Project Ambulare - In-Place Movement Tracking for VR

ECE 445 Design Document

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Project 68

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Contents

1 Introduction

1.1 Objective

Virtual Reality (VR) has become increasingly popular recently thanks to its ability to immerse users in an experience. Within VR technology, the term *room scale* refers to the size of the play area that the user can move in and still have their movement conveyed in the VR world. Reasonably there's a limit to how big a play area can be, often meaning that the user moves around in the world with the use of a controller. To address this, various treadmill solutions have been proposed [1], but these systems still take up too much space in our opinion and are too costly for the public.
What we are proposing is an affordable device that both recreates the ability to "walk" in a VR world without needing a spacious play area, and can be quickly setup, torn-down, and stored. When wearing this device, the user can walk in place and their “movements” will be translated into relative movement in the VR world. The device in question will be a soft elastic band worn around the knee equipped with an Electromyography (EMG) to measure muscle activity and an Inertial Measurement Unit (IMU) to measure direction. Lightweight software will run on the user’s computer and translate this sensor data into movement of variable speed, rotation, and direction (forwards/backwards).
The avatar's body should turn according to the user's leg position and not be dependent on their head movement, though this capability needs to be supported by the VR application.
Since our device would need to be safe, portable, and comfortable, it will be powered by a 9V battery connected to a voltage regulator circuit powering the different modules.

1.2 Background

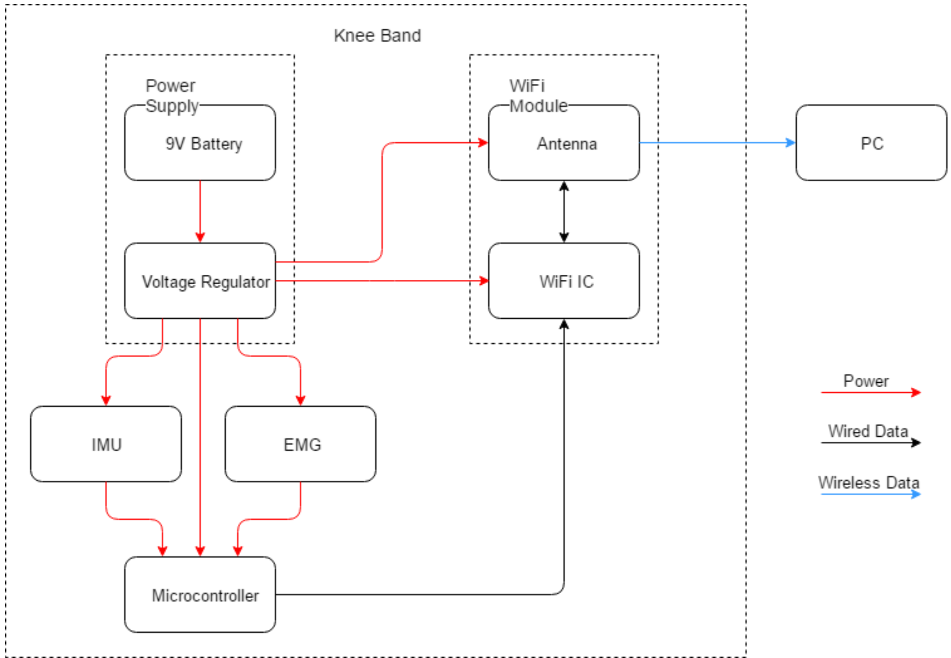
Various attempts from the industry to address walking problems in VR have been made through a treadmill approach, and most of them are not yet available for purchase by the public. A few notable mentions are Virtuix Omi, Vue VR Treadmill, and Kat Walk. Although these products promise realistic walking experience utilizing the treadmills, they all share the same problems of size and pricing. Not only do they take up a lot of space to set up and store, they also cost at least as much as a new VR headset (roughly $700) [2][3].

Our product aims to create a realistic-feeling experience while taking cost into highest consideration. We want to provide VR users with this device as an optional add-on as the requirement for VR is already an investment. Though we are confident our product will take VR to the next level. If our product does what we set out to do – sufficiently complementing while not taking away from the experience – then we have succeeded.

1.3 High-Level Requirements List

- The device must be easy to wear and take off while providing comfort for the users. The device should weigh no more than 5lbs.
- The device should operate within a margin of error to reproduce walking forwards in 360 degrees and at a few different speeds at an acceptable lag of <= 20ms.
- The device should be affordable to most users when produced on a large scale, costing less than $100.

