Power Hardened Intelligent Localizer (PHIL)

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Abstract

This report details the design of an anti-theft system for the recovery of stolen bicycles. This system includes an embedded power system, which converts an unsteady AC bicycle dynamo voltage to a steady DC voltage, an embedded signal processing system, which detects bicycle theft via an accelerometer, and a backup battery to power the system in the event a stolen bicycle is not being used. The final product was found to convert power with reasonable efficiency, detect theft with high accuracy, and the GPS beacon accurately reported å location of stolen bikes.

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1 Introduction

This report details the design and verification of a novel anti-theft system for the recovery of stolen bicycles. The engineering challenges addressed by this system begins with the conversion of a variable AC voltage from a bike dynamo to a steady DC voltage required for the powering of peripherals and for the charging of a lead acid battery. In addition, this project includes the embedded programing of a microcontroller to process accelerometer data when detecting theft, and PCB design required to miniaturize the system for consumer use.

Chapter one provides an overview of the project. Chapter two provides a detailed description of the design process for the system, which includes component descriptions, design considerations, parameter calculations, and detailed schematics of system modules as well as the PCB for component mounting. Chapter three details the verification procedures to document system performance and ensure operating within design specifications. Chapter four provides the cost analysis for the project including parts used and labor required for assembly and testing. Chapter fives provides a brief summary of the engineering accomplishments of the project, uncertainties in testing and verification, ethical considerations, and future work to improve the product.

1.1 Project Motivation

According to the national bike registry, 1.5 million bicycles are stolen every year in the United States[1]. Current systems for bike theft recovery run off disposable batteries, rely on software that charges a monthly service fee, require the user to report that the bike has been stolen before querying its location, and transmit location data continuously which consumes unneeded power and violates the user's privacy needlessly. The aim of this project is to create a personal anti-theft system that addresses these flaws. We will implement a dynamo power system, which is self-sufficient; it runs off the mechanical energy of the bike to power the GPS without ever the need to replace batteries. A user controlled GPS beacon uploads location data to a free online tool so that the product can be sold as a one-time purchase. An accelerometer then enables the GPS beacon when it detects the bike has been stolen. This allows the user to be immediately notified in the event of a theft and ensures location data is generated only when necessary.

1.2 Project Summary

1.2.1 Objective

The project goal is to design an anti-theft system, which improves over current systems. To do this, an accelerometer sensor is used to detect motion greater than the set threshold value, which correlates to normal movement around a bike stand. An AC to DC converter and voltage regulation system powers the anti-theft system off the bike dynamo and charges a rechargeable battery for the event that the stolen bike is not in use.

The regulation system will step down the line voltage to meet the power requirements of specific peripherals. An uninterruptible power system keeps the peripherals running off the dynamo, or the battery, whichever has the highest voltage. The control architecture, implemented on the microcontroller, will power these peripherals on demand in order to conserve energy. It will turn on the system when a user flips the on switch and enable the accelerometer. It will wait for a signal from before reporting that anomalous sensor data indicates the bike has been stolen. It will then disable the accelerometer and enable the GPS to report location data.

1.2.2 Summary of Benefits

- Low power system, which is passive and runs off the bikes own mechanical energy.
- Functions for a significant amount of time off the power reserve stored in the battery even if the bike is stolen and left idle.
- Bike can be located at will whether it is moving or not.
- System only transmits location data when the bike has actually been stolen.
- User is notified of theft immediately rather than having to report the theft themselves and has their privacy protected by having location data transmitted only upon theft.

1.2.3 Summary of Features

- Industry grade dynamo power system.
- Industry quality location services with fast update time.
- High accuracy accelerometer for theft detection.
- Microcontroller capable of high frequency operation for fast response time.
- Compact design and secure enable capability for ease of use.

1.3 Block Diagram

Figure 1 below shows the overall block diagram for our system.

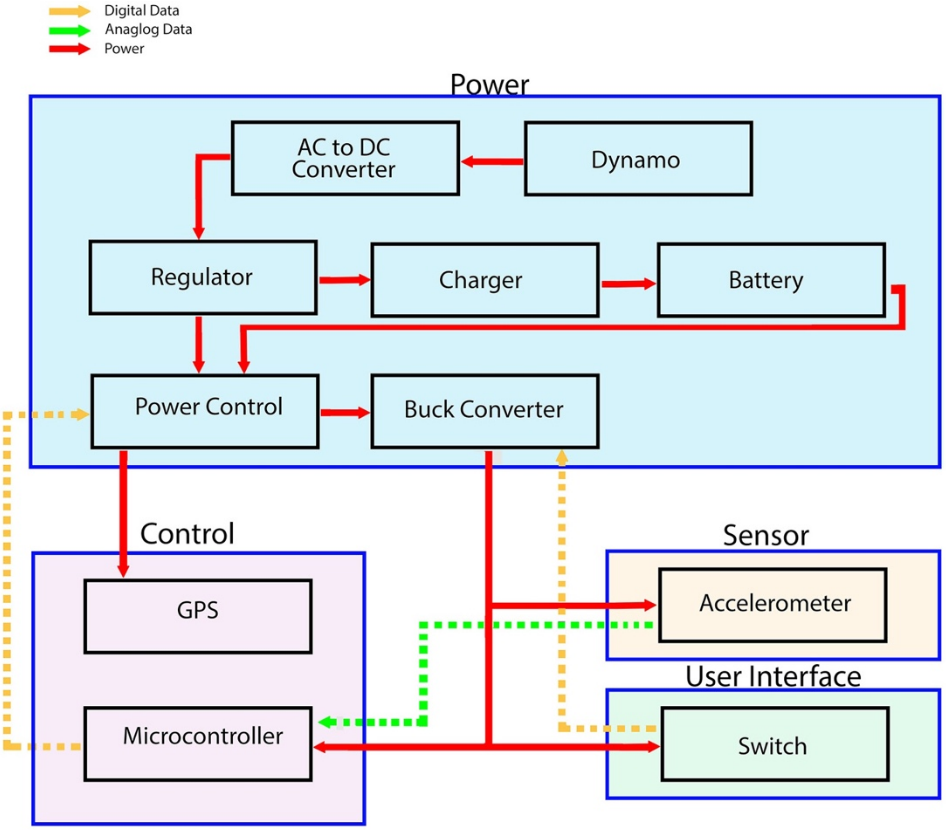

Figure 1: Block Diagram

2 Design

2.1 Block Descriptions

2.1.1 Power System

Bike World USA Dynamo

This module takes input power from the mechanical energy generated by the motion of the bike. This is a standard industry grade dynamo system with an average power rating of **12V, 6W** output we can tap with the power system for the dedicated peripherals. This system will allow the anti-theft system to be powered using the energy generated from the bikes motion instead of a disposable battery. Power line output goes to the battery.

This module was sourced because it is the highest voltage consumer grade dynamo on the market. It is a standard magnetic generator which, when mounted with the rotor against the bike wheel, generates an AC voltage proportional to the bike speed. The dynamo was tested during the course of the project and was found to give output voltages within the range required for the power system at average cycling speeds.

AC/DC Converter:

Power line input comes from the dynamo. This is the AC to DC converter that will allow the regulation of an unsteady dynamo voltage to a steady DC voltage signal with variable amplitude as input to the high voltage regulator IC. This conversion system uses a bridge rectifier circuit and then a simple capacitive filter to smooth the ripple in the DC signal. Power line output from the AC/DC converter is to the high voltage regulator.

A bridge rectifier design was chosen for the AC/DC converter due to its low loss and high efficiency. A filter capacitor was sourced which ensured **5%** ripple at the output for the maximum unloaded voltage output of **50V** of the dynamo at nominal current draw. This was mainly to ensure high efficiency over the range of dynamo speeds. The high voltage regulator seen can adapt to a wide range of input voltages, approximately three volts above the desired output voltage, so larger ripples at higher speeds are acceptable.

LM317HV High Voltage Regulator:

Power line input comes from the AC/DC converter. This high voltage linear regulator was used to step down the variable DC voltage from the AC/DC converter to a constant 9V output for use in the power system. Line output goes to the battery charger and the power system control block.

This linear regulator was one of the highest power regulators produced by linear technologies. Its input voltage rating is **50V** and current rating is **1.5A**, which is a suitable for the unsteady input voltage from the dynamo. Its adjustable output rating allowed a constant **9V DC** output to be chosen for the power system, ensuring stable operation below the speed required to power the peripherals off the dynamo. This limits the voltages entering the circuit, in order to ensure safe and reliable operation of the power system and protect the user's safety.

BQ24450 Lead Acid Battery Charger IC

Power line input comes from the high voltage regulator. This is the IC charger that will allow us to safely charge a lead acid battery at a range of output voltages coming from the regulator. This charger is a lead acid battery charger, which can support a maximum input of **40V** and **8A**. Power line output from the charger is passed to the input of the lead acid battery.

This lead acid battery charger was sourced from TI due to it's adjustable output voltage capability and its wide range of acceptable input voltages. This charger is in fact has the largest input voltage and current rating of any TI charger for lead acid batteries, which could be found. At a rating of **8A** and **40V**, it could in fact be plugged right into the output of the AC/DC converter if the user operated at a constant bike speed. Variable bike speed required the use of the regulator to insure steady output from the charger. However, even catastrophic failure of the power system will not damage the charger, protecting the safety of the user and lengthening the lifespan of the battery.

8V-3.2Ah Lead Acid Battery

Power line input comes from the charger. This is the reservoir, which will allow the anti-theft system to run off battery power for a significant amount of time while the bike is not being used. This battery is an **8V**, **3.2Ah** Lead Acid Battery. Power line output from the battery is passed to the power system control block.

There was a lot of thought that went into sourcing the battery. We were originally planning to use a lithium ion polymer battery. Because of its higher charge capacity by weight, I lithium ion polymer battery would have been more effective for a design targeted towards high-speed cyclists. However, we realized that for commuters and most other average cyclists, a lithium ion polymer would actually be dangerous when carrier with the bike outside, especially in high heat. That, combined with the safety hazard of any error in charging output causing the battery to explode pushed us toward using a lead acid battery. The upside of this is that this design which used an off the shelf charger that was able to reliably adapt to a wide range of inputs and charge a battery that was not as sensitive to charging input, yielding a more reliable design overall.

