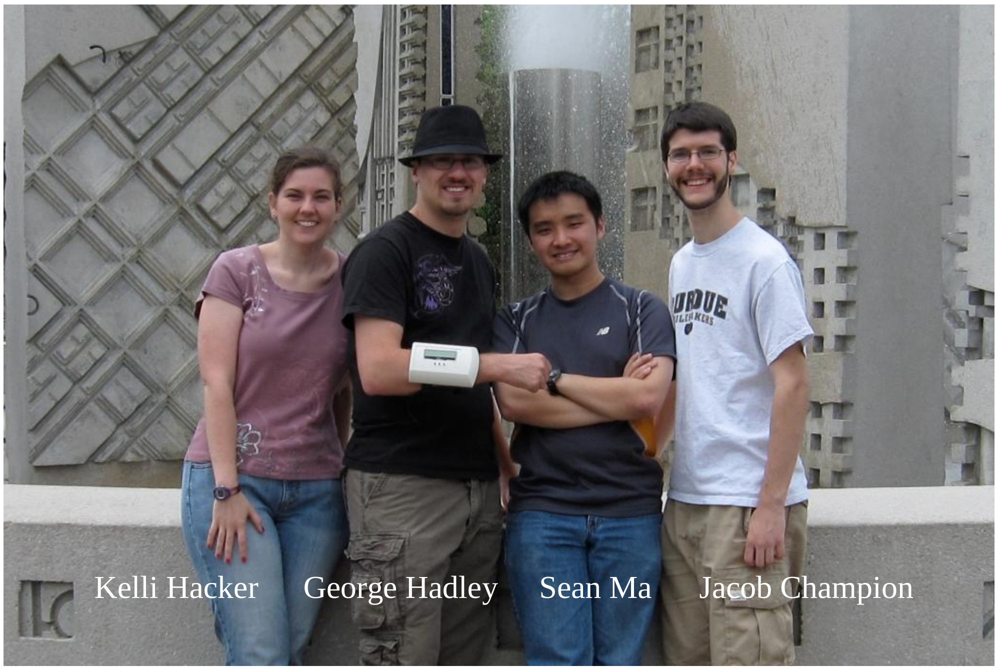
ECE 477 Final Report – Spring 2010
Team 3 – The Gauntlet



Team Members:

#1: George Hadley **Signature:** ____________ **Date: 5/07/10**

#2: Sean Ma **Signature:** ____________ **Date: 5/07/10**

#3: Jacob Champion **Signature:** ____________ **Date: 5/07/10**

#4: Kelli Hacker **Signature:** ____________ **Date: 5/07/10**

CRITERION	SCORE	MPY	PTS
Technical content	0 1 2 3 4 5 6 7 8 9 10	3	
Design documentation	0 1 2 3 4 5 6 7 8 9 10	3	
Technical writing style	0 1 2 3 4 5 6 7 8 9 10	2	
Contributions	0 1 2 3 4 5 6 7 8 9 10	1	
Editing	0 1 2 3 4 5 6 7 8 9 10	1	
		TOTAL	

Comments:

TABLE OF CONTENTS

Abstract

The Gauntlet is an arm-wearable device which provides snowsports enthusiasts with real-time information - current velocity, temperature, altitude, and airtime - via headphone audio. In addition, it has an "emergency mode" which uses GPS to navigate the user back to a programmable safe location. The device is powered by a lithium polymer battery which is monitored and recharged in-circuit. The Gauntlet has a target battery life of ten hours, so its components have been selected to be low-power, and the device will be operational in subfreezing temperatures. This report includes descriptions of the design and creation of the Gauntlet, as well as several analyses of the product in the context of the environment, the patent system, ethics, reliability, and safety.

1.0 Project Overview and Block Diagram

The Gauntlet has two primary operating modes – a “normal mode” which communicates a user’s velocity, temperature, altitude, and airtime over the user’s headphones, and an “emergency mode” which navigates the user back to an initial safe point if the user becomes lost. The user interacts with the Gauntlet using a character LCD and three pushbuttons, shown in Figure 1-1, which display and control a menu-based user interface. The user can change preferences such as headphone volume and audio output timing. Important information such as preferences, battery information, and the GPS waypoint path are saved to persistent microSD storage.

Figure 1-1: The Gauntlet

Internally, the Gauntlet can be divided into four main subsections: central control, environmental sensors, user interface, and power. The block diagram in Figure 1-2 shows these subsections and how they interface to one another. The central control, consisting of a PIC24F microcontroller and Flash storage, coordinates each subsection and provides overall control for the Gauntlet. The user interface includes pushbuttons, an LCD, and the audio output circuitry. Environmental sensors consist of a GPS unit (to provide location and velocity information), a combination pressure sensor/thermometer (providing altitude and temperature), and an accelerometer (to provide airtime measurements). Power includes a rechargeable lithium-polymer battery, its charger and monitor, a buck-boost converter to provide power to the rest of the circuit, and a shutdown control to protect against battery undervoltage.

