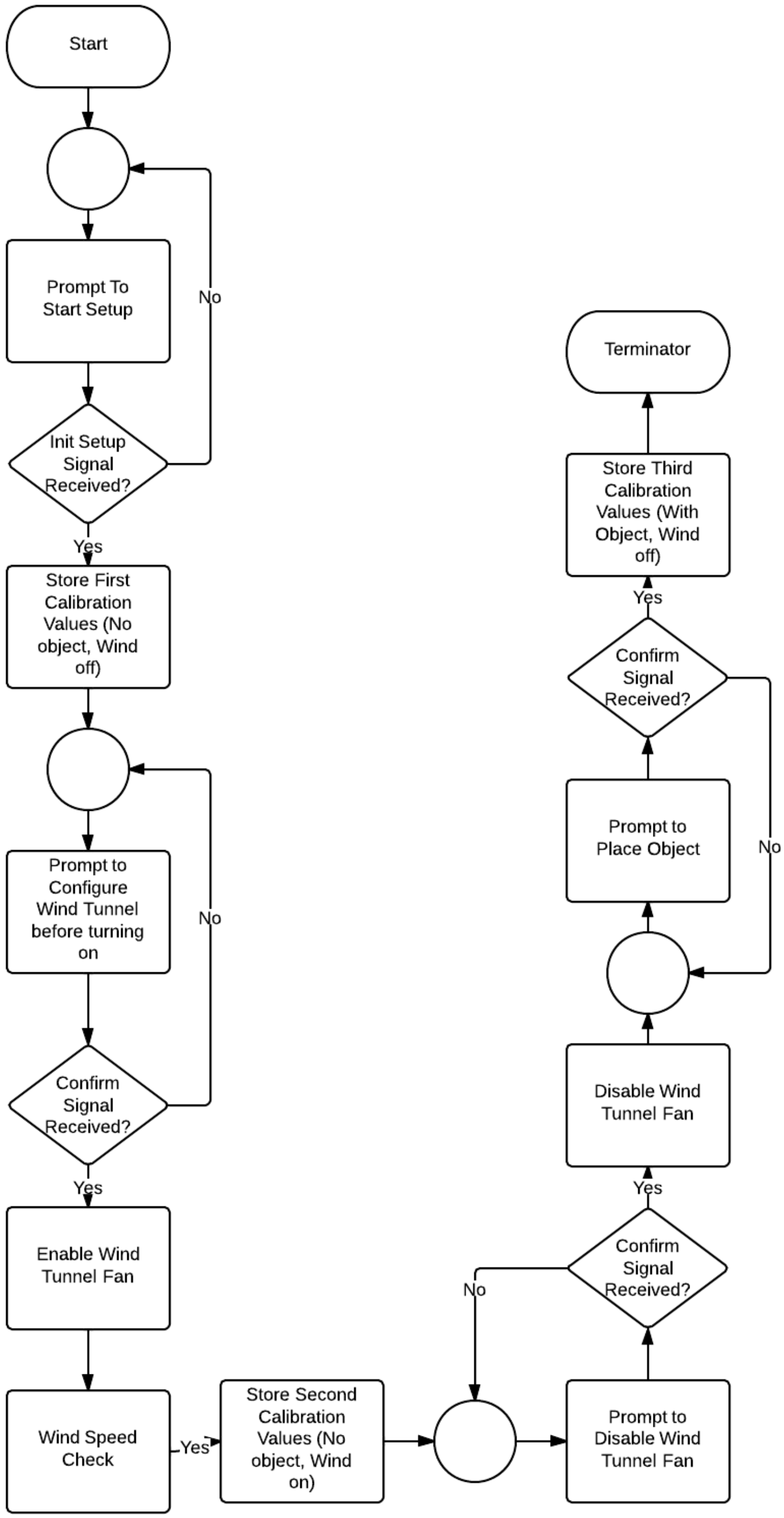

Figure 3: The calibration procedure of the system.