Power System Control

Line power input comes from the high voltage regulator and from the battery. This system implements a simple power switching mechanism with the use of two diodes. The higher voltage from the battery or the high voltage regulator is passed to the output in order to power the peripherals. The other terminal sees a high impedance to stop current flow and prevent battery discharge when the dynamo voltage can be utilized. Line power output goes to the GPS module and to the buck converter used to power the anti-theft system.

We decided to design an uninterruptable power supply, which would provide constant power input to the anti-theft system in the event of a theft. This system utilized two basic diodes to pipe power from the output of the high voltage regulator and from the battery. Since the regulator output is always nine volts with sufficiently large input voltage from the AC/DC converter, the battery will always be conserved in the event the bike is moving. When the bike is not moving, the voltage will drop and the anti-theft system will run off the battery. Overvoltage protection on the charger ensures that the battery never charges when the voltage drops due to use. This system also prevents the output from ever dropping at low bike speed by ensuring that the battery always goes to output when a lower potential is seen at the regulator output.

LM2595-3.3V Buck Converter

Power line input comes from the power system control block. The buck converter will convert the line voltage of **8V-9V** from the control block to meet the power requirements of each peripheral at **3.3V**. This IC buck converter implements a DC voltage step down to ensure the power line output does not spike above the **3.3V** voltage rating of the peripherals used in the anti-theft system. Power line output goes to the peripherals.

This buck converter was sourced because of its high power operation capabilities. It can support up to **40V** at the input and will drive loads with up to **1A** current draw. The use of this IC over a custom buck converter was a product driven decision. The preliminary designs detailed in the design review had undesirable transients above the input voltage rating of the peripherals chosen for use in the anti-theft system. The use of this IC increased efficiency and delivered much more stable transient behavior than a custom design. The need to include gate drivers in a custom design due to the fact that this power supply turned on the microcontroller required to actuate a switching signal was also a huge factor. The current rating of the buck converter was also considered. This high current rating led to a small drop in efficiency for lower current operation. However, it allowed high frequency microcontroller operating and design scaling and was found not to affect the reliability of the final anti-theft system. Therefore, the high current buck converter was preferred.

2.1.2 Control

Spot Trace GPS Module

Power input at **8-9V** comes from the power system control block. This is a basic GPS beacon, which will determine the location of the bike for transmission to an online service. The GPS beacon has a transmission service for location viewing. At this point no free service exists so this project will use this spot trace module with the online service to display location data.

This GPS module was also a major consideration in the final design. We did some prototyping with a GPS data logger and considered building a GSM broadband transmission architecture to yield a self-sufficient design, which could transmit location data directly to a cell phone over broadband. However, using GSM would limit the utility of the final product in environments where GPS signal is strong and broadband connectivity is limited. As GPS signal has a higher utility in many environments, a module which would allow the transmission of GPS data directly to a dedicated receiver for display on a webpage accessible to the user is preferable. Also, using accelerometer data to give movement alerts after the bike has been stolen would not be a viable heuristic for movement at a constant speed. Therefore, a module was sourced which had the capability to give movement alerts at changes in GPS coordinates. This did result in including a premade component of significant complexity. However, it was decided that this module would have a higher impact on the quality of the final product than a custom design. The software design overhead of a data logger with transmission capabilities was both outside the scope of this hardware based course and would take time away from the power system and embedded programming aspects more central to this project.

MSP430 Microcontroller

Data line input comes from the switch and the accelerometer module. Power line input at **3.3V** comes from the buck converter. This microcontroller will implement the control architecture. This system takes in data from the switch and accelerometer and uses this data to send enable signals to turn on each peripheral at the appropriate time. The system remains off until the device is enabled via the discrete switch. At this time the accelerometer module is powered and the device waits for the event that the accelerometer registers theft. On detecting theft, the GPS is powered by the microcontroller and the accelerometer is disabled for power conservation until the system is disabled. Separate data outputs are used to turn on power to each of the peripherals.

This microcontroller was sourced because of its high frequency capabilities data retentive flash memory. The MSP430 series allows the development of complex embedded systems and comes with a large amount of GPIO pins for use in data input for processing and output to power system. The memory capabilities of the G2553 module, which allowed us to store large chunks of code on the chip and solder it directly onto the board for use in the portable anti-theft system. The use of MSP430 ensured high frequency operation and a large amount of IO and memory capability enabling design scaling in the event that higher accuracy required the use of more sensors in the following design iteration.

2.1.3 Sensors

Adafruit ADXL335 3 Axis Accelerometer

The accelerometer measures acceleration of the bike frame. Power line input at **3.3V** comes from the buck converter. An accelerometer will be concealed on the bike to determine if the acceleration data is inconsistent with that allowable around a lock stand for a short amount of time. This device is a **14 bit 3-axis** accelerometer. The accelerometer will activate the theft detection system (GPS) by sending a signal to the microcontroller when the acceleration of the bike exceeds the set threshold value. The output voltage of the accelerometer varies linearly with change in acceleration from **~1.46V** (positive extreme) to **~3.6V** (negative extreme). The sensitivity of the accelerometer is of the range 270-330 mV/g. The analog output of the accelerometer is then converted to a digital value using ADC conversion which gives an output in the range of **~330mV** to **~700mV** (for all three axis), i.e. **1-2.27g**. A threshold value of **400mv (1.2g)** was then set for the accelerometer, after mounting it on the bike and varying the acceleration. Sensor data is taken as output to the microcontroller module. The flow chart for the microcontroller software is shown below in **Figure 2**.

The choice of this accelerometer was based on its onboard voltage regulation capabilities. The onboard voltage regulator ensured that any transient spikes up to **5V** would not lead to a failure in the chip. The **3.3V** input of the accelerometer matches the input requirement of the microcontroller, allowing the use of a single buck converter in the system and ensuring a more compact final design.

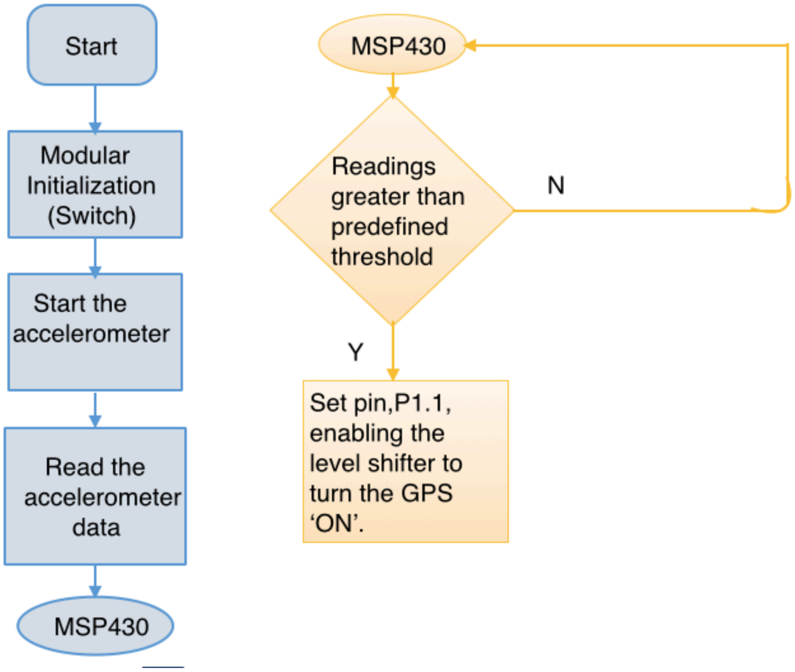

Figure 2: Anti-Theft Software Flow Chart

2.1.4 User Interface

Switch

The user actuates this switch manually. This switch will arm the anti-theft module when the bike has been locked at the stand and disable it when the user returns to unlock the bike. This ensures that the anti-theft detection system is only used when the user is not in possession of the bike and allows an accelerometer reading to become a viable heuristic for theft detection. Subterfuge will be used to disguise the switch's true purpose. Data line is output to the control architecture implemented on the microcontroller.

The original conception of this project included a digital bike lock enabled by either blue tooth or a fingerprint sensor, which would clip onto a mounting bracket storing housing the anti-theft system. This would securely and automatically arm the device whenever the bike lock was removed to lock the bike, and disarm it when the bike's owner engaged the lock bracket. However, the miniaturization and mechanical complexity involved in the design of the lock lead the instructors to suggest limiting the scope of the project to the anti-theft system itself. In the future, another group is encouraged to design a digital bike lock for use in enabling the anti-theft system designed in this project.

2.2 AC/DC Converter Design

The bridge rectifier will consist of four 1N4002 rectifier diodes, which are rated for a maximum RMS voltage of **50 V** and a current of **0.2A**. These values are selected to exceed the output voltage and current of the bike dynamo. **Figure 3** presents the voltage plot after the bridge rectifier; note the frequency is doubled.

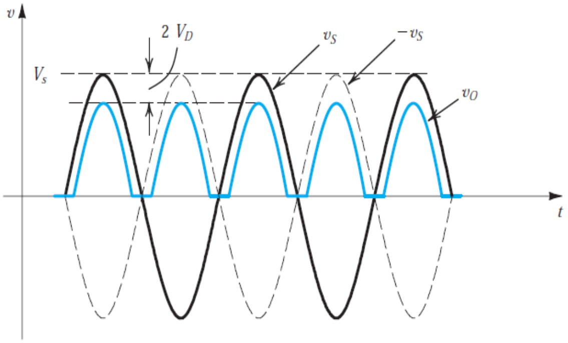

Figure 3: Bridge Rectifier Output

Directly following the rectifier is a filter capacitor, which reduces the ripple in the signal. From **Equation 1**, this capacitor is selected to be **460 µF**.

$$V_{ripple,C} = 0.7\times\frac{I_L}{2fC} \tag{1}$$

The factor of **0.7** is to account for the dissipation limit of voltage regulators. It allows for a higher range of currents to flow. The ripple voltage should stay within **5%** of the desired DC voltage meaning **V** $_{\textbf{ripple}}$ **= 0.05V**$_{\textbf{DC}}$**.** I am choosing the desired voltage based on a high-speed rider, which yields **2.5V** as shown below in **Equation 2**.

$$V_{ripple} = 0.05\times 50 = 2.5\ V \tag{2}$$

2.3 IC Design

2.3.1 LM317HV Voltage Regulator Design

LM317AHV[2] is the 3-terminal adjustable voltage regulator selected because it is able to supply excess of **1.5A** of load current with an output adjustable voltage between **1.2V** to **57V.** Its input-output voltage differential is limited by **$3V \leq V_{IN} - V_{OUT} \leq 60V$** which allow for the bike dynamo's varying voltage output.