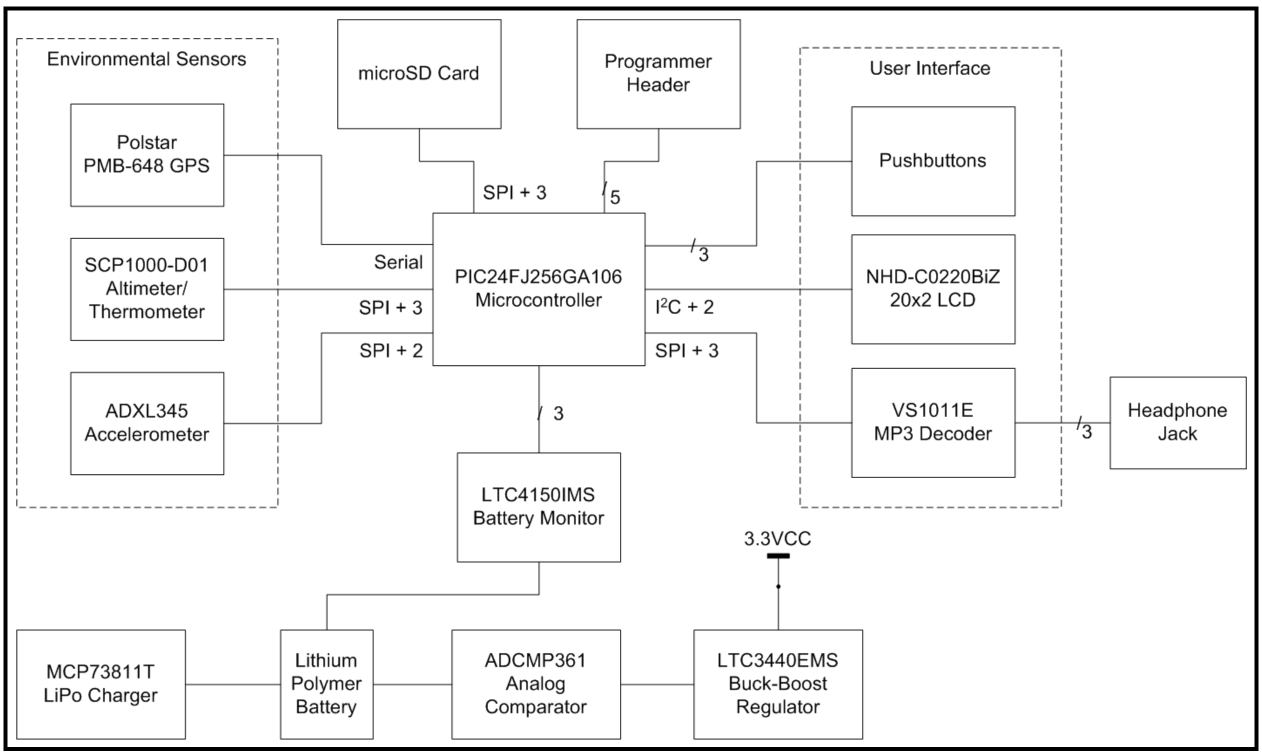


Figure 1-2: System Block Diagram

2.0 Team Success Criteria and Fulfillment

The Project Specific Success Criteria for the Gauntlet are as follows:

1. An ability to communicate sensor data via audio to the user
2. An ability to recharge and monitor an on-board battery
3. An ability to determine current location via GPS

4. An ability to direct the user to a "safe" waypoint
5. An ability to save acquired data to persistent storage

Each of these five PSSCs was satisfied. The Gauntlet communicates airtime, altitude, temperature, and current velocity over a pair of standard headphones. A lithium-polymer battery is charged, protected, and monitored by several onboard components, and the Gauntlet can relay the current battery status to the user using the character LCD. A Polstar PMB-648 GPS receiver provides the user's current longitude and latitude, and the Gauntlet is able to use this information to provide a "compass arrow" pointing back along the path to the initial safepoint during navigation. Finally, battery, waypoint, and preference information are saved to an onboard microSD card during operation.

3.0 Constraint Analysis and Component Selection

3.1 Design Constraint Analysis

Because the Gauntlet is a wearable device, form factor is important. Very few large components could be chosen; those components that are larger modules need to be low-weight so that the device is comfortable to wear. The entire printed circuit board must be small enough to fit easily on an arm, and the components chosen needed to be durable enough to survive falls by the user. Because the device is battery-powered, most components need to have low power consumption. Finally, because the device is designed to be worn while skiing or snowboarding, it is very important that each component can operate at temperatures below freezing. Our team has been very careful to select components that are operational to a minimum of -20°C.

3.1.1 Computation Requirements

The Gauntlet receives GPS data – including current position, horizontal velocity, and a rough estimate of altitude – once every second. Combined with the more precise altimeter data from the pressure sensor, the microcontroller needs to calculate downhill velocity for presentation to the user, which requires trigonometric functionality. The onboard accelerometer must be periodically polled for jump and crash conditions, and the pressure sensor provides on-demand temperature and altitude information. In emergency mode, the microcontroller needs to navigate the user though a series of GPS waypoints, which again requires trigonometric computation. Finally, audio samples need to be buffered into memory from a microSD card and streamed to the audio controller during an audio output routine.

Of these requirements, only the streaming audio is time-critical. This requires a minimum throughput to present acceptable audio quality. All other computations can be done on demand from the user, so small delays will be acceptable.

3.1.2 Interface Requirements

The Coulomb counter used for battery life monitoring requires three pins to function – one for a periodic count pulse, one for the count polarity (charging vs. discharging), and one for a digital reset. Three pushbuttons interface to the microcontroller to allow the user to select an operating mode for the Gauntlet. Because the microcontroller has a limited number of onboard SPI peripherals, two GPIO chip selects are required to multiplex the accelerometer and altimeter/thermometer ICs. Two pins are required to use the accelerometer's free-fall and motion interrupt support, and two pins are required to signal an altitude measurement and receive a measurement interrupt from the onboard altimeter. One pin is needed to shut down the LCD for low power consumption. Finally, one pin is needed to shut down the audio decoder when its capabilities are not needed by the system. In total, the microcontroller requires fourteen GPIO pins for its interfaces.

3.1.3 On-Chip Peripheral Requirements

The Gauntlet's off-chip peripherals require a minimum of three SPI interfaces – one each for the audio decoder and microSD card, and one for the altimeter and accelerometer to share. (Because the sensor data is not time-critical, the altimeter and accelerometer can be multiplexed. This will require two GPIO pins for use as chip selects.) An I2C bus is required for the low-power LCD, and the GPS unit requires a UART for serial communication. In total, our peripherals require a minimum of one I2C bus, three SPI interfaces, and one UART on our microcontroller.