2 Design



2.1 Microcontroller

2.1.1 Functional Overview

The microcontroller is responsible for measuring the data from the electrodes and transmitting it to the computer via the WL1837 WiFi module [1]. For the purpose of gathering high precision measurement while keeping the cost low, we choose TI MSP430F5659 as this MCU has a 12-bit ADC and plenty of interfaces to connect to our WiFi module and IMU unit. The module has many interfaces including USB, I2C, UART, and SPI so it will be able to connect to the other modules without troubles.

2.1.2 Supporting Material

The ADC resolution is calculated as follow:

$$ADC_{res} = \frac{V^{R+} - V^{R-}}{2^N}$$

The potential difference between the reference points on the leg muscles is usually measured between less than 50µV to 30mV. Taking the average of this range which is 14975 µV along with the number of bits N=12 [4] we have the resolution of:

$$ADC_{res} = \frac{V^{R+} - V^{R-}}{2^N} = \frac{14975\mu V}{2^{12}} = 3.656\ \mu V$$

Which mean for each step of quantization out of 4096 steps, we achieve an accuracy of 3.656 µV with each step; or .0244% of the full scale.

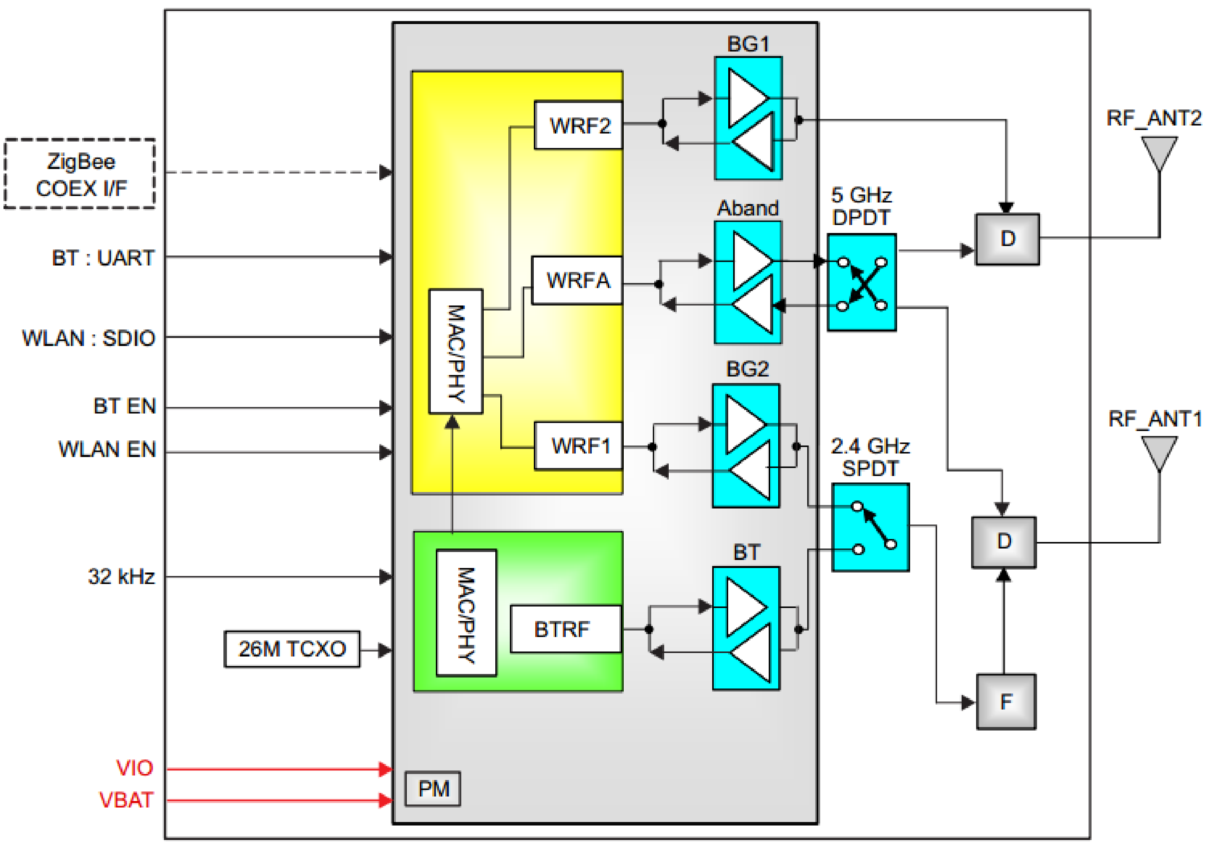
2.2 WiFi Module

2.2.1 Functional Overview

The WiFi module is responsible for transmitting the measured data to the computer. According to Oculus's Best Practice Guide [5], the ideal latency for VR experience should be around 20ms or less, thus a fast transmitting method is desirable. Currently, channel 2.4GHz has relatively high latency [6] at around 35ms to 60ms because of overlapping networks so 5GHz band with an average latency of 4.5ms was chosen. We pick TI WL1837 because this module supports 5GHz band and provides many different connection methods.

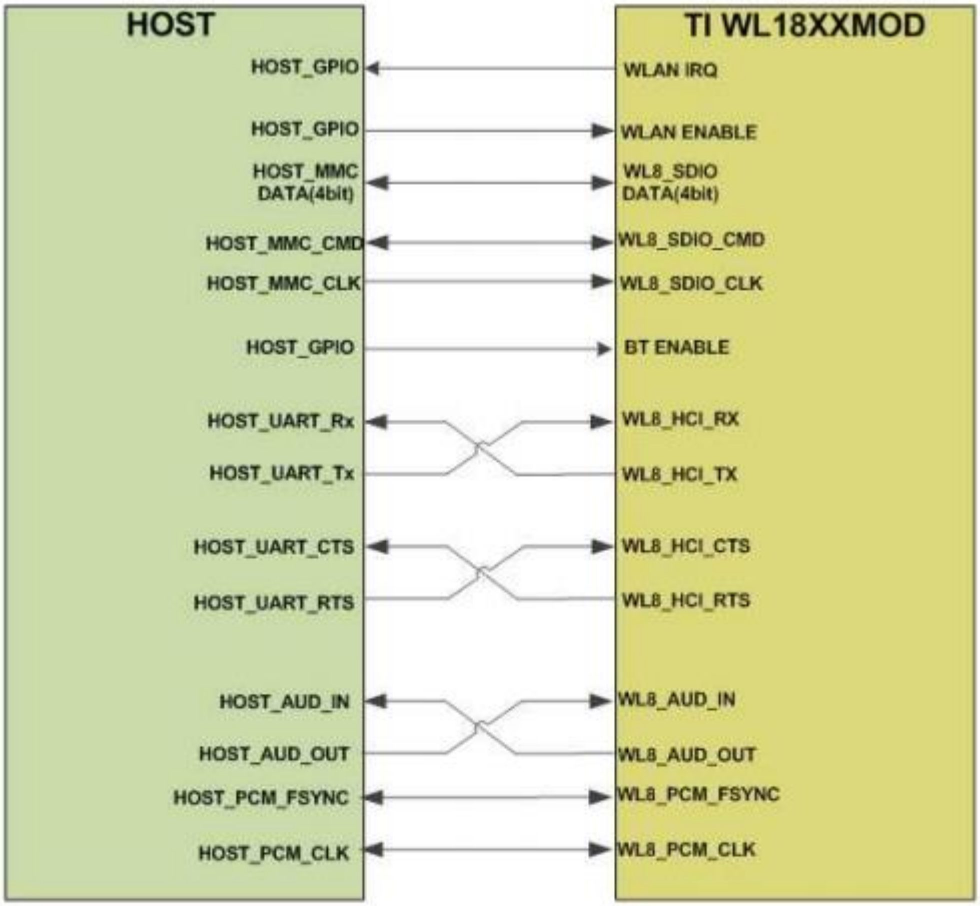
2.2.2 Supporting Material

The functional block diagram can be seen below. Notably future is dual antenna for 5GHz band which will increase the signal's strength.



NOTE: Dashed lines indicate optional configurations and are not applied by default.

As for connection, the model supports Universal asynchronous receiver/transmitter (UART) so we will use a UART to USB adapter to program it. The full IO connection operational mode can be found below.