The choice to use an integrated circuit for the voltage regulator was due to the need for high efficiency and the varying voltage output of the bike dynamo. **Figure 4** illustrates the purpose of the rectifier and regulator subsystem.

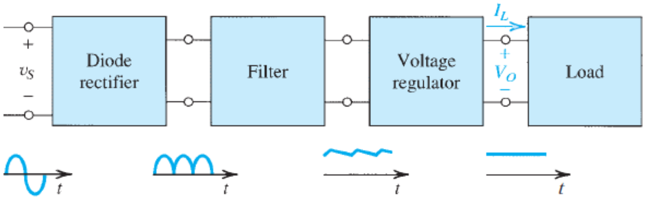

Figure 4: Stages of DC Power Supply

Figure 5 presents the circuit diagram for the IC Regulator. The two resistances can be calculated using **Equation 3**.

$$V_o = 1.25\times\left(1+\frac{R_2}{R_1}\right)+I_{adj}R_2 \approx 1.25\times\left(1+\frac{R_2}{R_1}\right) \tag{3}$$

The output voltage, **V_o = 9V** to account for an estimated **90%** efficiency across the regulator. Then selecting **R_1 = 240Ω**, the second resistance can be calculated **R_2 = 1488Ω**

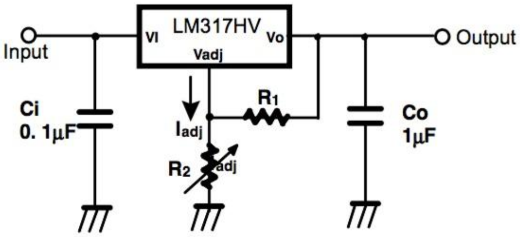

Figure 5: LM317AH Circuit Configuration

2.3.2 BG24450 Lead acid Battery IC Charger

Battery Charger Known Parameters

IC charges 8V, 3.2 Ah lead acid battery (4 cell)[3]

VTH = 5.9V

VFLOAT = 9V – 9.2V

VREF = 2.3V

RC = 47kΩ

RT=620Ω

RISNS=0.5Ω

Charge Rate = 0.05C – 0.3C

Figure 6 below shows the circuit diagram for the **BG24450**[4] battery charger.

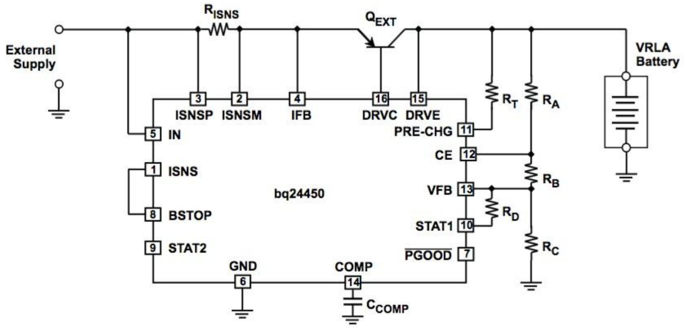

Figure 6: BQ24450 Circuit Configuration

The current required for varying charge rate can be calculated using **Equation 4**.

$$Charge\ Rate = \frac{I}{3.2\ Ah} \tag{4}$$

The IC charger supports charging currents between **160mA** and **960mA** [2]. The following equations are applied to parameterize the surrounding circuit elements. **Equation 5** defines the float voltage.

$$V_{FLOAT} = \frac{V_{REF} \times (R_A + R_B + R_C)}{R_C} \tag{5}$$

Then with $\mathbf{V_{BOOST} = 9.8V}$, **Equation 6** is applied in order to calculate the resistance, R_D.

$$V_{BOOST} = \frac{V_{REF} \times (R_A + R_B + R_C \parallel R_D)}{R_C \parallel R_D} \tag{6}$$

Equation 7 can then be applied to calculate R_B, which solves R_A.

$$V_{TH} = V_{REF} \times \left(\frac{R_A + R_B + R_C \parallel R_D}{R_B + R_C \parallel R_D} \right) \tag{7}$$

Battery Charger Resistor Values

RA=110kΩ RB=27kΩ RD=470kΩ

2.3.3 LM2595-3.3V Buck Converter

IC Buck Converter Known Parameters

Source is 8V, 3.2 Ah lead acid battery

VIN (max) = 8V VOUT = 3.3V ILOAD (max)=200mA

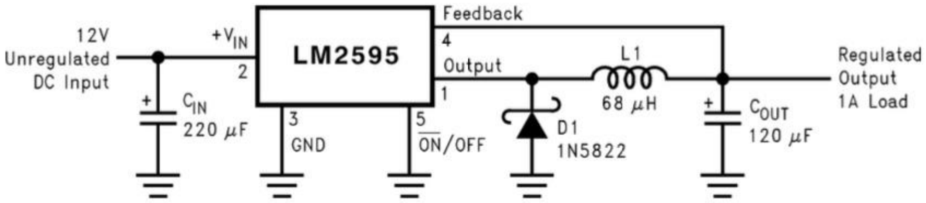

Figure 7: LM317AHV Circuit Configuration

The **LM2595**[5] buck converter circuit configuration is shown above in **Figure 7**. The inductor value is selected to be **L_1 = 100µH** from examination of the inductor selection shown below in **Figure 8**.

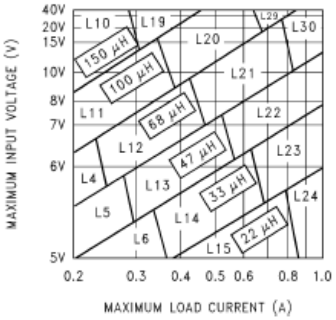

Figure 8: Inductor Selection

The output capacitor, C_{OUT}, is estimated to be a **100µF**, low ESR, surface mount capacitor. Its value is dependent upon output voltage and is acceptable as long as it does not exceed **330µF**.

The catch diode, *D_1*, selection is based upon two essential requirements that are detailed in **Equation 8** and **Equation 9**.

$$D_1\ current\ rating\ \geq 1.3\times I_{LOAD(max)} \tag{8}$$

$$D_1\ reverse\ voltage\ rating\ \geq 1.25\times V_{IN(max)} \tag{9}$$

Thus, the current and voltage rating of the catch diode must exceed 130 mA and 10 V respectively. A Schottky SK12 **1A** diode is selected for its fast switching action.

The input capacitor C_{IN}, must again be a low ESR capacitor in order to prevent large voltage transients at the input. Ceramic capacitors are chosen for this application their requirements are detailed in E**quation 10** and **Equation 11** shown below.

$$C_{IN}\ RMS\ current\ rating = 0.5\times I_{LOAD} \tag{10}$$

$$C_{IN}\ voltage\ rating = 1.5\times V_{IN(max)} \tag{11}$$

A forward capacitor is not required for our system because V_{OUT} does not exceed **10V**.

2.4 Microcontroller Control Flow

The control flow for the microcontroller is shown below in **Figure 9**. When the device is powered on, the accelerometer turns on and the GPS remains off. When the microcontroller registers theft, the GPS turns on and the accelerometer is powered down.

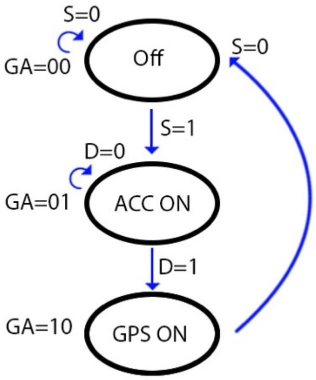

Figure 9: Control Flow

2.5 Level Shifter Design

In order to implement switching in the GPS power line we needed to implement a transistor level shifter to accommodate the large difference between the microcontroller switching voltage and the GPS power line voltage. The level shifter circuit is shown below in **Figure 10**.

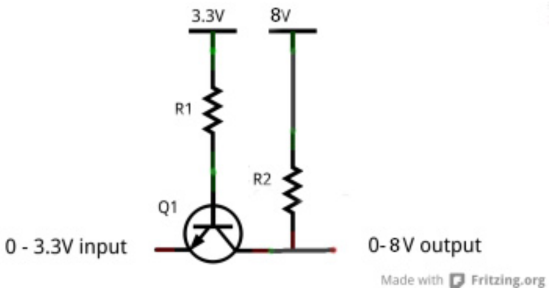

Figure 10: Level Shifter

R1 is chosen as **2.2kΩ** and R2 is chosen as **10kΩ**. The **3.3V** input comes directly from the buck converter and the **0-3.3V** logic signal comes from the microcontroller. The **0-8V** power line goes to the GPS line power input.