3.1.4 Off-Chip Peripheral Requirements

The off-chip sensor requirements for the Gauntlet are as follows: one GPS receiver module, one absolute pressure sensor and thermometer, a three-axis accelerometer, and a Coulomb counter for the lithium polymer battery. The user interface requires three pushbuttons, an MP3 decoder, and an I2C LCD, which are described in detail below. Finally, a microSD card is used for storing read-only audio and user-defined GPS/altitude waypoints. No other glue logic or off-chip peripherals are needed.

3.1.5 Power Constraints

Our armband is powered by an onboard rechargeable battery pack. Because of this, low-power peripherals are paramount to usability. The Gauntlet has a target battery life of ten hours, so most of our off-chip peripherals need to either have a low-power mode or have the ability to be turned off by the microcontroller when not needed. Also, our power regulation circuit will need to be highly efficient. This implies that very few of our chips will be dissipating a lot of power, but since the Gauntlet is small package strapped to the arm of the user, it is important to keep the operating temperature down.

3.1.6 Packaging Constraints

The Gauntlet is unobtrusive enough to wear on the arm. This means that it is small enough not to interfere with a skier/snowboarder's arm movements while on the slope. The device needs to be no more than a few centimeters thick and be no longer or wider than a "below-average" upper arm. Also, it weighs five ounces or less; to ensure that it can be comfortably strapped to the user. The Gauntlet needs to be durable enough to survive a hard fall onto packed snow or ice without injuring the user or becoming damaged.

3.1.7 Cost Constraints

The closest competitor to the Gauntlet appears to be the Flaik snowsports armband (described in detail in [1]). Unfortunately, there appears to be no readily available pricing information for the Flaik – it needs a resort-wide network to work, so Flaik systems are not sold to the general public. It seems likely that an armband such as the Flaik would run at least $200-300 if sold individually. Similarly, GPS-enabled armbands and wristwatches for runners tend to cost approximately $300. The Gauntlet needs to be priced in this range to be competitive.

3.2 Component Selection Rationale

3.2.1 Altimeter

The two pressure sensors which were considered for use on the microcontroller were VTI's SCP1000-D01 [2] and Freescale's MPXA6115 [3]. The SCP1000 is an extremely low-power (down to 3.5 uA at 3.3V) absolute pressure sensor with up to 9 cm of altitude resolution. It communicates via a SPI bus and does all analog-to-digital conversions internally. Conveniently, it also houses an accessible onboard thermometer. The MPXA6115 is an analog pressure sensor which uses significantly more current (4 mA) and would require at least a 17-bit

ADC to get the resolution that the SCP1000 provides. Its main selling point was its packaging – whereas the SCP1000 is housed in an incredibly small circular package, the Freescale chip is a much more manageable SSOP – but the SCP1000 became the clear choice once a breakout board was discovered.

3.2.2 Accelerometer

The Bosch BMA150 [4] and the Analog ADXL345 [5] were excellent candidates for the onboard three-axis accelerometer. Both are low-power (200 uA or below at 3.3V) and interface to a microcontroller over SPI, while providing high sensing resolution. The ADXL345 has an advantage in that it provides free-fall and motion interrupt support while using less power than the BMA150. Also, the ADXL345 has an available breakout board solution, whereas the BMA150 has an extremely small 3x3mm LGA package. For these reasons, we chose the former IC.

3.2.3 Audio Decoder

For the onboard audio decoder, the main competitors were VLSI's VS1011e [6] and STMicroelectronics' STA013 [7]. Both chips are streaming MP3 decoders which operate on low voltage (3.3V) and current (50 mA for the VS1011e; 30 mA for the STA013). In addition to MP3 decoding, the VS1011e can also decode WAV files, giving us some added flexibility. It also houses an on-chip headphone driver, which reduces the amount of circuitry needed to present audio to the user. The STA013, in contrast, requires an off-chip DAC. Because both are evenly priced, and the VS1011e is a one-chip solution, we chose the VS1011e despite its higher current draw.

3.2.4 GPS

Parallax's Polstar PMB-248 and PMB-648 [8] were the only two GPS modules that received true attention from our group. In addition to being reasonably priced and fairly low-power, they both require no external circuitry or RF design, and one team member has experience working with Polstar modules. The PMB-648 is slightly more expensive, but its chipset is more reliable and provides faster fix times, so we chose it over its brother.

3.2.5 Microcontroller

The two microcontrollers examined by our team were the Microchip PIC24FJ256GA106 [9] and the Atmel ATXMEGA256A1 [10]. Both are clocked at a maximum of 32 MHz (though the PIC has half the throughput of the ATX), have 256K of Flash and 16K of RAM, and are operated at low current. Both meet the peripheral and general-purpose interfacing requirements stated above, and each microcontroller has floating-point libraries available for it. The PIC is a 16-bit processor, while the ATX is an 8-bit device, but the ATX gives one more SPI interface and fifteen more I/O pins. The ATX is also approximately $5 more expensive than the PIC, which sells for four dollars. Because both chips met our minimum requirements, the PIC IC has a smaller package, and one team member has extensive experience with PIC microcontrollers, it was decided that the Microchip PIC will do nicely for the Gauntlet.

3.3 Summary

The Gauntlet does not perform time-critical calculations, so its peripheral requirements are modest: a handful of general I/O pins, three SPI interfaces, an I2C bus, and a UART are all that are needed for the microcontroller to do its work. Components were chosen for their small form factor, low current consumption, cold-weather operation, and ease of use. Because of these design choices, the Gauntlet can be used comfortably for long periods of time, providing maximum enjoyment for the user.

4.0 Patent Liability Analysis

Key hardware features of the Gauntlet include GPS waypoint navigation, an audio interface, an accelerometer and altimeter, and SD Card storage. In addition, the Gauntlet features a number of important software features, including the use of GPS and accelerometer data for the calculation of slope grade and downhill velocity, the use of accelerometer data for recording airtime, and the conveyance of information to the user through the use of an audio interface. There are a number of patent liability issues here, such as patents issued for GPS navigation devices such as Garmin car navigation systems, but due to the prevalence of prior art with GPS technology and GPS being contained in the public domain, patent liability is not expected to present serious problems for the Gauntlet project.

