University of Illinois

Senior Design Design Review

Acoustic Spoke Tensiometer for Bicycle Wheels

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Contents

I. Introduction

1. Objectives

This project aims to design a tensiometer for bicycle wheels based on the audible frequencies emitted by the spokes when they are being struck. Currently available techniques require clamping of the spokes individually in order to determine the tension based on the physical deflection of the spokes. This method is time consuming and highly dependent on the proper calibration of the meters. This project was created to measure each bicycle spoke quickly without making individual measurements to each spoke.

The goal of this project is to measure the effective spoke length and input other parameters (butted/non-butted spokes) to calculate an optimal tension for each bicycle spoke. The device will pluck each spoke consistently so that the resonating frequency can be accurately measured and used to determine the tension in the spoke. This device would be ideal for individuals that want to make adjustments to their bicycles and bicycle repair shops that need to make measurements quickly and accurately for a multitude of customers.

Benefits

- Consistent and accurate measurements
- Calculates optimal tension of the spokes for the user
- Does not require frequent recalibration
- Quickly measure the tension for each spoke in a wheel

Features

- Convenient measurement of spoke length
- Built in plucker to ensure clean striking of the spokes
- User controlled precision range
- Real-time intuitive visual display for readings
- Stores readings for an entire wheel in memory

The project relies upon the fundamentals of tension in a string which is derived from basic physical laws.

$$T = m(2FL)^2 \qquad (1)$$

Equation 1 describes the relationship, where F is the frequency of the resonating wire, L is the length of the wire, and m is the mass per unit length of the wire. With regards to bicycle spokes, the mass per unit length can be treated as a constant meaning that tension depends primarily on the length of the bicycle spoke. The frequency of the resonating spoke that the microphone will pick up combined with the inputted length of the spoke will give the tension of each bicycle spoke.

II. Design

1. Block Diagram

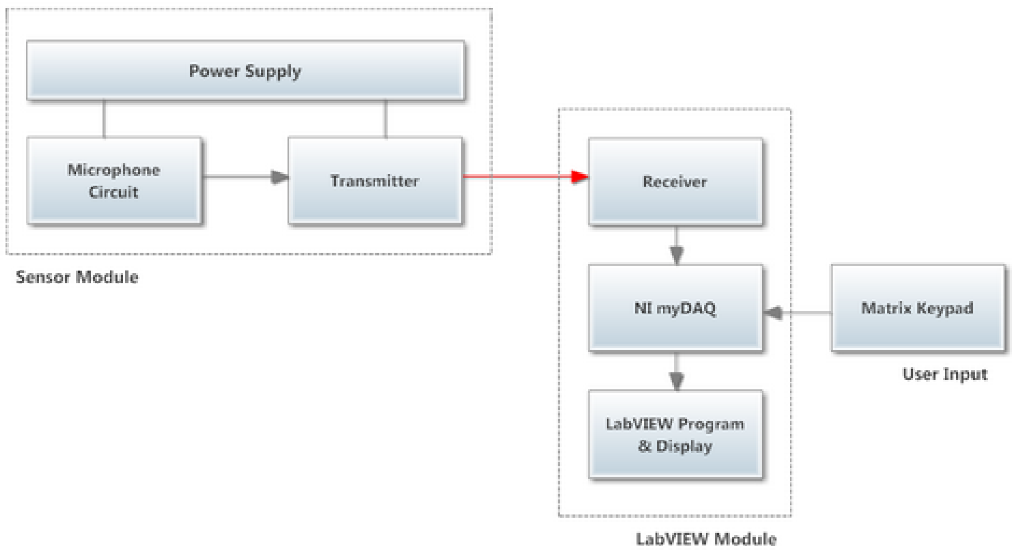

Figure 1: Modular Block Diagram

2. Block Description

Power Supply: This power supply will be a 5V independent source powering the Sensor Module since it will be a standalone unit separate from the LabVIEW module. It consists of batteries in series which apply a 6V signal. The signal is passed through a step-down regulator which will regulate the voltage at 5V as well as guarantee a 1A current.

Microphone Circuit: The sensor module will be a unidirectional microphone that takes in the frequency emitted by the resonating bicycle spokes. This signal will be boosted by an amplifier which will then be relayed to the transmitter.

Transmitter: The transmitter will take the amplified signal from the microphone and transmit it wirelessly to a receiver. This is done to create a portable device for our sensor module to measure the tension of the bicycle spoke without being tied down by a computer.

Receiver: The receiver will gather the signal relayed via the transmitter and input it into the NI myDAQ board's audio in port via a 3.5mm audio jack.