2.6 Schematics and PCB Design

2.6.1 Component Schematics

The MSP430 Launchpad and Adafruit accelerometer boards used in this project are detailed in the schematics shown below in **Figure 11** and **Figure 12.**

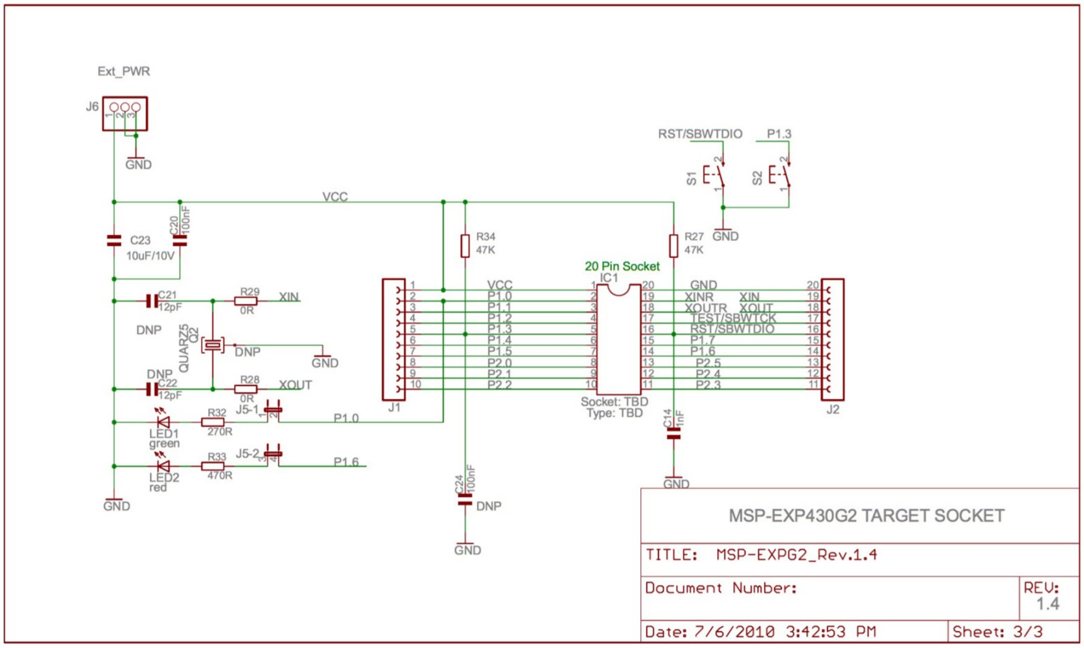

Figure 11: Launch Pad Schematic

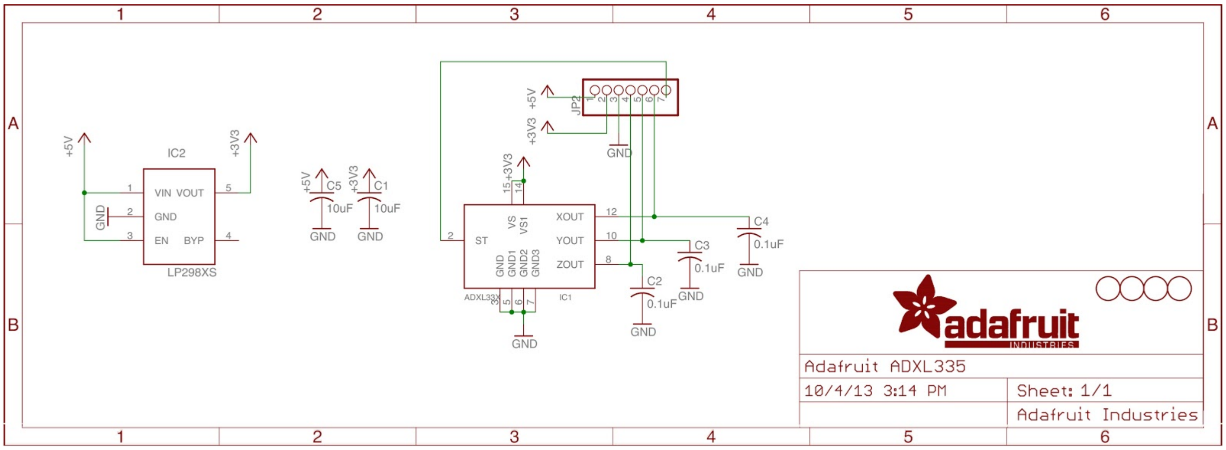

Figure 12: Accelerometer Schematic

2.6.2 Overall Circuit Schematic and PCB Design

Figure 13 and **Figure 14** show the schematic and PCB design for this project.

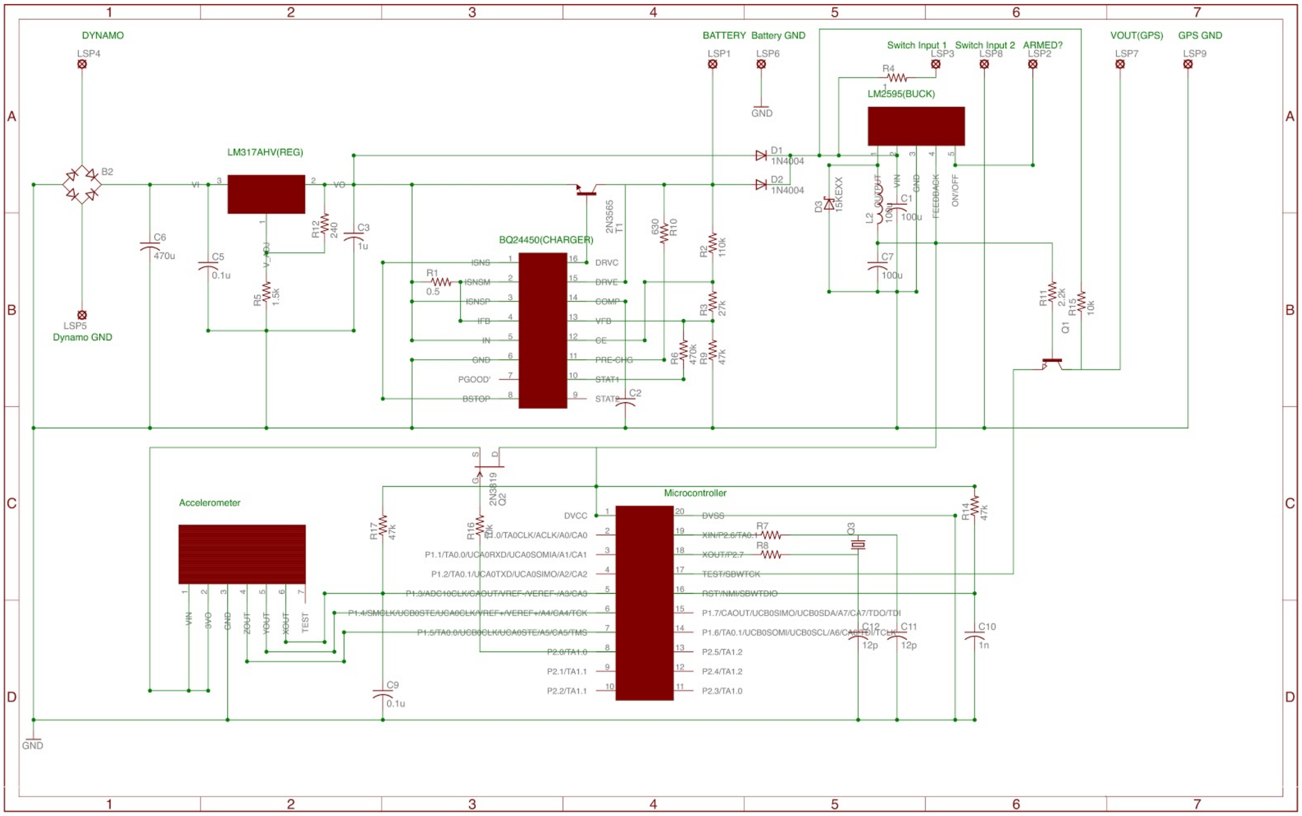

Figure 13: Overall Schematic

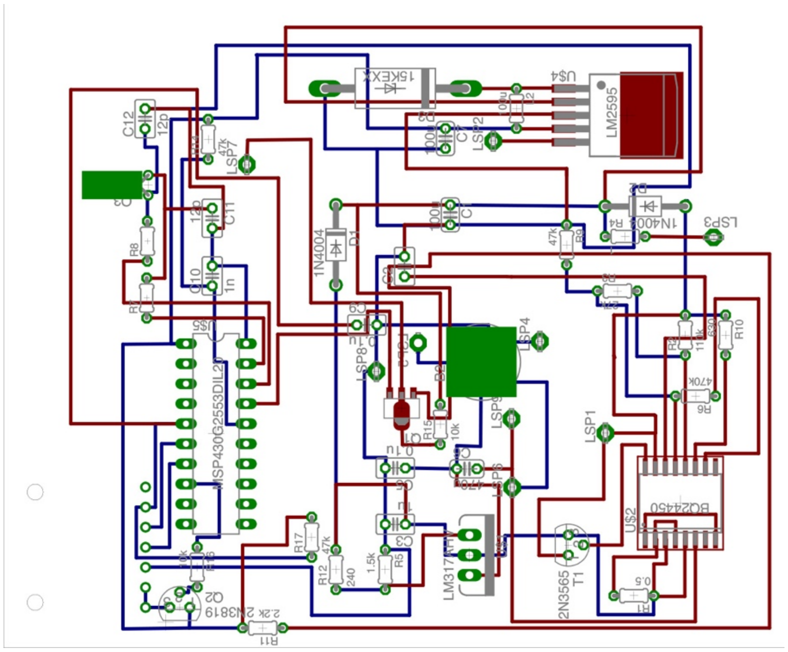

Figure 14: PCB Board

3 Verification

3.1 Power System

3.1.1 Dynamo

2.1 Bike Dynamo:

The bike dynamo provides unregulated AC voltage up to **51.36V** at a cycling speed of **25MPH**. The cadence of an average rider is **70 RPM** and **100 RPM** or about **12 mph** for road bike speed[6]; this corresponds to a voltage output of **17.93V$_{\mathbf{rms}}$** or **25.36V peak** from the dynamo.

Figure 15 presents the bike dynamo voltage output curve for no load conditions. This test will be repeated with simulated load of the IC lead-acid battery charger. **Equation 12** below gives the voltage versus speed characteristic found in this experiment.