4.1 Results of Patent and Product Search

4.1.1 Route Based on Distance [11]

Patent No.: 7,627,423

Filed: March 10, 2005

Condensed Abstract:

The patent describes systems, methods, and a device for generating a route based on distance. An example provided by the patent is software instructions to receive a distance input and generate a route based on the distance input.

Key Claims:

Claim 1: “A portable electronic device for generating a running route, comprising: a global positioning system (GPS) receiver; a processor; a memory in communication with the processor; and program instructions storable in memory and executable by the processor to receive a distance input and to generate a running, route that begins at a starting location and ends at the starting location, and to receive location information from the GPS receiver to track the portable electronic device along the running route, wherein the running route has a length substantially equal to the distance input, and wherein the running route includes an off-road portion.”

Claim 9: “A portable electronic system for generating a running route, comprising: a first computing device connectable to a network, wherein the first computing device includes: a global positioning system (GPS) receiver; a processor; a memory in communication with the processor; a display in communication with the processor and memory; and program instructions storable in memory and executable by the processor to receive a distance input and to generate a running route that begins and ends at a starting location, and to receive location information from the GPS receiver to track the device along the running route, wherein the running route has a length substantially equal to the distance input and is generated based on a selectable set of criteria and a selectable rating factor associated with a particular criteria, and wherein the running route and device location are graphically represented on the display.”

Claim 23: “The system of claim 9, wherein the device is a portable handheld device attachable to another physical object.”

Claim 25: “The system of claim 24, wherein the training log includes elevation information associated with the running route.”

4.1.2 Navigation device, method, and program [12]

Patent No.: 7,565,240

Date Filed: November 28, 2005

Condensed Abstract:

The patent describes a navigation device capable of storing user-selectable waypoints and using waypoint information to guide the user from an initial waypoint to a destination waypoint.

Key Claims:

Claim 1: “A navigation device for providing guidance from a user's current location to a set destination waypoint, characterized by comprising: destination waypoint setting means for setting a destination waypoint; history storing means for storing positional information on destination waypoints and the latest dates when the stored destination waypoints were used for guidance therein; storage controlling means in response to an instruction for guidance start to the set destination waypoint, for checking the history storing means if the set destination waypoint is already stored in the history storing means, if yes, renewing the latest date (S7) for the set destination waypoint in the history storing means and if not, storing positional information on the set destination waypoint in the history storing means at a predetermined timing (S9); displaying means for displaying the positional information stored in the history storing means; and destination waypoint selection means for selecting a destination waypoint with referring to the displayed positional information.”

Claim 4: “A navigation device for providing guidance from a user's current location to a set destination waypoint, characterized by comprising: destination waypoint setting means for setting destination waypoints; history storing means for storing positional information on the set destination waypoints therein; storage controlling means for storing positional information on destination waypoints in the history storing means at a predetermined timing when destination waypoints are set by the destination waypoint setting means and guidance starts; displaying means for displaying the positional information stored in the history storing means; and destination waypoint selection means for selecting a destination waypoint with referring to the displayed positional information, further characterized in that the predetermined timing refers to a timing when a predetermined time has passed since guidance started for the set destination waypoint and the history storing means determines whether the predetermined time has passed and stores positional information on the set destination waypoints therein.”

4.1.3 Flaik Sports Armband (Commercial Product) [13]

The Flaik sports armband is a handheld navigation device designed for sports enthusiasts. It features a GPS device and allows snowsports enthusiasts to track their movements over the course of their skiing and snowboarding trips. It also features radio communication capability to track other users, such as a ski instructor tracking his or her ski school students for the day.

4.2 Analysis of Patent Liability

4.2.1 Route Based on Distance (Patent No.: 7,627,423)

The Gauntlet has a number of similarities to features of the device mentioned in this patent, in particular the use of elevation data in conjunction with the GPS and the idea of a personal navigation device that tracks one's movements. This patent seems to be focused on a personal GPS for running and training purposes, and is in this way fundamentally different from the Gauntlet. The possibility for patent infringement may exist here, and precautionary steps should be taken to minimize patent infringement liability.

4.2.2 Navigation Device, Method, and Program (Patent No.: 7,565,240)

This patent appears to lay out the framework for a standard navigational device, and the Gauntlet seems to infringe on this patent in a number of ways, such as by saving waypoints to memory and guiding the user from one waypoint to another. This patent appears to be written for vehicular navigational devices, such as Garmin GPS units that have become ubiquitous in many cars. Nonetheless, potential for patent infringement does exist here, and action may need to be taken to minimize patent infringement liability.

4.2.3 Flaik Armband

The Flaik armband is a commercial product, though no patents related to the device are known at this time. Both the Gauntlet and the Flaik share certain fundamental characteristics, such as the use of a GPS unit in a wearable form factor and the application to winter snowsports. However, aside from this basic similarity, the systems are not particularly alike, the Flaik adding in radio tracking capability to track users of the armband while the Gauntlet has an audio interface to communicate information to the user. Therefore, it is believed that infringement is unlikely, as the use of GPS is in the public domain.

4.3 Action Recommended

4.3.1 Route Based on Distance (Patent No.: 7,627,423)

This patent uses terminology and examples that suggest it is intended for use as a personal running device, but could be considered infringing with the Gauntlet on the basis of doctrine of equivalents. That said, the patent may be able to be challenged for being trivial, as it appears to be a logical extension of traditional GPS technology. Otherwise, however, the patent may need to be licensed.

4.3.2 Navigation Device, Method, and Program (Patent No.: 7,565,240)

The potential for patent infringement certainly exists with this patent, which covers a broad and overreaching field of technology infringeable under doctrine of equivalents. That said, however, the patent could be challenged on the grounds that it is not novel, based on prior art in the field. Failing at this, however, the patent may need to be licensed.

4.3.3 Flaik Armband

Potential for patent infringement seems unlikely based on current knowledge, so no current actions need to be performed to minimize patent infringement liability.