NI myDAQ: The NI myDAQ board will acquire both an analog input (from the microphone circuit via the transceiver) and a digital input (Matrix Keypad) and then send the signals to LabVIEW for processing.

LabVIEW Program & Display: LabView will apply proper filtering techniques to exclude unwanted frequencies that the microphone is picking up. The software tool will also be able to calculate the resonating frequency that the microphone is picking up and hence, the tension of the bicycle spoke. LabView will also display a user friendly interface that indicates the tension of each bicycle spoke.

The sensor unit will be mountable to any standard truing stand along with the plucking device. Figure 2 shows approximately where to the two components would be mounted. The decision for separate components was made taking in the consideration that vibration of the sensor unit would likely cause unwanted disturbance. Wireless communication between the sensor and the myDAQ makes the device easier to set-up and removes unnecessary cords.

Figure 2: Standard Truing Stand with Mount Locations
http://ecx.images-amazon.com/images/I/51eAyoo-3hL._AA300_.jpg

3. Simulations

Amplifier: An amplifier will be used to increase the voltage signal from the microphones output before sending it through the transmitter to the receiver. The goal is to lessen the effect of ambient noise that is likely to be picked up from the receiver. This will limit the effective error in the calculated tension that would result from such noise. To test the effectiveness of the amplifier that was chosen for this design, a design was generated in Multisim, which is available in Figure 3. With that design, two simulations were run to test the generated output of the amplifier. One simulation was performed with an input voltage signal amplitude of 1mV and another simulation with an input voltage signal amplitude of 1V. The resulting graphs are available in Figures 4 and 5.