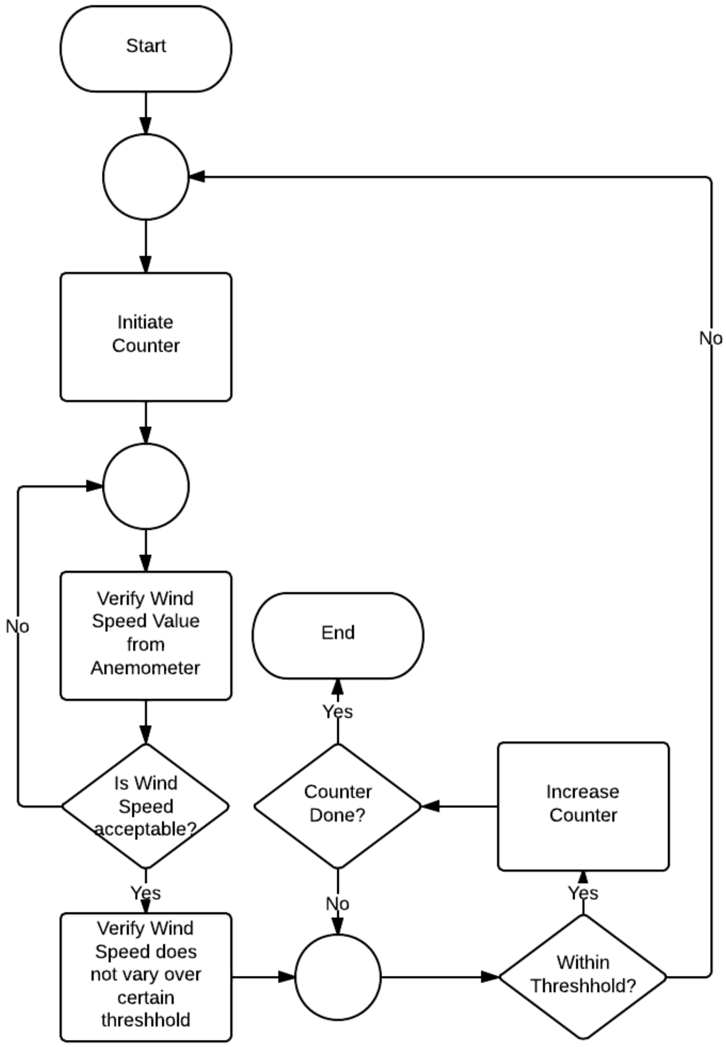

Figure 4: The wind speed check procedure.

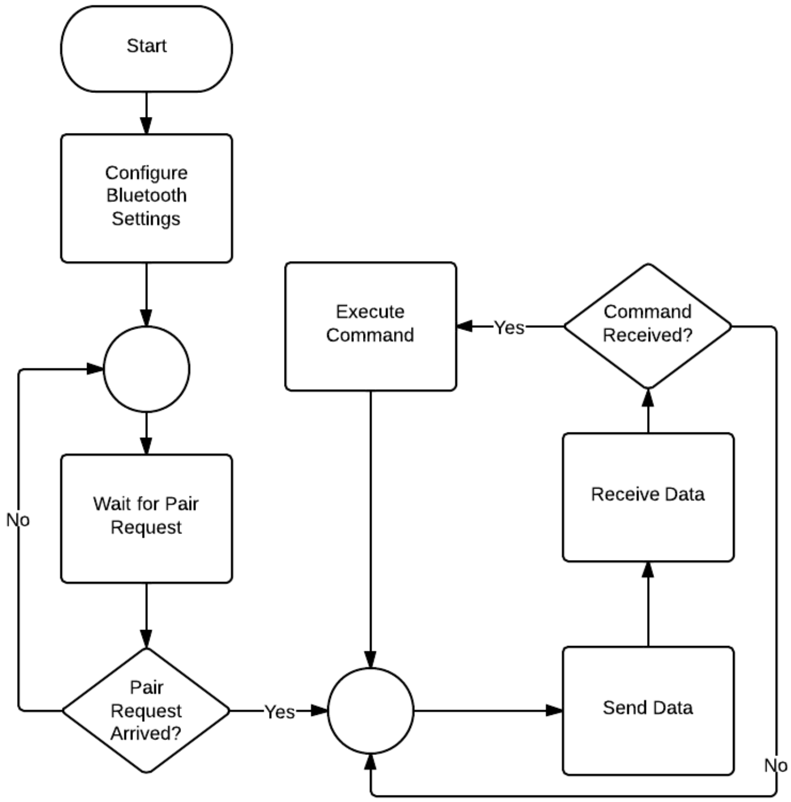

Figure 5: The communication procedure of the system.

Poster

AeroBal

Team Members:

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Description

The wind tunnel of the Department of the Civil Engineering at UPRM is used to measure aerodynamic forces acting on objects. The tunnel uses a manually controlled balance to measure drag and lift forces which makes this tool and procedure imprecise and outdated. **AeroBal** brings the tunnel to the 21st century by automating the process using sensors, motors, LCD screens, and Bluetooth compatibility, running on a powerful TM4C ARM Cortex-M4 processor.

AeroBal uses strain gauge sensors to accurately detect the forces exerted by the wind current. An LCD screen functions as the primary interface for controlling the system and displaying data in real time, which allows users to easily see experimentation data. To add extra ease, users are able to connect through Bluetooth to the system using a mobile application which permits convenient control of the system and the ability to read the data from the comfort of their tablets. Pressure, barometric, humidity, and temperature sensors will be implemented to give more data to the user. All of these sensors should give users more productivity when conducting research using the tunnel.