5.0 Reliability and Safety Analysis

The safety of the user is a critical issue. User safety could be compromised by proximity to the device, because the user is more likely to be seriously injured if something happens to the Gauntlet, and by the use of lithium-polymer batteries. Functionality is dependent on communication with several sensors, creating a critical reliability issue.

5.1 Reliability Analysis

Components in the Gauntlet are most likely to fail due to either complexity or heat. The most complex parts are the PIC24FJ256GA106 microcontroller and the VS1011E MP3 decoder. The PIC24 is a complex component with 64 pins, and the VS1011E is a complex component which includes a DSP processor and a digital to analog converter, in addition to 48 pins, 33 of which are functional. The LTC3440 buck-boost converter and MCP73811 charge manager will have to dissipate the most power and will be the hottest components on the Gauntlet, making them more likely to fail.

The <u>Military Handbook – Reliability Prediction of Electronic Equipment</u> [14] was used to calculate the number of failures per million hours, λ_p, and mean time to failure (MTTF) for each component. The microprocessor model was used to analyze the PIC24 and the VS1011E. The average junction temperature of the PIC24 was determined to be 50ºC from the datasheet [9]. The VS1011E is an MP3 decoder, but it contains a 16/32 bit DSP, so the model of a 32 bit microprocessor was used for die complexity [6]. Linear microelectronic models were used to analyze the LTC3440 and MCP73811. Because the LTC3440 might be operating at high temperatures, the maximum junction temperature of 125ºC was used to determine the temperature factor π_T [15]. A junction temperature of 105ºC, found on the MCP73811 datasheet, was used in calculations for the charge manager [16].

PIC24 $\lambda_p = (C_1 * \pi_T + C_2 * \pi_E) * \pi_Q * \pi_L$

Parameter name	**Description**	**Value**	**Comments**
C_1	Die Complexity	0.28	16 bit microcontroller
π_T	Temperature Factor	0.29	T_J = 50ºC, Digital MOS
C_2	Package Failure Rate	0.025	Hermetic SMT, 64 pins
π_E	Environment Factor	4.0	Ground Mobile
π_Q	Quality Factors	10.0	Commercial product
π_L	Learning Factor	1.0	In production for > 2 years, since 2008
Entire design:		λ_p = 1.812	MTTF ≈ 63 years

VS1011E – MP3 Decoder $\lambda_p = (C_1 * \pi_T + C_2 * \pi_E) * \pi_Q * \pi_L$

Parameter name	**Description**	**Value**	**Comments**
C_1	Die Complexity	0.56	16/32 bit core VSDP processor (used 32 bit)
π_T	Temperature Factor	0.29	T_J = 50ºC, Digital MOS
C_2	Package Failure Rate	0.013	Hermetic SMT, 33 functional pins (used 36 pins)
π_E	Environment Factor	4.0	Ground Mobile
π_Q	Quality Factors	10.0	Commercial product
π_L	Learning Factor	1.0	In production for > 2 years, since 2005
Entire design:		λ_p = 2.144	MTTF ≈ 53 years

LTC3440 – Buck-Boost $\lambda_p = (C_1 * \pi_T + C_2 * \pi_E) * \pi_Q * \pi_L$

Parameter name	**Description**	**Value**	**Comments**
C_1	Die Complexity	0.01	Linear, less than 100 transistors
π_T	Temperature Factor	58	T_{Jmax} = 125ºC, Linear
C_2	Package Failure Rate	0.0034	Hermetic SMT, 10 pins
π_E	Environment Factor	4.0	Ground Mobile
π_Q	Quality Factors	10.0	Commercial product
π_L	Learning Factor	1.0	In production for > 2 years, since 2001
Entire design:		$\lambda_p = 5.936$	MTTF ≈ 19 years

MCP73811 - Charger $\lambda_p = (C_1 * \pi_T + C_2 * \pi_E) * \pi_Q * \pi_L$

Parameter name	**Description**	**Value**	**Comments**
C_1	Die Complexity	0.01	Linear, less than 100 transistors
π_T	Temperature Factor	21	T_{Jmax} = 105ºC, Linear
C_2	Package Failure Rate	0.0019	Hermetic SMT, 5 pins (used 6 pins)
π_E	Environment Factor	4.0	Ground Mobile
π_Q	Quality Factors	10.0	Commercial product
π_L	Learning Factor	1.0	In production for > 2 years, since 2007
Entire design:		$\lambda_p = 2.176$	MTTF ≈ 53 years

The failure calculations above are an initial cause for some concern because they are all above the recommended value of one failure per 1 million hours. However, upon further analysis, some of these concerns are mitigated. Using 10 as a quality factor for commercial components is probably excessive given the standards of manufacturing today. The use of a lower quality factor such as 5 would dramatically reduce the estimated failure rates and create a more accurate model. Other conservative estimations for individual components could also make the model more accurate and decrease the estimated failure rate. The worst case of 32 bits was used for die complexity for the VS1011E, with a junction temperature of 50ºC. The die complexity is probably slightly lower, and given its outdoor winter application, the junction temperature could easily be lower, lowering the overall failure rate. In addition, the worst case junction temperature was used in calculations for the LTC3440. Also, a die complexity for between 1 and 100 transistors was used, although the LTC3440 model shows four transistors, which would lower complexity considerably [15]. The LTC3440 needs to dissipate power, so adding a heatsink may need to be considered to increase safety and reliability. The MCP73811 model includes six transistors, even though the die complexity value used is for up to 100 transistors [16]. Lowering this complexity value may increase reliability, and adding a heatsink may be considered for the linear charger.

5.2 Failure Mode, Effects, and Criticality Analysis (FMECA)

The main functional blocks of the Gauntlet schematic are shown in Appendix C. The functional blocks are the power, microcontroller, audio, and sensors and user interface. The memory is included in the microcontroller functional block. A Failure Mode, Effects, and Criticality (FMECA) analysis was performed for each functional block and is shown in Appendix F.