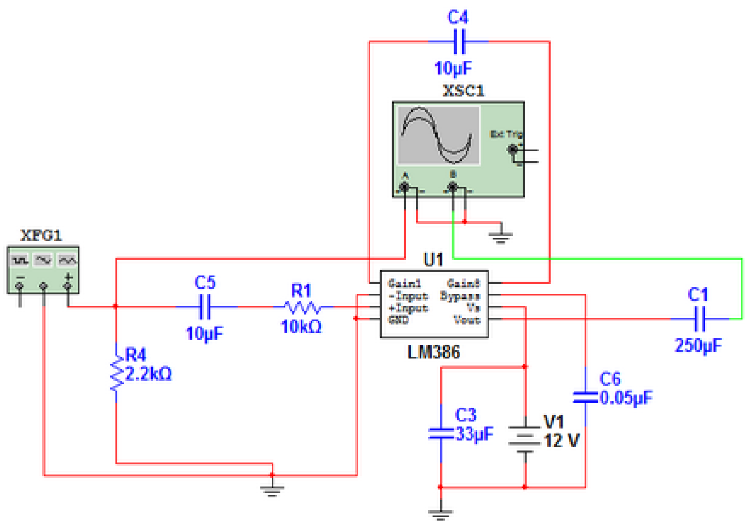

Figure 3: Multisim Amplifier Block Diagram

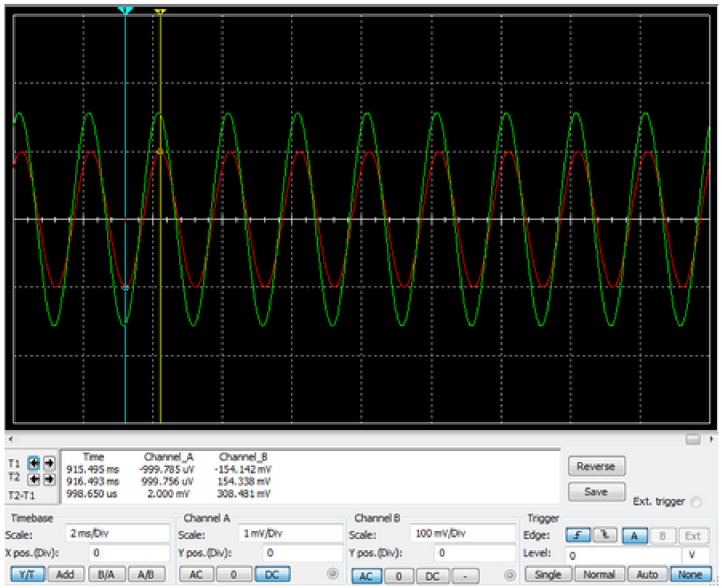

Figure 4: 1mV Input Simulation

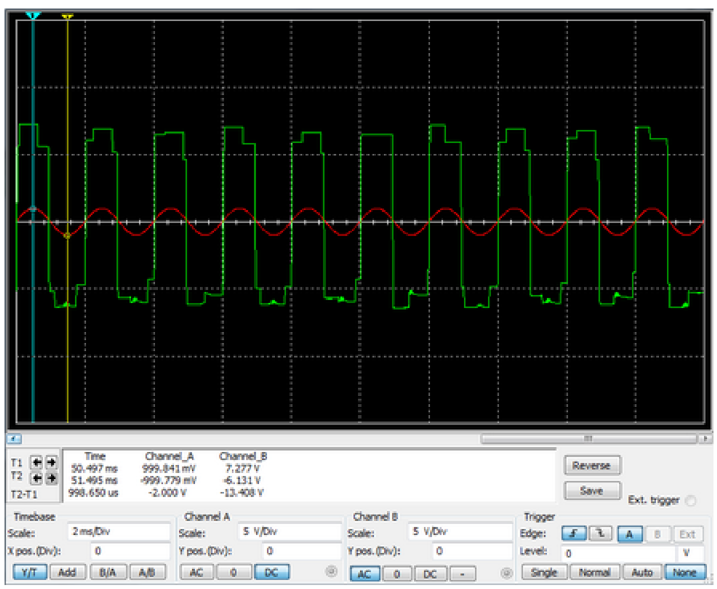

Figure 5: 1V Input Simulation

The level of amplification can be easily adjusted by varying the input resistor of the circuit. Figure 4 shows that for a smaller input voltage the input is greatly amplified by close to a factor of 154. It also maintains the input waveforms shape and would likely maintain the audio output of the signal. For a larger input voltage, Figure 5 shows that the signal is amplified less and is much more distorted by the amplifier. The generated waveform resembles more of a rectangular wave rather than the inputted sine wave. This presents an issue if the output voltage of the microphone is closer to one volt than one millivolt. To address this issue, either a different microphone or amplifier would be necessary. Also, depending on the performance of the transmitter and receiver, an amplifier may not even be necessary.

III. Schematics

1. Sensor Module

Module Components:

- 5V Power Supply
- Microphone Audio Pre-Amplifier
- Transmitter Circuit

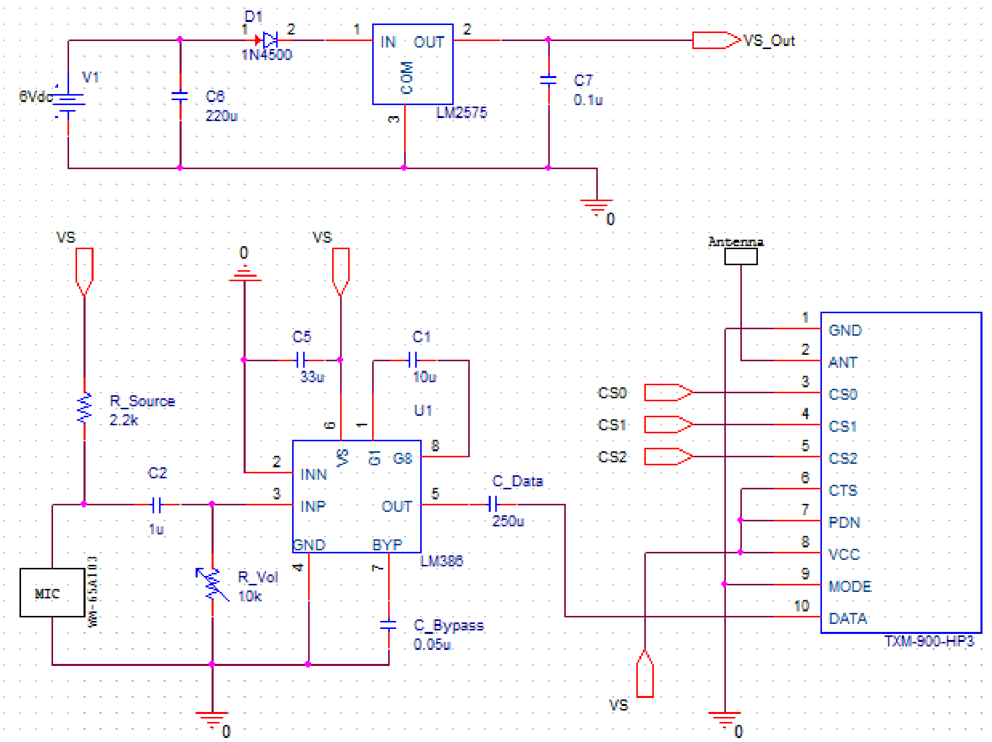

Figure 6: Sensor Module Block Diagram

Labels for Circuit:

- V1 = 2x 3V Button Cell Battery
- C6 = Decoupling Capacitor
- D1 = Diode to prevent reverse polarity

- C7 - Decoupling Capacitor
- Vs_{Out} = Power Supply Output
- Vs = Power Input from Power Supply
- C2 = Input Signal Capacitor
- R_{Vol} = Variable Resistor (Amplification)
- C5 = Supply Voltage Capacitor
- C1 = Gain Capacitor
- C_{Bypass} = Bypass Capacitor
- C_{Data} = Amp Output Signal Capacitor
- C_{S0}, C_{S1}, C_{S2} = Channel Selection
- Antenna = 50 Ω
- LM2575 = DC Step-Down Voltage Regulator
- LM386 = Instrumentation Amplifier
- TXM-900-HP3 = RF Transmitter

The sensor module is made up of 3 main components which include the power supply, the microphone preamplifier and the transmitter.

In the power supply, a 220uF capacitor is used on the input side to prevent any input voltage ripples. A 0.5V diode is placed in the signal path into the voltage regulator for reverse polarity protection. The LM2575 voltage regulator was selected because of its high quality and low noise, and it is able to maintain a constant 5V output at 1A guaranteed current, which satisfies the circuitâs requirements of 5V at 20mA. A 0.1uF decoupling capacitor is placed across the ouput to smooth out any ripple that might occur from the voltage regulator output.

The preamplifier circuit has a $2.2k\Omega$ pull up resistor to ensure that in case of the microphone being disconnected, the input maintains a steady voltage. A 1uF coupling capacitor is connected to the input to block out any DC current. a 10uF capacitor is place between Pin 1 and 8 of the LM386 such that they are on either side of an internal $1.35k\Omega$ resistor. If not bypassed in some way, the chip would set the initial gain at 20. If a 10 uF capacitor is placed across these pins, it provide a low impedance path for the audio frequencies to go around the internal resistor. That effectively removes the resistor from the signal path allowing the internal 150 $k\Omega$ resistor to set the gain at 200. The value of the capacitor sets the frequencies that pass around the resistor. The smaller the value, the more low end frequencies get cut off. Using the formula $f = \frac{1}{2*\pi*C*Xc}$ where the value of the resistor is substituted for Xc, the capacitive reactance. $f = \frac{1}{2*\pi*0.00001*1350} = 12Hz$. (0.00001 is 10 uF expressed as Farads and 1350 is 1.35k). If too low a value for the capacitor is used (e.g. 1uF = 0.000001 F), the result is 118 Hz. A 0.05uF bypass resistor is connected to Pin 7 of the LM386 to reduce noise.

2. Receiver Module

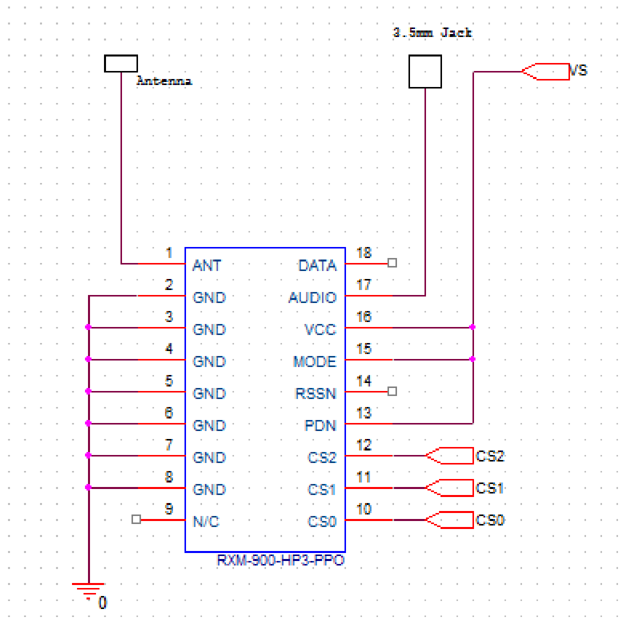

Figure 7: Receiver Module Block Diagram

Labels for Circuit:

- V_s = +5V Supply Voltage from myDAQ
- C_{S0}, C_{S1}, C_{S2} = Channel Selection
- Antenna = 50 Ω
- 3.5mm Jack = Input into Audio LINE IN on myDAQ
- RXM-900-HP3-PPO = RF Receiver

The receiver module has an AUDIO out which will output the analog audio that was inputted into the transmitter to a 3.5mm jack. The 3.55mm jack is used for easy input into the myDAQ. Channel Select determines the band of frequency at which to receive the signal. PDN is high to signal that the circuit should be receiving a signal.