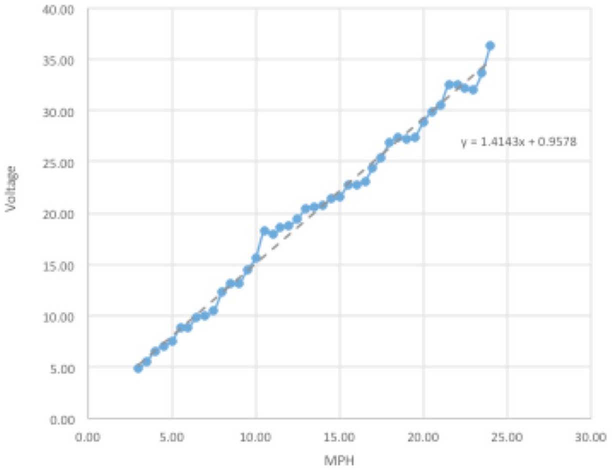

Figure 15: **Dynamo Voltage Output (No Load)**

$$y=1.4143x+0.9578 \tag{12}$$

The open load test confirms that the dynamo power supply can supply the voltage needed for the regulation system (**12V**) at average cycling speed of **12 mph**. Loaded motor characterizations are provided in Appendix B for **0.2A** (nominal current draw of the power system), and for **0.6A** as well as **1A**, medium and high current draws respectively. The dynamo power supply meets the requirements laid out in Appendix A, the requirements and verification.

3.1.2 AC/DC Converter:

The AC/DC converter was tested at a range of AC voltages corresponding to AC dynamo output voltages outputs up to maximum bike speed of **25 mph**. It produced DC voltage with ripple within the **5%** tolerance required by the design requirements detailed in Appendix A. As stated above, the system was designed for maximum open circuit voltage of **50V** at maximum bike speed of **25 mph**. The ripple at nominal speeds leading to voltages up to **25V peak** at average biking speed is negligible. The system was tested with **50V** peak input and the output ripple was found to be **2.496V** at nominal current draw, within the ripple remains under **5%** for speeds lower than **25 mph**.

3.1.3 LM317HV High Voltage Regulator

The voltage regulator used was tested at DC voltages from the minimum voltage required for the desired output voltage to be produced up to the peak output voltage expected from the dynamo, corresponding to **50V** output at **25 mph** as given by the open load test detailed above. It produced voltages within **5%** of the **9V** output required in the saturation regime with Vin greater than **12 V**, as specified in the design requirements in Appendix A. The data is detailed in Appendix B.

3.1.4 8V-3.2Ah Lead Acid Battery

This lead acid battery was tested to ensure its capacity was consistent with the rated **3.2 Ah** capacity after charging from the charging IC in our system. It was discharged into a digital load at constant current of **0.2A**, the nominal current draw of our power system. The discharge time was **935 minutes** yielding a capacity of **3.166Ah**, well within our 5% tolerance. The battery meets the design requirements in Appendix A. The discharge curves and data tables are presented in Appendix B.

3.1.5 Power System Control

The power system control was tested by ensuring that the output power line drove the battery when the supply was off and by the regulator when the supply was on. This capability of the system was shown in the demo and verified beforehand in the design cycle.

3.1.6 LM2595-3.3V Buck Converter

The buck converter was tested to ensure that it converted output voltages from **7V** to **9V** to the **3.3V** output required by the peripherals in the anti-theft system, within tolerance of **5%** detailed in the design requirements in Appendix A. The data is recorded in Appendix B, where the output characteristic shows that the LM2595 gives output within tolerance for the entire saturation regime with Vin greater than **3.75V**, as expected for a DC regulator.

3.2 Control

3.2.1 Spot Trace GPS Module

This GPS module was tested to ensure that its location was accurate to within 10 feet and its boot time after power was supplied was within **30s**. These tests are detailed in the design requirements recorded in Appendix A. The coordinates of the alma mater statue were recorded and the accuracy is within tolerance, as shown in Appendix B.

3.2.2 MSP430 Microcontroller

The microcontroller was tested by introducing an accelerometer signal at threshold and confirming that the GPS power enable pin turned on and accelerometer pin turned off.

3.3 Sensors

3.3.1 Adafruit Accelerometer

The accelerometer output was displayed on an LCD and this output was used to set the threshold for theft detection. The accuracy of the accelerometer was tested by ensuring a consistent threshold was reached for movement indicative of theft.

4. Costs

4.1 Parts

Table 1: Parts Costs

Part	Description	Supplier	Manufacturer	Retail Cost ($)	Bulk Purchase Cost ($)	Actual Cost ($)
Dynamo	Dynamo Generator 12V 6W	Amazon	Bike World USA	1 x $32.55	$32.55	$32.55
PS-832	8 Volt/3.2 Amp Hour Sealed Lead Acid Battery with 0.187 Fast-on Terminals	Amazon	Powersonic	1 x $18.99	$18.99	$18.99
MSP430 Dev Board	Launchpad with Microcontroller	Amazon	Texas Instruments	1 x $16.45	$16.45	$16.45
SPOT Trace GPS	GPS Tracking Module	SPOT	SPOT	DAWG	DAWG	DAWG
Adafruit ADXL335	5V READY TRIPLE-AXIS ACCELEROMETER	Adafruit	Adafruit	1 x $14.95	$14.95	$14.95
Battery Charger	BG24450 Lead Acid Battery Charger	Digikey 296-24367-1-ND	Texas Instruments	1 x $6.76	$6.76	$6.76
Microcontroller Chip	MSP4302553G	Digikey 296-28429-5-ND	Texas Instruments	1 x $2.66	$2.66	$2.66
Regulator	LM317HV	Digikey: LM317AHVT-ND	Linear Technology	1 x $0.71	$0.71	$0.71
Buck Converter	LM2595	Digikey LM2595SX-3.3	Linear Technology	1 x $3.93	$3.93	$3.93
Switch	MTA106DPC	Digikey MTA106DPC	Alco	1 x $8.16	$8.16	$8.16
Power NMOS	ZVN4306AV	Digikey ZVN4306AV-ND	Diodes Incorporated	1 x $1.50	$1.50	$1.50
Power PNP	2SA2127-AE	Digikey 2SA2127-AEOSCT-ND	On Semiconductor	1 x $0.58	$0.58	$0.58
Power NPN	BCX56-16,115	Digikey 568-1642-1-ND	NXP Semiconductors	1 x $0.49	$0.49	$0.49
Power Inductor	28683C	Digikey 811-1213-2-ND	Murata Power Solutions	1 x $0.94	$0.94	$0.94
Bridge Rectifier	W04G-E4/51	Digikey W04G-E4/51GI-ND	Vishay Semiconductor	1 x $0.65	$1.95	$0.65
Schottky Diode	1N5822	Digikey 497-11370-1-ND	STM Micro electronics	3 x $0.39	$0.39	$1.17
Capacitor (12pF)	RDE5C1H120J0S1H03A	Digikey 490-8967-1-ND	Murata Electronics	2 x $0.37	$0.37	$0.74

Capacitor (1000pF/1nF)	C317C103K5R5TA	Digikey 399-4206-ND	Kemet	1 x $0.24	$0.24	$0.24
Capacitor (0.1uF/100nF)	K104Z15Y5VF5TL2	Digikey BC1160CT-ND	Vishay BC	2 x $0.21	$0.21	$0.42
Capacitor (1uF)	FK24X7R1H105K	Digikey 445-8517-ND	TDK Corporation	1 x $0.24	$0.24	$0.24
Capacitor (100uF)	TAP107M020CCS	Digi Key 478-6235-ND	AVX Corporation	2 x $5.78	$5.78	$11.56
Capacitor (470uF)	TWAE477M100CBEZ0700	Digikey 478-9685-ND	AVX Corporation	1 x $94.43	$94.43	$94.43
Resistor (0.5Ω)	AC01000005007JA100	Digikey PPC1W.50CT-ND	Vishay BC	1 x $0.77	$0.77	$0.77
Resistor (1Ω)	RWM06221R00JA15E1	Digikey RWMB-1.0CT-ND	Vishay Sfernice	1 x $1.07	$1.07	$1.07
Resistor (620Ω)	CF14JT620R	Digikey CF14JT620RCT-ND	Stackpole Electronics	1 x $0.10	$0.10	$0.10
Resistor (2.2kΩ)	CF14JT2K20	Digikey CF14JT2K20CT-ND	Stackpole Electronics	1 x $0.10	$0.10	$0.10
Resistor (10kΩ)	CF14JT10K0	Digikey CF14JT10K0CT-ND	Stackpole Electronics	2 x $0.10	$0.10	$0.20
Resistor (27kΩ)	CF14JT27K0	Digikey CF14JT27K0CT-ND	Stackpole Electronics	1 x $0.10	$0.10	$0.10
Resistor (47kΩ)	CF14JT47K0	Digikey CF14JT47K0CT-ND	Stackpole Electronics	3 x $0.1	$0.10	$0.30
Resistor (110kΩ)	CF14JT110K	Digikey CF14JT110KCT-ND	Stackpole Electronics	1 x $0.10	$0.10	$0.10
Resistor (470kΩ)	CF12JT470K	Digikey CF12JT470KCT-ND	Stackpole Electronics	1 x $0.10	$0.10	$0.10
Total						$220.96

4.2 Labor

Table 2: Salary

Member	Hours	Salary	Overhead	Cost
Ifraah	250	$40/h	X2.5	$25,000
Lei	250	$40/h	X2.5	$25,000
Wyatt	250	$40/h	X2.5	$25,000
		TOTAL		$75,000

5. Conclusion

5.1 Accomplishments

Throughout the course of this semester we really came together as a group and completed a project that was far outside our previous level of expertise. Coming into the class, we had no experience with Eagle CAD, limited knowledge of power electronics, no knowledge of how to charge a battery, and we had no previous programming experience with the microcontroller we used for the project. We worked with the Power TA, Jackson Lenz, to learn the skills we needed to implement the power system. We learned Eagle CAD by doing online tutorials and adapted existing microcontroller code to run on the platform we were using. We did our own motor characterization for the dynamo and our own discharge tests for the battery. We got our whole project to work on the PCB, even if there were a few lingering issues before our final PCB draft. All in all, even though our project didn't turn out perfect, it was close. The hardest thing we had to learn was how to deal with failure. We didn't give up on our project even when it seemed hopeless. We didn't stop working on it after we knew we could get a good grade. We pushed ourselves to make a product, which we could be proud of. By chasing perfection, we achieved excellence.