Criticality levels of high, medium, and low are used in the FMECA analysis. High criticality is reserved for when a failure could cause harm to the user, and its failure rate should be below 1 failure in 10^9 hours of operation. Medium criticality is used when a failure could result in major irreparable circuit damage. The failure rate of medium criticality failures should be below 1 failure in 10^7 hours of operation. Low criticality covers failures which do not cause harm to the user or irreparable circuit damage. Failure rates should be below 1 failure in 10^6 hours of operation for a low criticality failure.

5.3 Summary

The Gauntlet is a reliable and safe device overall. However, a few design changes may need to be considered to increase safety and reliability in future iterations. Adding a low-pass filter to reduce switching noise to the analog comparator or changing resistor values to increase the safety margin will decrease the likelihood of battery failure, increasing the safety of the user. Currently, any device failure, while unlikely, may render the Gauntlet useless. Reliability may be increased by adding redundancy and increasing the robustness of the design. However, the current design should be reliable for several years.

6.0 Ethical and Environmental Impact Analysis

The design of the Gauntlet brings about several ethical and environmental issues that need to be addressed before being put to market, such as the possibly environmentally harmful manufacturing of the components, the non-biodegradable nature of the device, and the implications of its functionality.

6.1 Ethical Impact Analysis

There are many ethical implications for the Gauntlet that need to be addressed before it can be marketed. The first is that the device must be safe for the average user to carry around and use, as covered in the Reliability and Safety Analysis. As noted in the aforementioned analysis, the Gauntlet is a relatively safe device overall, with most of its components being low-power with not much impact on the user, so the prime example of a possibly harmful component would be the lithium-polymer battery. An under-voltage of the battery (such as from the battery discharging too much) could cause it to expand and possibly explode, which would cause injury to the user. An over-voltage (such as from a short circuit somewhere in the board) could result in fire and an explosion, which would also cause injury to the user. Given these highly critical problems, aside from the precautions mentioned in the previous report, all of the operating conditions that the Gauntlet will likely be exposed to must be tested so that this event is virtually impossible. For further preventative measures, warning labels will be put into the user manual and on the device itself to prevent users from improperly using the device. For example, we would warn the user not to store the device in an extremely hot environment, and to only charge the device using the given DC power jack, as a voltage that is too high may burn the board or cause the aforementioned explosion.

The Gauntlet is meant to be a helpful tool for its users to bring for their outdoor activities. This means that the device must be able to function fully while the user is skiing at a relatively high velocity down a snow-covered slope. While the activity itself carries risk to the user, the Gauntlet must in no way be the cause of such risk. An example would be if the audio malfunctioned, and simply released a noise that would distract the possibly very concentrated user from avoiding the potential obstacles on a ski slope. To mitigate this, thorough testing of the audio circuitry and software will need to be conducted in order to make sure that whatever is released on the user's headphones will be exactly what the user wants to hear, and that the output sound is of a reasonable pitch so that it doesn't distract the user.

Another example would be to design around the conditions that the Gauntlet will be in. It is very likely that the user will fall, and the Gauntlet will be put under a lot of stress and strain. In this case, our packaging must be durable enough to handle such impact and keep the components safe from harm. This includes the strap that holds the device on the user's arm, since the user will likely have a hard time keeping the Gauntlet on their arm as they perform their outdoor activities, and a natural reflex is to try and catch the device when it falls. This could cause the user serious injury if this happens during a run downhill. Another example would be that the device must work under moist conditions. This can be accomplished using some proper sealing of the electronic components in the case.

The most crucial function on the device that needs attention is the emergency mode. The Gauntlet's emergency mode is supposed to lead the user back to a safe point by retracing a path that has been recorded before. This function is put in so that, when the user is lost, they can activate this mode as a guide back to safety. At this point, the user will be entirely dependent on the Gauntlet to perform its function fully and reliably. This has many implications to the design. The algorithm used to trace a path back to the safe point must be solid enough so that it can reliably retrace its steps back to the starting point. It should, under no circumstances, lead the user away from safety. The device must remain low-power enough for the battery to last; otherwise the Gauntlet may simply stop working in the middle of leading the user back to safety. Several components will play a major role in the emergency mode: The GPS will determine current position and heading, the microSD card will be where the waypoints are stored, and the LCD and audio will be the main interfaces to tell the user where to go. Because the user is depending on the device to lead them to safety, each component needs to be in full working condition under virtually any circumstance. Extensive testing under extreme conditions must be done on retrieving information from both the GPS and from memory, and relaying the information through the audio and visual components of the device, so that in the worst case, the Gauntlet will still lead the user back to a safe place.

6.2 Environmental Impact Analysis

The environmental impact of the Gauntlet is a major concern in designing that must be addressed before mass-production. The device is made up of many different components, each of which must, ideally, follow a set of rules to be environmentally friendly. The vast majority of components selected for the device are RoHS compliant, which means that they do not contain any hazardous substances as outlined in the RoHS standard, which includes mercury, lead, cadmium, hexavalent chromium, polybrominated biphenyls, and polybrominated diphenyl ethers [17].

The manufacturing of the PCB releases toxic chemical into the environment, and we use leaded solder to secure our parts. Unfortunately, there is no alternative to the manufacturing process. In the future, “green” PCB’s may be looked into, but for this project, this could not be a concern due to there being no good alternative. Lead-free solder can be used as an alternative to the leaded solder, but it was not a large concern of this project, but there was none readily available for the design of the Gauntlet.

The LCD is the first concern in terms of the environmental impact of the Gauntlet where there was an actual design consideration. A chemical known as Nitrogen Trifluoride (NF_3) is used during the manufacturing of LCD displays. Nitrogen Trifluoride is considered a “missing greenhouse gas” and is approximately 17,000 times more potent than CO_2 as a contributor to global warming, and will stay in the atmosphere for an estimated 550 years [18]. Given time, a more environmentally friendly LCD may be used as a replacement, but such an LCD has not yet been found, considering that NF_3 as a chemical is already an improvement over its predecessor, perfleurocarbon, another potent greenhouse gas, which will stay in the atmosphere for over 10,000 years [18]. Thus, there are currently no better alternatives to this chemical in the manufacturing of the LCD.