3. User Input

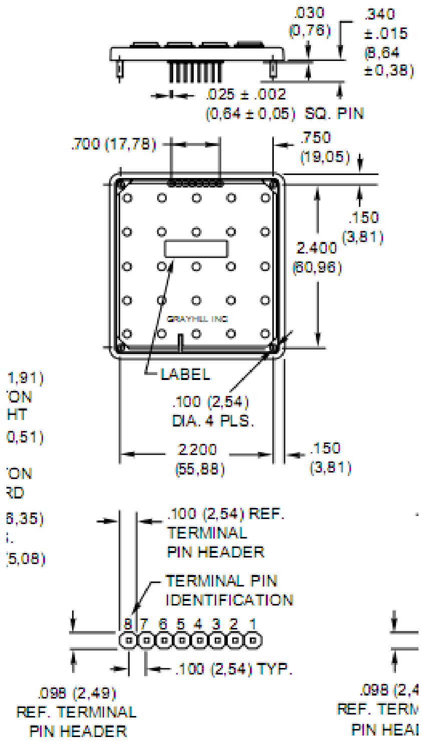

Figure 8: Keypad Pin Layout

The user input module will use a 4x3 matrix keypad. The keypad has 8 digital output pins which feed into the digital input ports on the myDAQ. Users will press a button which will output certain pins as high. LabView will determine which corresponding key was pressed depending on which output pins are high.

4. myDAQ & LabVIEW Module

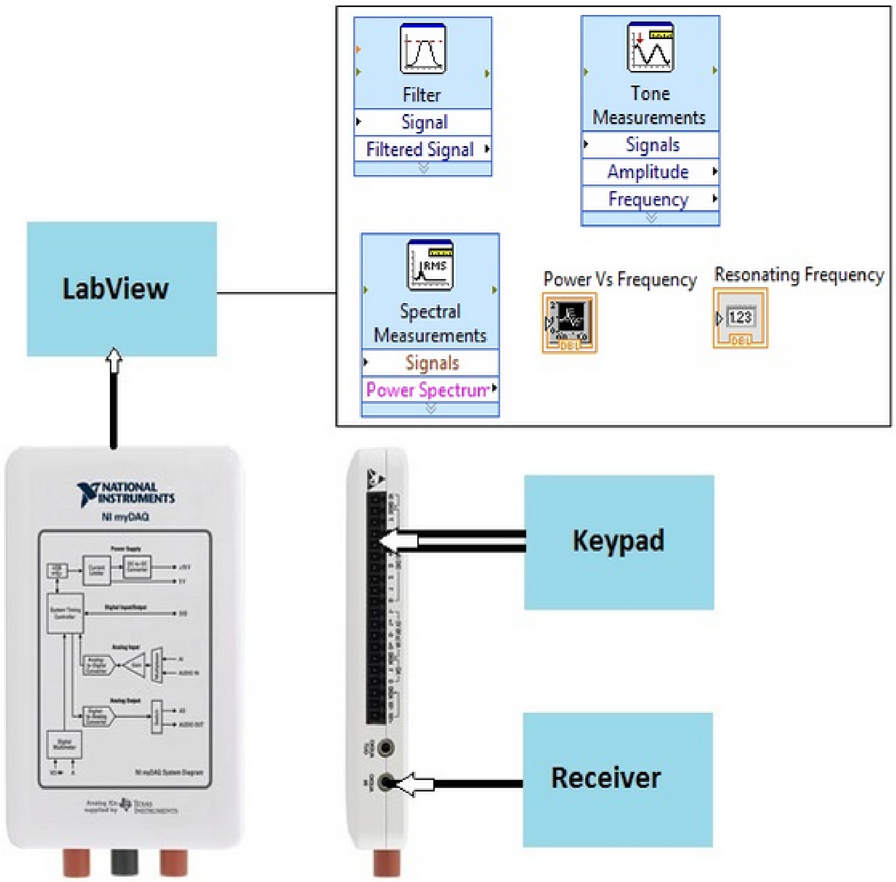

Figure 9: Basic LabVIEW Block Layout

The LabVIEW module will take the output from the receiver and keypad and feed it into the NI myDAQ. The myDAQ will serve as a bridge to communicate with the LabVIEW software which will process the data. The block diagram shows some possible signal processing techniques LabVIEW will use and how the display will be shown.