5.2 Uncertainties

We were very close to finishing this project completely. We only had a few small remaining issues by the demo, which we failed to fix. The first was that the microcontroller would be reset without being damaged if the power line pulled high without the ground line being properly connected. Noise in the circuit filtering into the ground bus was resetting the microcontroller sporadically when we mounted it to the board. In the final design, we connected the microcontroller ground directly to the DC ground of the bridge rectifier. We had the microcontroller working on the PCB but because of this noise problem we decided to demo with the microcontroller fixed to the launch pad and wired to the PCB so we would not risk having the microcontroller reset itself during the demo.

We also had a problem with the accelerometer having its zero g value reset every time we modifier the PCB. The weight change of the PCB caused small changes in the zero g values, which caused the previous threshold value to be incorrect. We solved this problem by attaching the microcontroller to the launch pad and reprogramming it on the fly with the mounted accelerometer.

The last problem was the most embarrassing. When we initially designed the project we used a single transistor gated with a 3.3V switching signal from the microcontroller in order to arm the power line supplying 9V to the GPS. We did not test this until the last minute and we realized that the switching signal was never gating the transistor. We stayed up all night before the demo trying to fix it and realized too late that we needed a level shifter. The final design includes a level shifter, which will fix the issue but this functionality was the only thing we could not show in the demo.

5.3 Ethical considerations

The purpose of this project is to develop a locking system for the bike that is capable of detecting its location in case of theft. It is extremely important that this design does not harm the user or damage the bike components in any way. This follows the fifth and sixth code of IEEE Code of Ethics[7]:

> *"To accept responsibility in making decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment."*

Throughout the course of this project, we will learn about the control architecture and its interaction with the user and wireless communication infrastructure used in the GPS localization. This will improve our understanding of the technology used in fabricating this architecture and its viability for solving societal problems beyond those addressed in this project. Our competence in designing control systems and making use of sensors will increase during the course of this project. This follows the fifth and sixth code of IEEE Code of Ethics:

> *"To improve the understanding of technology; its appropriate application, and potential consequences; To maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations."*

We will make sure that our power system does not exceed the load device tolerance levels. This follows the ninth code of IEEE Code of Ethics:

> *"To avoid injuring others, their property, reputation, or employment by false or malicious action."*

5.4 Future work

The original conception of this project included a digital bike lock to securely enable and disable the anti-theft system. We were encouraged by faculty to limit the scope of this project to the anti-theft system itself. We used a simple switch to enable and disable the anti-theft system. However, if the anti-theft system were miniaturized to the point that it could fit in a lock bracket, then the digital bike lock could enable the system when it was taken off to lock the bike, and disable it when the lock was properly installed again for use. In the event of theft, the lock could even help arm the system if a current carrying wire in the bracket was broken when the lock was cut. A blue tooth signal from a phone or even a fingerprint sensor could allow the lock to secure the bike.

The original conception of the project also included a free location service, which would replace the GPS beacon used for this project. This would require creating a GPS receiver, which could cache location data from a satellite uplink and upload it to the web for viewing by the user. One could also imitate the location alert feature of the GPS beacon by sending the user alters when the GPS coordinates of the bike changed radically upon movement.

5.5 Acknowledgements

- Super Awesome PCB Fabrication Guy (Mark Smart of the ECE Parts Shop)
- Super TA Jamie Norton that was our official TA and advised us on our design cycle
- Super TA Jackson Lenz, Power Electronics Expert that kept us from burning the building down
- Dr. Makela who was our official professor and helped us conceive this project

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Appendix ARequirement and Verification Table

Table 3: Requirements and Verification Table

Part	Requirements	Verification	Pt.
Power			
Dynamo	The bike dynamo must supply a minimum of **12V peak** in an unloaded state for an average cycling speed of **12 mph**.	1. Attach a dynamo and a cadence sensor to a bike wheel. Attach the voltage output of the dynamo to the multi meter. 2. Increment bike speed from **3 mph** to **25 mph** in **0.5 mph** intervals and record the output voltage. 3. Generate an equation for the voltage versus speed and find the voltage at **12 mph**. 4. Ensure that this voltage is above **12V**, the minimum required for **9V** output after regulation.	10
	The dynamo must continue to supply voltage above **12V** peak when the loaded at current draws up to **100mA**, the nominal current draw of the system.	1. Connect the motor driving the dynamo to a high current supply. Connect the impedance generator to the dynamo. Tap the voltage across the dynamo. 2. Set the impedance generator to constant currents of **0.2A**, **0.6A** and **1A**. Drive the motor voltages from **5V** to **20V** in **1V** increments and measure the rpm of the motor at each input voltage. 3. View the dynamo output on the oscilloscope and determine the value of the loaded dynamo voltage. 4. Convert the motor rpm speed to bike speed. Generate a loaded voltage versus speed curve for	10

		each current draw. Find the loaded voltage at an average bike speed of **12 mph** for each current draw. 5. Ensure that this loaded voltage remains above **12V peak**, the minimum required voltage to ensure **9V** output from the regulator**.**	
	The dynamo must supply **120Hz** after rectification in order to provide ripple of less than 5% at the output of the regulator.	1. Connect the motor driving the dynamo to a high current supply. Connect the impedance generator to the dynamo. Tap the voltage across the dynamo. 2. Set the impedance generator to constant currents of **0.2A**, **0.6A** and **1A** increments. Drive the motor voltages from **5V** to **20V** in **1V** increments and measure the rpm of the motor at each input voltage. 3. View the dynamo output on the oscilloscope and determine the frequency. 4. Convert the motor rpm speed to bike speed. Generate an equation for the frequency versus speed and find the frequency at the average speed of **12 mph**. 5. Ensure that this frequency is above **120Hz**, the minimum value required for **5%** ripple after regulation.	10
Rectifier Subsystem	The rectifier subsystem must convert an AC voltage range from **12V peak** to **50V peak** to a DC voltage with a ripple less than **5%**.	1. Connect a function generator to the rectifier circuit and filter capacitor 2. Generate AC voltage of **12V peak** to **50V peak** in **5V** increments at **60Hz**. 3. Display the output of the filter capacitor on the oscilloscope. 4. Ensure that the output ripple remains below **5%** of the peak	10

		value.	
Regulator	The regulator must step down DC voltages in the range of **12V** to **50V** to **9V±0.45V**.	1. Connect a function generator to the bridge rectifier and filter capacitor prior to the voltage regulator. 2. Generate a **12V** to **50V** sine wave signal using the function generator in **1V** increments at **60 Hz**. 3. Ensure that the regulator output voltage remains **9V±0.45V**.	5
Battery	The battery will charge to its **3200mAh** within tolerance of 5% capacity with the charging system.	1. We will charge the battery after drainage by connecting the battery to the battery charger powered by the dynamo power system. 2. The battery will first be discharged to the minimum safe voltage. 3. The dynamo will be run at the motor speed corresponding to **12 mph**. The battery will charge from the charger IC. We will measure the current into the battery until the charger IC cuts off this current. 4. The battery will then be discharged into the digital load with the current set to **0.2A**, the nominal current draw of this system. The voltage at the terminals will be measured at time intervals of **30 min**. 5. Once the voltage is at then we will perform current integration to determine the capacity of the battery after charging. Midpoint Riemann sums will be taken by averaging each two consecutive current points and multiplying them by the time interval to find the capacity of the battery	10

Buck Converter	The regulation converts a line output from the power system between **7V** and **9.45V** to the following line outputs. The line output is **3.3V±0.165 V**.	1. The line input to the buck converter will be connected to a DC power supply at DC voltage of **7V** to **9.45V** in **0.1 V** increments**.** 2. The line output will be tapped to ensure the resulting signal remains within the tolerance for that subsystem component listed in requirements.	5
Power System Control	Voltage and current directly from the output of the voltage regulator if it exceeds potential across the battery. A. Power system drives the output line high to **3.3V±0.165V** and from the battery when the dynamo is not being powered and from the regulator when the bike is moving. B. Power system drives the output lines out of the buck converter to **3.3V±0.165V** only when the system is armed.	A. a. Set the arming signal to high. Tap the output from the buck converter, outputs from the regulator and battery before diodes, and output to the buck converter after diodes. b. Ensure that the output from the regulator matches the input to the buck converter exactly when the bike is moving and that the impedance looking from the buck converter to the battery is high. c. Ensure that the output from the battery matches the input to the buck converter exactly when the bike is stationary and the impedance looking from the buck converter to the regulator is high. d. Ensure that the output lines from the buck converter always stay at **3.3V±0.165V** and **5V±0.25V**. B. Toggle the arming signal to low and ensure that the output line drops from **3.3V** to **0V** when the bike is stationary and when it is moving.	10
Control			
GPS	A. The GPS module provides a location within accuracy of **20 m** when armed. B. Boot time of the GPS after supply is switched ON is less than 30 sec.	A. a. Power input will be provided within tolerance determined above. b. We will test accuracy of the GPS subsystem by tapping the signal at the known location about campus as given in campus architecture plan and	10

		comparing the reading of the GPS to this location. B. The power line input is supplied to the GPS and the time for the location data to be updated on the website is recorded.	
Microcontroller	A. The microcontroller turns on the accelerometer module by providing enable signals within **1V±1 mV, 0.5 s** after the switch is flipped. B. The microcontroller turns on the GPS module by providing enable signal within **1V±1 mV, 0.5 s** after the accelerometer exerts stolen signal.	1. The microcontroller sends out a 1-bit high signal when the acceleration exceeds the threshold value of 0.1G. 2. The stolen output signal is high and the accelerometer is turned off.	10
Sensors			
Accelerometer	A stolen signal is generated once the acceleration exceeds the threshold value of **0.1G**.	1. The accelerometer will be calibrated for it’s zero ‘g’ value. 1. The accelerometer module will detect the acceleration in three axes: x (left/right), y (up/down), z (front/back). 2. The acceleration is displayed on an LCD chip to make sure that the acceleration measured is accurate.	10