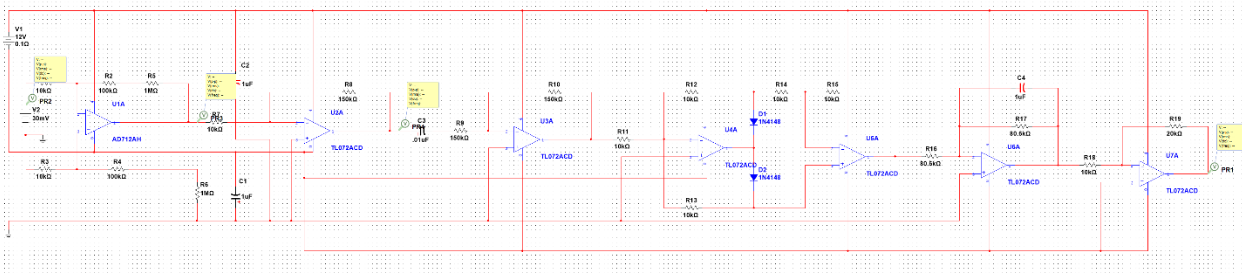


2.3 Electromyography (EMG)

2.3.1 Functional Overview

This circuit will amplify the muscle’s electricity and filter it before passing the signal to the MCU. Because the range of muscle’s electric potential is quite small [7], the signal is amplified various times and passes through low and high pass filters.

2.3.2 Supporting Material



In the first part of the circuit, we amplify the signal to a total gain of:

$$G=\frac{-R2}{R1}=\frac{1000000\Omega+100000\Omega}{10000\Omega}=-110$$

We then amplify the signal again with an inverting amplifier:

$$G=\frac{-R2}{R1}=\frac{-150000\Omega}{10000\Omega}=-15$$

After this we use a capacitor to AC coupling and effectively remove the DC error offset in the signal, follow by an active high pass filter. The cut off frequency is:

$$Fc=\frac{1}{2\pi RC}=\frac{1}{2\pi*150000\Omega*10^{-8}F}=106\text{Hz}$$

Once that is done we rectifying the signal with an active full-wave rectifier before running it through a low pass filter. The reason for this is that we want to get the absolute value of the signal for easy measurement before passing to the MCU. The cut off frequency this time is:

$$Fc=\frac{1}{2\pi RC}=\frac{1}{2\pi*80600\Omega*10^{-6}F}=2\text{Hz}$$

Before finally we amplify the signal again:

$$G=\frac{-R2}{R1}=\frac{-20000\Omega}{10000\Omega}=-2$$

2.4 Inertial Measurement Unit (IMU)

2.4.1 Functional Overview

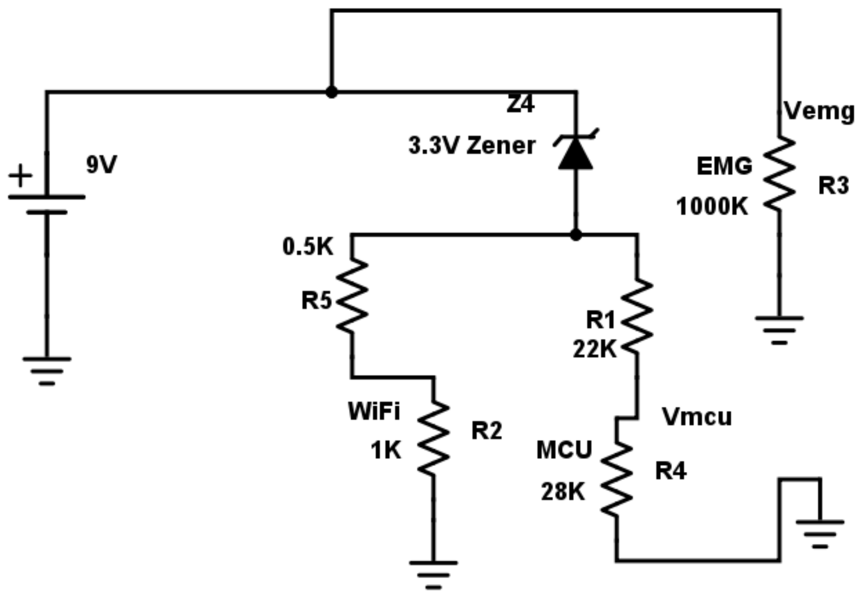
This module consists of 3-axis accelerometer, 3-axis gyroscope, and 3-axis magnetometer to provide nine degree of freedom (9DOF) as raw output data. By measuring angular velocity, acceleration, and heading, these data will be sent to the computer for further processing and transforming to estimate real time input from user. The module has I2C and SPI connection but we will use SPI because it's faster.