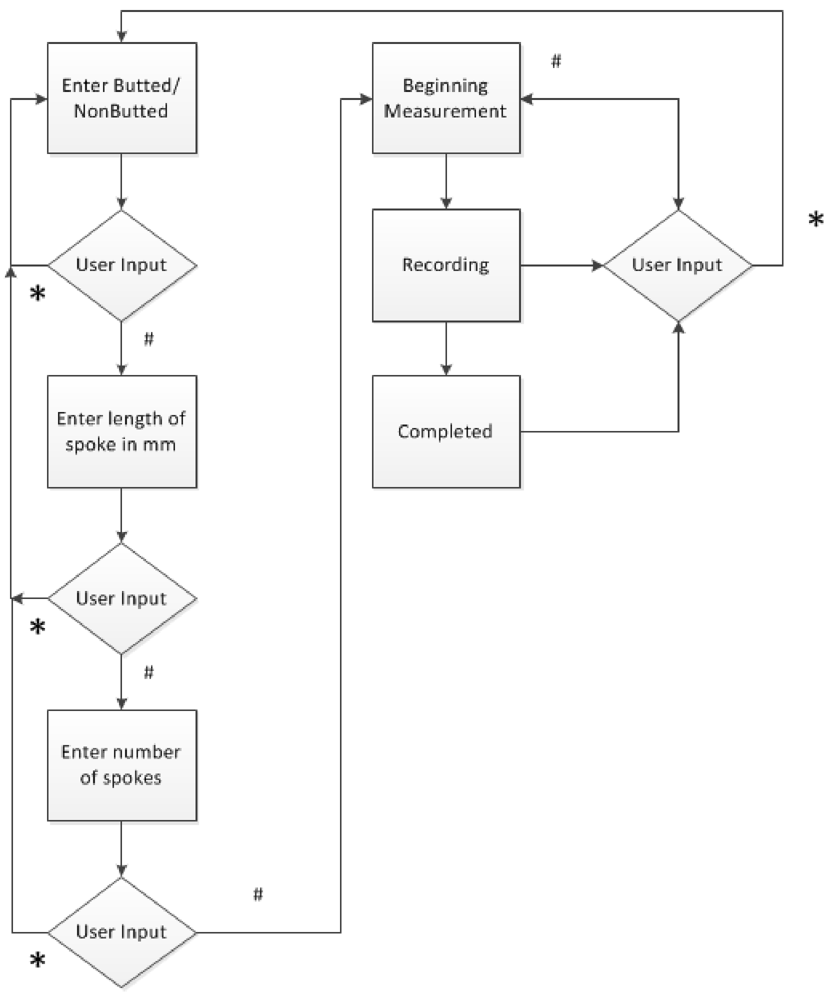

Figure 10: User Interface Program Flowchart

The flow chart indicates the software component of the decision making process. At all times the user has control of what LabVIEW is processing. The flow chart uses a step by step process to gather information about the bicycle spoke and the user will communicate with LabVIEW using a keypad to enter physical numbers. Hitting the # key will confirm the entry and the * key will restart the process from the beginning.

IV. Verification & Tolerance

1. Testing & Verification

The following table shows the expected operation of each module along with the appropriate test to verify a correct operation. If all of the following parts work, the circuit as a whole should perform the desired function of recording the frequency of each plucked spoke and calculating the related tension.

Table 1: Table of Requirements and Verification Tests

Component	Verification Procedure
1.0 Sensor Module: Able to capture a frequency within the range of a plucked spoke and accurately (within 5% of the initial frequency) transmit that signal to the receiver unit connected to the my-DAQ.	**Test:** A 500 Hz signal is generated through the function generator and output through a speaker. The output of the receiver will be connected to an oscilloscope. If working properly, the displayed waveform should have a 500 Hz(±5%) frequency. A non-related signal means part of the module is not operating correctly.
1.1 Power Supply: For all components of the sensor module to operate correctly it will supply a continuous voltage of 5V.	**Test:** Power supply will be connected to a 1.5 $k\Omega$ resistor and with the voltage across it probed on a multimeter. 5V being detected across the resistor signifies a working power supply.
1.2 Microphone: Continuously captures and transmits frequencies from 200-1000 Hz.	**Test:** A varying signal from 200 to 1000 Hz will be output onto a speaker using a function generator. The output of the microphone will be probed and displayed on an oscilloscope. If the microphone works a graph of voltage values corresponding to the range of frequencies will be displayed.
1.3 Amplifier: Amplifies the signal from the microphone by a factor of 150(±5%) and maintains the frequency within 5% of the input.	**Test:** A waveform from a function generator with a 1mV amplitude at a frequency of 500 Hz will be supplied to the input of the amplifier. The output will be displayed on an oscilloscope where the resulting amplitude and frequency will be measured. An operating amplifier will have an amplitude of 150 mV (±5 7.5mv) with a frequency of 475-525 Hz.