The Gauntlet is mostly low-power, and uses a small rechargeable battery, so during the use of the device, there will be very little environmental concern. The device in full use will consume approximately 0.84W of power at maximum voltage (4.2V) and current (200mA), which will not be significant even when charging.

Another possible concern is the battery. The battery in the Gauntlet is a rechargeable Lithium-Polymer battery. Although for the most part environmentally friendly, if the battery is not disposed of properly (i.e. thrown into a landfill and incinerated), it could prove hazardous to the environment [19]. The best way to prevent this that can be done at the prototyping stage is to make sure the battery lives for as long as possible without having to replace it. This is impossible in practice, so a possible buy-back program may be implemented so that the batteries can be recycled properly for monetary compensation. Another way to increase the battery life is to indicate the time to recharge the battery to the user so as to maximize battery life. Also, instructions about battery disposal could be included in the user manual, as there are ways to make the battery “landfill safe”.

Finally, the packaging for the Gauntlet is in a non-biodegradable plastic case. Again, the disposal of the case is of concern. OKW Enclosures created the case from recycled plastics, and therefore, the plastic case is recyclable as well. The buy-back program mentioned above may also be implemented to motivate users to give their products to be recycled.

7.0 Packaging Design Considerations

Being designed for skiers and snowboarders, the packaging of the Gauntlet needs to fulfill several requirements. Because the design of the device is to make it wearable on the forearm, the weight and size of the package were taken into consideration. The material must be light enough that the device will not cause any strain on the user while they are engaging in their activities, and small enough to fit comfortably over their arm without any problems. Also, due to the Gauntlet's intended use and target demographic, the packaging must also be sturdy enough to protect the delicate electronic components inside from any crashes or falls.

7.1 Commercial Product Packaging

During the search for commercial products that could be compared to the Gauntlet, we found one competitor in the Garmin Foretrex Series, and one product that is similar in terms of packaging and demographic: the Flaik Snow Sports Armband. Both are wearable devices designed for outdoor enthusiasts that relay information. The Foretrex Series is designed for runners, however, and the Flaik has a very different usage from the Gauntlet, being more of a tracking device so that lost skiers can be found easier.

7.1.1 Product #1: The Garmin Foretrex Series

The Garmin Foretrex Series is a series of wearable GPS devices for hikers, skiers, and kayakers. It is designed to be worn on the wrists, while the Gauntlet is designed to be worn on the forearm. In terms of functionality, it is very similar to the Gauntlet in that it uses a GPS to store waypoints and keep track of its user's position [20].

The packaging of the Foretrex is very small. It is designed to be worn like a wristwatch, and thus, has about the same weight as one. The embedded system is strapped to the user's wrist using a Velcro band. Much of the space is taken up by the monochrome LCD screen which displays a path from where the user had been. The Gauntlet's LCD screen will only display characters, due to most of the information being relayed through audio.

The Foretrex, while having a small, very portable package, does not need to withstand the force that the Gauntlet will, due to the target consumers of the latter having to use the product while actually doing their winter sport activities. The LCD screen will not be needed, as the users will more likely need to look in front of them when the device is in use. The package of the Gauntlet will be slightly larger to fit better onto the forearm, and to keep all of the components inside safe from impact.

Figure 7-1: The Garmin Foretrex 301

7.1.2 Product #2: The Flaik Armband

The Flaik Armband is designed for snowboarders and skiers just like the Gauntlet. It also keeps track of its wearer's velocity, GPS position, and altitude [21], similar to the Gauntlet. However, unlike the Gauntlet, which relays real-time information to the user, the Flaik relays information to a server in order to keep track of all of the snowboarders and skiers on the mountain, as well as to record the users' performance on the mountain.

The packaging for the Flaik is small, about the size of a cellular phone, and is worn on the upper arm. The actual Flaik is in a plastic enclosure that is separate from the band itself, as shown in Figure 7.2 below. Unlike the Gauntlet, the Flaik has no need for a human interface. It only needs to relay information to a server, and the user can access it later, whereas the Gauntlet needs to send the information instantly. Because the Flaik does not have the human-interface needs of the Gauntlet, its packaging can afford to be much smaller.

Figure 7-2: The Flaik Snow Sports Armband

7.2 Project Packaging Specifications

The packaging used for the Gauntlet is the OKW Ergo-Case plastic enclosure [22]. The case itself is designed to be worn on the forearm, as shown in Figure 7-3. Because the material is plastic, it fits the “lightweight but sturdy” criterion that is needed for the Gauntlet to perform its functions without hindering the user. The ergonomic design of the enclosure ensures that the user can wear it on their arm without any discomfort, and there is plenty of room inside the case for the components that were selected previously.

The character LCD screen was placed at the approximate center of the top of the case so that the user can see it without much trouble, and for the more aesthetically pleasing symmetric placement. The pushbuttons for the user to interact with are below it. The audio jack is on the side of the case toward the user (see “back view” in Appendix B). Some holes were to be drilled onto the case for the above specifications to be put in, as the case does not come with them.

The cost of the enclosure is $22.32 per unit, the eyelet kit is $3.04, and the belt strap is $4.92, making the total cost of the packaging $30.28. However, all of these are available as free samples from OKW Enclosures, Inc., and so we took advantage of that for the prototype.

Figure 7-3: The OKW Ergo-Case (M)

7.3 PCB Footprint Layout.

The final PCB layout is in Appendix D. As can be seen, there is a lot of room for components on the board, which must fit within the dimensions of the Ergo-Case. [23] suggests a size of about 128mm x 72mm (5.03” x 2.83”), not including screw mounts. Most of the devices determined in Section 3 are surface-mount devices. The PIC24FJ256GA106 microcontroller and the VS1011E-L MP3 decoder chip are both quad flat pack surface mount devices, whereas the LTC3440 Buck-Boost Regulator, LTC4150 Battery Monitor, and the MCP73811T Charge Management IC are all SOIC devices. The microSD card slot is also surface mounted, though all of the pin mounts are on one side.