Appendix B: Data Tables

B.1: Dynamo Verification

B.1.1 Open Load Dynamo Data

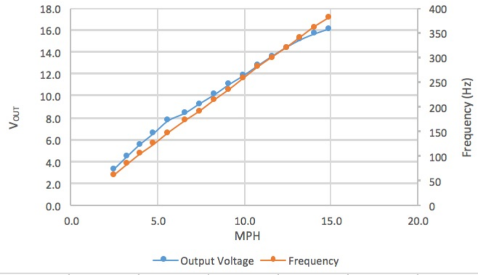
Table 4: Open Load Dynamo Data

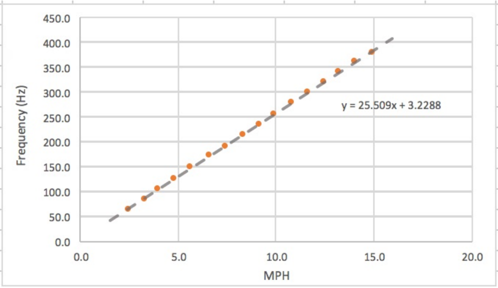
MPH	VOUT
3.00	4.90
3.50	5.50
4.00	6.60
4.50	7.09
5.00	7.47
5.50	8.80
6.00	8.89
6.50	9.90
7.00	10.09
7.50	10.47
8.00	12.26
8.50	13.10
9.00	13.10
9.50	14.50
10.00	15.64
10.50	18.23
11.00	17.90
11.50	18.60
12.00	18.86
12.50	19.40
13.00	20.50
13.50	20.61
14.00	20.70
14.50	21.38

15.00	21.53
15.50	22.70
16.00	22.80
16.50	23.15
17.00	24.42
17.50	25.43
18.00	26.87
18.50	27.42
19.00	27.20
19.50	27.45
20.00	28.90
20.50	29.90
21.00	30.50
21.50	32.50
22.00	32.54
22.50	32.25
23.00	32.08
23.50	33.68
24.00	36.40

B.1.2 Loaded Dynamo Characteristics-0.2A

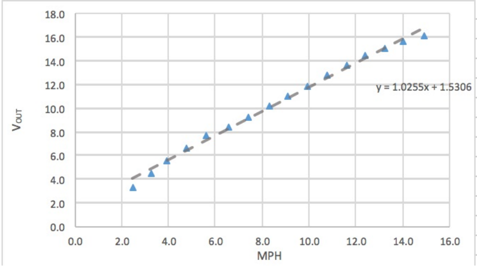
Dynamo Characteristics 0.2A





Loaded Voltage and Frequency Vs. Bike Speed

Frequency Versus Vs. Bike Speed



Loaded Voltage Vs. Bike Speed

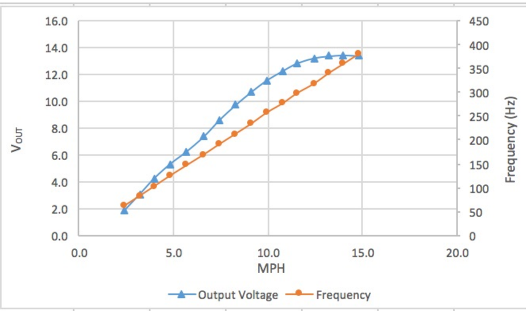
Table 5: Dynamo Data 0.2A

I_L = 0.2 A	V_{IN}	Flashes/min	RPM Roller	RPM 37c Wheel	MPH	V_{OUT} (RMS)	Freq (Hz)
	5.0	543.7	3094.3	28.6	2.5	3.35	63.3
	6.0	713.5	4060.7	37.6	3.3	4.54	85.4
	7.0	867.0	4934.3	45.7	4.0	5.57	105.0
	8.0	1047.1	5959.3	55.2	4.8	6.62	125.3
	9.0	1228.5	6991.6	64.7	5.6	7.76	148.4
	10.0	1441.0	8201.0	75.9	6.6	8.46	172.6
	11.0	1624.0	9242.5	85.6	7.4	9.30	191.9
	12.0	1818.4	10348.9	95.8	8.3	10.16	215.1
	13.0	1996.5	11362.5	105.2	9.1	11.05	235.3
	14.0	2173.5	12369.8	114.5	9.9	11.84	257.3
	15.0	2359.0	13425.6	124.3	10.8	12.76	280.4
	16.0	2539.5	14452.8	133.8	11.6	13.63	300.3
	17.0	2721.0	15485.8	143.4	12.4	14.44	319.8

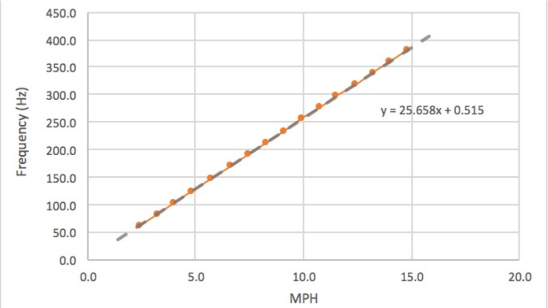
	18.0	2895.0	16476.0	152.5	13.2	15.12	340.2
	19.0	3069.0	17466.3	161.7	14.0	15.65	360.8
	20.0	3263.0	18570.4	171.9	14.9	16.13	380.2

B.1.3 Loaded Dynamo Characteristics-0.6A

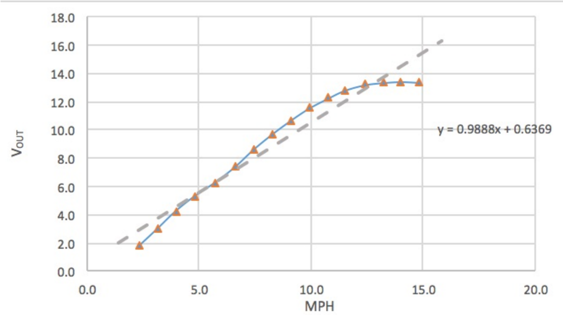
Dynamo Characteristics 0.6A



Loaded Voltage and Frequency Vs. Bike Speed



Frequency Versus Vs. Bike Speed



Loaded Voltage Vs. Bike Speed

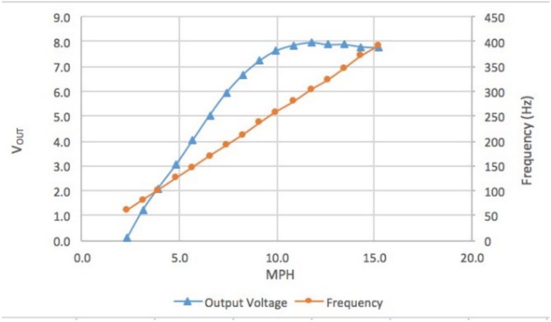
Table 6: Dynamo Data 0.6A

I_L = 1A	V_{IN}	Flashes/min	RPM Roller	RPM 37c Wheel	MPH	V_{OUT} (RMS)	Freq (Hz)
	5	515.5	2933.8	27.2	2.4	0.079	60.8
	6	693.8	3948.6	36.6	3.2	1.21	81.8
	7	863.8	4916.1	45.5	3.9	2.08	101.4
	8	1063.9	6054.9	56.1	4.9	3.03	125.3

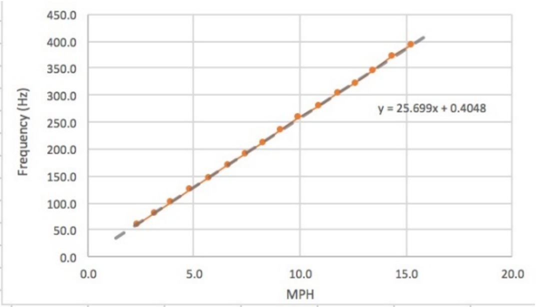
	9	1252.3	7127.1	66.0	5.7	4.02	147.4
	10	1445.0	8223.8	76.1	6.6	5.04	170.5
	11	1624.9	9247.6	85.6	7.4	5.91	190.8
	12	1814.8	10328.4	95.6	8.3	6.66	212.7
	13	2001.0	11388.1	105.4	9.1	7.22	236.3
	14	2177.1	12390.3	114.7	9.9	7.61	257.8
	15	2382.5	13559.3	125.5	10.9	7.85	279.1
	16	2584.7	14710.1	136.2	11.8	7.96	303.8
	17	2760.2	15708.9	145.4	12.6	7.88	322.1
	18	2950.2	16790.2	155.4	13.5	7.88	346.0
	19	3140.0	17870.4	165.4	14.3	7.79	371.0
	20	3340.0	19008.6	176.0	15.3	7.74	391.9

B.1.4 Loaded Dynamo Characteristics-1A

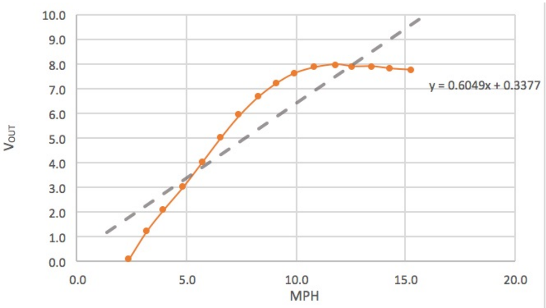
Dynamo Characteristics 1A



Loaded Voltage and Frequency Vs. Bike Speed



Frequency Versus Vs. Bike Speed



Loaded Voltage Versus Vs. Bike Speed

Table 7: Dynamo Characteristics 1A

I_L = 1A	V_{IN}	Flashes/min	RPM Roller	RPM 37c Wheel	V_{OUT} (RMS)	Freq (Hz)
	5	515.5	2933.8	27.2	0.079	60.8
	6	693.8	3948.6	36.6	1.21	81.8
	7	863.8	4916.1	45.5	2.08	101.4
	8	1063.9	6054.9	56.1	3.03	125.3
	9	1252.3	7127.1	66.0	4.02	147.4
	10	1445.0	8223.8	76.1	5.04	170.5
	11	1624.9	9247.6	85.6	5.91	190.8
	12	1814.8	10328.4	95.6	6.66	212.7
	13	2001.0	11388.1	105.4	7.22	236.3
	14	2177.1	12390.3	114.7	7.61	257.8
	15	2382.5	13559.3	125.5	7.85	279.1
	16	2584.7	14710.1	136.2	7.96	303.8
	17	2760.2	15708.9	145.4	7.88	322.1
	18	2950.2	16790.2	155.4	7.88	346.0
	19	3140.0	17870.4	165.4	7.79	371.0
	20	3340.0	19008.6	176.0	7.74	391.9