1.4 Transmitter/Receiver: Continuously transmits a wireless signal that maintains a frequency and amplitude within 5% of the original value.	**Test:** Waveforms from a function generator with a 100mV amplitude at a frequencies of 200 and 1000 Hz will be supplied to the input of the transmitter. The output of the receiver will be displayed on an oscilloscope where the amplitude will be checked to be within the range of 95-105mV and the frequencies should be between 190-210 Hz and 950-1050 Hz.
2.0 LabVIEW Module: Takes in data from receiver and keypad matrix and calculates the correct frequency along with the corresponding tension within 5% of a tension calculated by a manual tensiometer. Information will be displayed with an easy to read module through LabVIEW.	**Test:** A waveform will be supplied to the input of the transmitter with a frequency of 440 Hz and amplitude of 150 mV. User input for a non-butted 330 mm spoke will be input. The LabView module should calculate a tension within 5% of 138Kgf (the perfect tension). No tension calculation or a tension outside of that range means the module is not working as a whole.
2.1 Keypad Matrix: Allows for an easy to use responsive user input to the Labview program.	**Test:** LEDs will be connected to the output pins of the matrix keypad. The LEDs that correspond to the key pressed should light up; anything else constitutes a non-working keypad.
2.2 myDAQ : Provides quick and updated information from the input signals as well as a power supply for the LabVIEW Module	**Test:** The LabVIEW measurement and automation explorer will be setup and a 100 mV amplitude sine wave with a frequency of 500 Hz from a function generator will be connected to the input of the myDAQ. The module in LabVIEW should instantly output a waveform corresponding to a 500 Hz, 200 mV peak to peak signal. This can also be used to verify that the myDAQ is supplying 5V from its supply terminals.

2.3 LabView : Quickly filters the signal supplied to the myDAQ and calculates the responding tension as well as provide all the data in an easy to read module.	
Requirement 1: Filters out the frequencies in the input signal outside the range of 200 to 1000 Hz.	**Test 1:** Supply a range of frequencies from 0 to 1500 Hz to the input of the myDAQ. A frequency vs time graph will be implemented through LabVIEW and connected to the output of the low-pass filter. A working filter will only show frequencies between 200 to 1000 Hz.
Requirement 2: Calculates the tension within 5% of the reference value when supplied a frequency at the input of the myDAQ.	**Test 2:** Supply a waveform to the input of the myDAQ with a frequency of 440 Hz and amplitude of 150 mV. User input for a non-butted 330 mm spoke will be input. The LabVIEW module should calculate a tension within 5% of 138Kgf (the perfect tension).

2. Tolerance Analysis

Microphone Frequency Filter It is important to determine the range of frequencies the microphone can detect. The microphone should be able to detect frequencies as low as 370 Hz and as high as 900 Hz. The microphone should not pick up ambient noise or other unwanted frequencies such as previously resonating spokes. The microphone should also have a quick response rate to allow for the measurement of each spoke as the wheel spins.

We will introduce low frequencies to the microphone with a signal generator connected to a speaker and see if it can detect the signal to establish the lower bound of the frequency range. We will repeat the process with higher frequencies to determine the upper bound of the frequency range. In order to determine the response rate of the microphone, we will vary the signal on the signal generator and measure the time it takes for the microphone to output a different voltage. Using an IF Filter will prevent other resonating frequencies from other spokes to interfere in proper signal acquisition. The final report will indicate the range of acceptable frequencies and the response rate at which our microphone can operate on.

V. Cost and Schedule

1. Cost Analysis

Labor

Table 2: Value of Labour

Employee	Labor
Xi Li	12 hrs/week x 2.5 x 12 weeks x $30/hr ($60k Salary) = $10,800
Andrius Bobbit	12 hrs/week x 2.5 x 12 weeks x $30/hr ($60k Salary) = $10,800
Sakeb Kazi	12 hrs/week x 2.5 x 12 weeks x $30/hr ($60k Salary) = $10,800
TOTAL	($10,800/person x 3 persons) = $32,400