2.5 Voltage Regulator

2.5.1 Functional Overview

The Voltage Regulator will take 9V input from our 9V Battery and output 9V to the EMG, 3.7V to the WiFi module, and 118µA to the Microcontroller (the required current). We will use a 3.3V Zener Diode to limit the voltage being provided to the WiFi Module and the Microcontroller accordingly. At the expected operating voltage of 8.4V, our WiFi Module will receive 3.61V, our Microcontroller 3.03V, and our EMG 9V. The voltage provided to the WiFi Module has to be between 2.9V and 4.8V, and the Microcontroller voltage cannot be below 1.8V or above 3.6V.

2.5.2 Supporting Material



2.6 Tolerance Analysis

Because of their natures, both the EMG signal and IMU data can be challenging to collect correctly. This will affect directly to the end results of the device, however within tolerance depend on the case.

For EMG signal, even though we amplify and filter it through various systems, the signal can be dirty because of the nature of non-ideal condition of electricity compare to theory. There are also other factors that could affect the data, for example magnetic field interference from electronic devices, to not applying enough gel on the electrode. At the very least, as long as we get an amplify offset from the circuit we can translate it to a moving speed in VR world. The biggest difference will be how this number changes depend on person, while taking in all risk exposure.

As for IMU, even though the module provides 9DOF, it still unfortunately suffers from drifting which cannot be corrected without more references data (for example, more IMU units). We plan to further test the modules to get to know its weakness and develop a plan for it, perhaps through the form of calibrating. We will also consider using cellphone as a reference data for the unit to correct itself in case of drifting.

3 Requirements and Verification

3.1 Verification table

Equipment and Requirement	Verification	Points
1. **Power System** a. Provide 9±0.3V to EMG sensor b. Provide 3.7±1.1V to wireless communication module c. Provide 2.8±0.7V and 6.5 mA current to IMU sensor d. Provide 2.7±0.9V and 118 µA current to MCU	**Verification procedure for requirement a,b,c,d:** a. Set up power system b. To test requirement A,B,C,D, place the multimeter in parallel with each of the corresponding component and the voltage and current should be within the requirement	20
2. **EMG sensor** **a.** Provide muscle electrical activity produced by skeletal muscles, which can be used to analyze activation level	**Verification procedure for requirement a;** a. Set up the EMG sensor on the knee band device and move your leg up and down with different speed, the EMG should be able to capture the change of moving speed, and has voltage of 3V ±1V	15
3. **IMU sensor** **a.** This sensor measures and reports a body's specific force, angular rate, and should be able to track the movement of muscles and the changes in position	**Verification procedure for requirement a:** a. Set up the IMU sensor on the knee band device and move your leg up with knee bands down with 90 degrees, the IMU should be able to capture the linear change of position, with ±2/±4/±8/±16 g linear acceleration full scale b. Set up the IMU sensor on the knee band device and turn your body to the left by 90 degrees, the IMU should be able to capture the change of angular velocity, with ±245 / ±500 / ±2000 dps angular rate full scale c. Set up the IMU sensor on the knee band device and turn your body to the right by 90 degrees, the IMU should be able to capture the change of angular velocity, with ±245 / ±500 / ±2000 dps angular rate full scale	15
4. Software **a.** Import data collected from EMG sensors, and should be able to transform the data from the position data to movement tracking in the VR program	**Verification procedure for requirement a:** a. When the user is wearing the EMG sensor device steps in the same place for 10 second with frequency less than 3 steps per second per leg and then stop, the figures in the VR program should also walk in straight for 10 second and then stop b. When the user is wearing the EMG sensor device steps in the same place for 10 second with frequency larger than 3 steps per second	15

	per leg and then stop, the figures in the VR program should also run in straight for 10 second and then stop c. When the user is wearing the EMG sensor device turn 90 degrees to the left, the figures in the VR program should also turn 90 degrees to the left d. When the user is wearing the EMG sensor device turn 90 degrees to the right, the figures in the VR program should also turn 90 degrees to the right	
5. MCU a. MCU must have at least 4 analog input and 15 digital input/outputs 2 PWM outputs b. Must be able to run from 3 to 10 Volts c. Processor must have clock of at least 16 MHz d. Control code must function as designed with an error rate no larger than 1%	**Verification procedure for requirement a:** a. Count the number of digital pins capable of PWM output, the number of analog inout pins, and digital input/output pins to ensure that the minimum amount is met. **Verification procedure for requirement b:** b. Power the MCU with 5V and run a LED testing script on it. If the LED flashes as desire when the MCU is functioning properly. **Verification procedure for requirement c:** c. Run the MCU 20 times a day and run for 5 days straight and ensure no more than 1 error occurs	20
6. Wireless Communication a. The MCU is able to connect to WiFi with a maximum range of 100m, and the transmission speed should be in the range of 13 +/- 3 dBm and with frequency of 5 GHz. b. Be able to transfer the data to the PC	**Verification procedure for requirement a:** a. When WiFi is ready, the MCU should be able to be programmed through WiFi. **Verification procedure for requirement b:** b. PC, the receiving end, should receive data from EMG and IMU sensors	15