B.2 Regulation System Verification

B.2.1 Buck Converter Output Characteristic

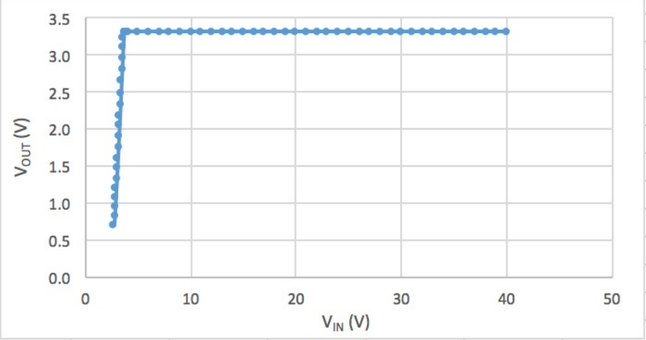


Figure 16: Buck Converter Output Characteristic

Table 8: Buck Converter Data

V in	V out
25.00	3.317
24.00	3.317
23.00	3.317
22.00	3.317
21.00	3.317
20.00	3.317
19.00	3.317
18.00	3.317
17.00	3.317
16.00	3.317
15.00	3.317
14.00	3.317
13.00	3.317
12.00	3.317
11.00	3.317
10.00	3.317
9.00	3.317

8.00	3.317
7.00	3.317
6.00	3.317
5.00	3.317
4.00	3.317
3.80	3.317
3.75	3.317
3.70	3.314
3.65	3.297
3.60	3.229
3.55	3.102
3.50	2.953
3.45	2.798
3.40	2.642
3.35	2.487
3.30	2.33
3.25	2.183
3.20	2.037
3.15	1.891
3.10	1.748
3.05	1.606
3.00	1.466
2.95	1.33
2.90	1.196
2.85	1.059
2.80	0.933
2.75	0.814
2.70	0.699

B.2.2 Regulator Output Characteristic

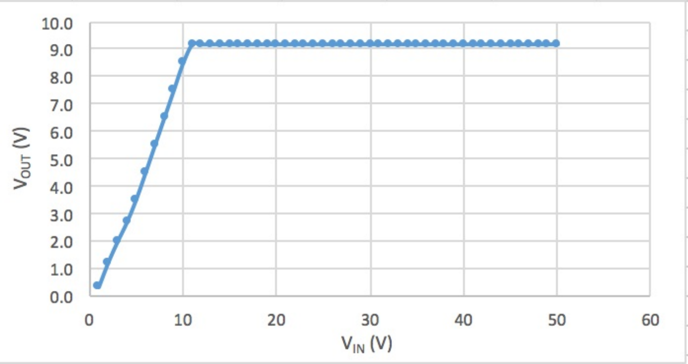


Figure 17: Regulator Output Characteristic

Table 9: Regulator Data

V_{in}	V_{out}
25	9.187
24	9.187
23	9.187
22	9.187
21	9.187
20	9.187
19	9.187
18.0	9.187
17.0	9.187
16.0	9.187
15.0	9.187
14.0	9.187
13.0	9.186
12.0	9.184
11.0	9.185
10.0	8.495
9.0	7.502

8.0	6.506
7.0	5.510
6.0	4.507
5.0	3.534
4.0	2.691
3.0	1.983
2.0	1.216
1.0	0.328

B2.3 Battery Verification

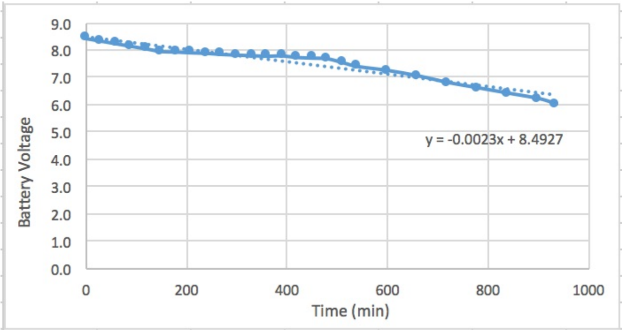


Figure 18: Battery Discharge Characteristic

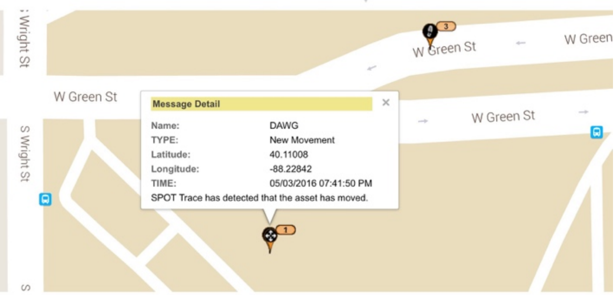
Table 10: Battery Data

Time (minutes)	V_{Out}
0	8.446
30	8.349
60	8.252
90	8.155
120	8.058

150	7.961
180	7.939
210	7.910
240	7.890
270	7.850
300	7.826
330	7.804
360	7.783
390	7.794
420	7.736
450	7.712
480	7.688
510	7.546
540	7.400
600	7.251
660	7.051
720	6.800
780	6.600
840	6.400
900	6.200
935	6.000

B.2.4 GPS Verification

Figure 19: Alma Mater Statue



Message Detail

Name:	DAWG
TYPE:	New Movement
Latitude:	40.11008
Longitude:	-88.22842
TIME:	05/03/2016 07:41:50 PM

SPOT Trace has detected that the asset has moved.

Figure 20: GPS Coordinates

Table 11: GPS Data

Coordinates Real	Coordinates Measured	Error
40.1099° N, 88.2284° W	40°06'36.3"N 88°13'42.3"W	20.41m

Appendix C: Acceleration Detection Code

```
#include "msp430g2553.h"
#include "lcd.h"
#define LED1 BIT0
int itoa(int n, char* out);
void reverse(char* str, int length);
int temp;
char buffer[33];
char buffer2[33];
char buffer3[33];
int itoa(int n, char* out)
{
	// if negative, need 1 char for the sign
	int sign = n < 0? 1: 0;
	int i = 0;
	if (n == 0)
```

```
        {
                out[i++] = '0';
        }
        else if (n < 0)
        {
                out[i++] = '-';
                n = -n;
        }
        while (n > 0)
        {
                out[i++] = '0' + n % 10;
                n /= 10;
        }
        out[i] = '\0';
        reverse(out + sign, i - sign);
        return 0;
}
void reverse(char* str, int length){
        int i = 0, j = length-1;
        char tmp;
        while (i < j)
        {
                tmp = str[i];
                str[i] = str[j];
                str[j] = tmp;
                i++; j--;
        }
}
int main(void)
{
        WDTCTL = WDTPW + WDTHOLD;
        //Stop WDT
        BCSCTL1 = CALBC1_8MHZ;
        //Set DCO to 8Mhz
        DCOCTL = CALDCO_8MHZ;
        //Set DCO to 8Mhz
        P2DIR &= ~0xF0;
        P2DIR |=BIT0;
        P2DIR&=~BIT3;
        // InitializeLcm();  //INITIALIZE LCD
        __delay_cycles(1000000);
        __enable_interrupt();
        int value1;
        int value2;
        int value3;
        char *text;
        while(1)
        {
                ADC10CTL1 = INCH_3 + ADC10DIV_3 ;
                ADC10CTL0 = SREF_0 + ADC10SHT_3 + ADC10ON + ADC10IE;
                ADC10AE0 |= BIT3;
```

```
ADC10CTL0 |= ENC + ADC10SC;
// Sampling and conversion start
__bis_SR_register(CPUOFF + GIE);
 // LPM0 with interrupts enabled
value1 = ADC10MEM;
itoa(value1,buffer);
 /* ClearLcmScreen();
PrintStr("X=");
//DISPLAY ON LCD
PrintStr(buffer);
*/
__delay_cycles(100000); // Wait for ADC Ref to settle
ADC10CTL1 = INCH_4 + ADC10DIV_3 ;
ADC10CTL0 = SREF_0 + ADC10SHT_3 + ADC10ON + ADC10IE;
ADC10AE0 |= BIT4;
ADC10CTL0 |= ENC + ADC10SC;
// Sampling and conversion start
 __bis_SR_register(CPUOFF + GIE);
// LPM0 with interrupts enabled
value2 = ADC10MEM;
itoa(value2,buffer2);
/*   ClearLcmScreen();
 PrintStr("Y=");
//DISPLAY ON LCD
PrintStr(buffer2);
 */
__delay_cycles(100000);
ADC10CTL1 = INCH_5 + ADC10DIV_3 ;
ADC10CTL0 = SREF_0 + ADC10SHT_3 + ADC10ON + ADC10IE;
ADC10AE0 |= BIT5;
ADC10CTL0 |= ENC + ADC10SC;
// Sampling and conversion start
__bis_SR_register(CPUOFF + GIE);
// LPM0 with interrupts enabled
value3 = ADC10MEM;
itoa(value3,buffer3);
/* ClearLcmScreen();
PrintStr("Z="); //DISPLAY ON LCD
PrintStr(buffer3);
*/
__delay_cycles(100000);
if((value>400)||(value2>400)||(value3>400))
{
        //P1DIR=0X0041;
        P1DIR &= ~0xF0;
        // set pin direction for led
        P1DIR |= BIT0;
        P1DIR |= BIT7;
        //P1DIR &= (~BIT6);
        P2DIR &=(~BIT0);
}
```

```
		}
}
// ADC10 interrupt service routine
#pragma vector=ADC10_VECTOR
__interrupt void ADC10_ISR (void)
{
		__bic_SR_register_on_exit(CPUOFF);
		// Return to active mode
}
```