Parts

Table 3: Bill of Parts

Part	Quantity	Provider	Cost
MyDAQ w/Labview	1	National Instruments	$199.00 (Student)
Receiver *(RXM-900-HP3-PPO-ND)*	1	Digikey	$43.40
Transmitter *(TXM-900-HP3-PPO-ND)*	1	Digikey	$23.60
Key Pad	1	Digikey	$4.00
3.5mm Jack	1	Monoprice	$0.65
Op-Amp *(LM386N)*	1	Digikey	$0.93
Microphone *(P9964-ND)*	1	Digikey	$2.18
Batteries *(P189-ND)*	2	Digikey	$0.38
Regulator *(LM2575)*	1	Digikey	$3.13
Capacitors	7	ECE Parts Shop	$1.40
Resistors	2	ECE Parts Shop	$0.20
Truing Stand	1	Amazon	$61.49
Park Tool Tension Meter	1	Amazon	$52.84

***All parts need to be ordered except available parts in ECE Parts Shop**

Total $390.75 + $32,400 = **$32,793.20**

2. Schedule

Table 4: Schedule & Responsibilities

Deadline	Week	Responsibilities	Team Members
2/13/2012 Design Review Signup	5	Determine capabilities of myDAQ and LabView	Sakeb
		Research appropriate transmitter and receivers	Andrius
		Research appropriate microphone and amplifiers	Xi
2/20/2012 Design Review	6	Ensure Design Review is correctly formatted and completed	Sakeb
		Order parts	Andrius
		Start implementing LabView block diagram	Xi
	7 - Building	Power Supply and wireless transmitter/receiver	Xi
		Keypad matrix	Andrius
		Microphone and amplifier	Sakeb
	8 - Simulate	Tolerance analysis of microphone and amplifier	Sakeb
		Keypad matrix	Andrius

		Power Supply and wireless transmitter/receiver	Xi
3/14/2012 Individual Progress Reports	9 - Integration of circuit with MyDAQ	Microphone and amplifier	Sakeb
		Keypad	Andrius
		Wireless transmitter and receiver	Sakeb
	10 - Coding in LabView	Frequency acquisition with proper filtering	Sakeb
		User input from keypad passes through to LabView	Andrius
		User friendly display panel	Xi
3/26/2012 Mock Up Demo Signup	11 - Debugging	Microphone and amplifier	Sakeb
		Keypad	Andrius
		Wireless transmitter and receiver	Xi
4/2/2012 Mock Up Presentation Signup	12 - Calibration	Microphone and amplifier	Sakeb
		Keypad	Andrius
		Wireless transmitter and receiver	Xi
	13 - Extensive Testing of all scenarios	Microphone and amplifier	Sakeb
		Keypad	Andrius
		Wireless transmitter and receiver	Xi
	14 - Component Analysis	Microphone and amplifier	Sakeb
		Keypad	Andrius
		Wireless transmitter and receiver	Xi
4/23/2012 Demo	15-Complete Presentation	Microphone and amplifier review	Sakeb
		Keypad review	Andrius
		Wireless transmitter and receiver review	Xi
4/30/2012 Presentation, Final Paper	16 - Complete Paper	Research microphone and amplifier	Sakeb
		Research keypad	Andrius
		Research wireless transmitter and receiver	Xi

VI. Ethical Consideration

1. Pledge to Ethics

The group intends to adhere to the IEEE Code of Conduct and Ethical Guidelines provided. The device produced in this project will not harm others in any way or form. This project shall not disclose of any personal information for unauthorized use and will ensure the safe storage of such information. All voltages will be safely regulated and all raw components shielded from user contact.

VII. Appendix

1. Resources

Components

- Receiver: `http://search.digikey.com/us/en/products/RXM-900-HP3-PPO_/RXM-900-HP3-PPO-ND/1917077`
- Transmitter: `http://search.digikey.com/us/en/products/TXM-900-HP3-PPO/TXM-900-HP3-PPO-ND/444157`
- Microphone: `http://search.digikey.com/scripts/DkSearch/dksus.dll?vendor=0&keywords=wm%2065a103`
- PreAmp: `http://media.digikey.com/pdf/Catalog%20Drawings/Audio/MicCartridgeCircuit.jpg`
- Keypad: `http://search.digikey.com/us/en/products/96AB2-102-R/GH5002-ND/180930`
- Batteries: `http://search.digikey.com/us/en/products/A76VZ/N402-ND/704827`
- Regulator: `http://www.ti.com/lit/ds/symlink/lm2575-n.pdf`

Research

- Keypad to LabVIEW Interface: `http://zone.ni.com/devzone/cda/tut/p/id/13650`
- Wheel Tension Measuring: `http://www.parktool.com/blog/repair-help/wheel-tension-measurement`
- Spoke Pitch: `http://www.bikexprt.com/bicycle/pitcheqn.htm`