4 Cost and Schedule

4.1 Cost Analysis

LABOR			
Salary/week	**Weeks**	**Persons**	**Total Labor**
$1,350	10	3	$40,500
PARTS			
Part	**Part Price**	**Quantity**	**Total Price**
MSP430F5659	$12	1	$12
WL1837MODGIMOCR	$34	1	$34
LSM9DS1	$	7	$
GRAND TOTAL	$		

4.2 Schedule

Week	Task
2/27	Start making EMG. Order parts if needed
3/6	Research about MCU interfaces development
3/13	Research about UART set up for WiFi module
3/20	Research about IMU via SPI
3/27	Connect EMG and MCU
4/3	Connect IMU and MCU
4/10	Connect WiFi to MCU

5 Discussion of Ethics and Safety

5.1 Safety Statement

5.1.1 Safety of EMG Sensors

The safety of user is always our primary concern when we design our project product. Based our current research, the peak-to-peak current of EMG is less than 2.37 μA, such that we can ensure that the current is way below the safety upper bound of direct current, which is 5 mA. Since our low current is comparatively low with the safety guidance, the sensor will not bring any discomfort effect to the user.

5.1.2 Safety of Battery Circuit

Our circuit will be powered by a 9.0V battery connected to a voltage regulator, therefore there is no high voltage in our battery circuit. However, we need to concern about chemical leakage from the battery, which is harmful to human. We will use a plastic protection shell to enclose the battery away from the circuit and other components.

5.1.3 Safety of Voltage Regulators

The linear voltage regulators will release heat during usage, and thus can lead to temperature increase of the device. Therefore, we will use a heat sinks to the voltage regulators, and will encase it with isolation shell in order to avoid being touched by the user.

5.2 Ethical Statement

We will abide IEEE code of ethics with following guidelines

5.2.1 To be honest and realistic in stating claims or estimates based on available data [8]

Our sensors movement tracking involves data analysis of user’s activation muscle movement and give the user corresponding feedback in the VR program. Therefore, we are responsible to test our design feedback tracking system is as accurate and comfortable as possible such that we can give user a realistic experience of VR walking.

5.2.2 To seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others [8]

Since we don't have much experience with VR tracking, we will seek out, and accept criticism, and acknowledge and correct errors, especially for the moisture sensor. Since our design will be based on tracking from the sensors, we will properly cite all of our sources used for the data transforming so that we credit properly the contributions of those studies.

6 Citations

[1] R. Wong, "VR startups: Stop trying to make virtual reality treadmills a thing," Mashable, 2015. [Online]. Available: http://mashable.com/2015/06/20/virtual-reality-treadmills/#PwLuAgY9biqa. Accessed: Feb. 9, 2017.

[2] [Online]. Available: http://www.vuetechnologie.com/product/vue-vr-treadmill/. Accessed: Feb. 9, 2017.

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[4] [Online]. Available: http://www.ti.com/lit/ds/symlink/msp430f5659.pdf. Accessed: Feb. 25, 2017.

[5] [Online]. Available: http://www.ti.com/lit/ds/symlink/msp430f5659.pdf. Accessed: Feb. 25, 2017.

[6] I. Grigorik, "Performance of wireless networks: WiFi - high performance Browser networking (O'Reilly)," High Performance Browser Networking, 2013. [Online]. Available: https://hpbn.co/wifi/. Accessed: Feb. 25, 2017.

[7] Nigg, B.M. and Herzog, W. [Online]. Available: http://people.umass.edu/~gc/protected/Nigg_Chap3_Force.pdf. Accessed: Feb. 25, 2017.

[8] "IEEE IEEE code of ethics," 2017. [Online]. Available: http://www.ieee.org/about/corporate/governance/p7-8.html. Accessed: Feb. 25, 2017.