The rest of the components will require header pins. The ADLX345 Accelerometer and the SCP1000 Pressure Sensor both come with breakout boards, and so require header pins in order to connect to the main PCB. The GPS module will connect to the board via ribbon cable, so header pins are needed for that as well, and the LCD and Battery Pack is not be mounted on the board.

8.0 Schematic Design Considerations

The Gauntlet is intended to be worn and used for several hours at a time in remote areas and below freezing temperatures, which creates several constraints. It needs to be small enough to wear comfortably on the arm and all components must be able to operate in below freezing temperatures. It must also have low enough power consumption to last for ten or more hours on a single charge. To meet these constraints, surface mount components with low current consumption and the ability to operate at temperatures at or below -20 °C were chosen.

8.1 Theory of Operation

The Gauntlet contains several functional subsystems. These are the microcontroller, power, memory, environmental sensors, audio and user interface. All subsystems operate at 3.3 V to simplify circuitry, eliminating the need for converters or separate power connections, and save power and space. All circuitry is located on one PCB.

8.1.1 PIC 24

The design utilizes a PIC24FJ256GA106 microcontroller, which in turn uses an external 12 MHz oscillator. An external oscillator was added to help ensure good communication with the GPS, which uses UART, and to increase accuracy of communication with other subsystems. The 12 MHz rate is fast enough to handle all the clock speeds needed for various subsystems in the Gauntlet. The PIC24 communicates with and controls all peripherals. A header is attached to programming pins to enable in-circuit programming of the microcontroller.

8.1.2 Power Regulation and Monitoring

The Gauntlet is powered by a 2000mAh lithium polymer battery with a nominal voltage of 3.7 V and a discharge cut-off voltage of 2.75 V [24]. The battery is regulated by the LTC3440 Buck-Boost DC/DC converter, and the values of discrete components in the regulator circuit were calculated to provide a 3.3 V, up to 600 mA power supply to the rest of the circuitry [15].

Battery life is monitored by the LTC4150 Coulomb Counter / Battery Gas Gauge. The coulomb counter senses the current into or out of the battery using a sensing resistor. Worst case current draw from the battery into the circuit is under 250 mA, and charging current into the battery could be as much as 450 mA, so 450 mA was used as the limiting current in calculations for the sense resistor [16]. A 0.1 Ω sensing resistor is used to limit voltage across the resistor to 50 mV. The coulomb counter sends an interrupt to the microcontroller when a certain amount of charge has passed through the resistor in either direction, allowing instantaneous battery capacity to be determined. A polarity pin allows distinction between charging and discharging interrupts [25].

The battery is charged by the MCP73811 Li-Polymer Charge Management Controller. It charges the battery at 450 mA and 4.2 V, both of which are consistent with the requirements of the battery [16, 24]. It is attached to a power barrel jack to which an external power supply can be attached to recharge the battery.

8.1.3 Flash Memory

The Gauntlet uses a 2 GB microSD card for flash memory storage. Audio data and GPS waypoints are stored on the microSD card and accessed by the microcontroller using an SPI interface. A FAT16 file system was used, and libraries provided by Microchip were used as drivers. The microSD clock rate is controlled solely by the Microchip driver, and adapts itself to the specific card being used. (The maximum clock rate for the microSD is 6 MHz, or half the clock rate of the microcontroller.) A microSD card is used rather than an SD to minimize the footprint on the PCB.

8.1.4 Environmental Sensors

The Gauntlet uses a GPS unit, a combination altimeter and thermometer, and an accelerometer to sense its environment. The GPS unit used is the Parallax PMB-648 High Sensitivity GPS Module, which has a small footprint and low power consumption. It communicates with the microcontroller on a serial connection using NMEA protocols at a baud rate of 9600, which is twice the standard rate, but in the midrange of allowable rates [26]. Information sent to the microcontroller includes current position, altitude, and velocity; this information is used in calculations and in saving waypoints. The SCP1000 Absolute Pressure sensor functions as an altimeter and thermometer for the Gauntlet. It communicates with the PIC24 as an SPI slave at a clock frequency of 500 kHz [2]. The ADXL345 Three Axis Digital Accelerometer sends data to the microcontroller using an SPI interface with a clock frequency of 500 kHz to make communication simpler because the altimeter and accelerometer will share an SPI bus [5]. Headers were placed so signals between the PIC24 and the individual sensors could be accessed for debugging.

8.1.5 Audio

The VS1011E Audio Decoder chip decodes MP3 files and drives the stereo earphone jack to send audio to the user. The microcontroller sends MP3 data through an SPI interface at 1 MHz, which is fast, but below its maximum rate of 3.5 MHz [6]. The VS1011E is used in “native” mode, in which the chip select is used to synchronize data, rather than in “compatibility” mode in which a synchronizing signal must be generated [6]. General purpose IO pins, which are not used, are pulled down with 100 kΩ resistors. The xDCS chip select pin, which can be used for the data interface, is pulled high so that the shared chip select setting can be used, or the chip select can be controlled by the microcontroller [6]. Resistors and capacitors are placed on the audio output to provide ESD protection from the audio jack [6]. Headers are available for signals traveling between the VS1011E and the microcontroller.

8.1.6 User Interface

The Gauntlet's user interface consists of the NHD-C0220BiZ-FSW-FBW-3V3M LCD screen and three tactile switches. The LCD screen uses an I2C interface to communicate with the microcontroller at its maximum frequency of 400 kHz, and it relays information to the user [27]. The backlight of the LCD is controlled by a switching transistor connected to the microcontroller to conserve power and give the microcontroller the ability to turn the backlight on and off. A decoupling capacitor and a few pull-up resistors are required to configure the LCD circuit. The tactile switches connect to the microcontroller through general I/O pins and will be debounced in software.

8.2 Hardware Design Narrative

The microcontroller uses SPI, I2C, UART, and interrupts to communicate with various subsystems. General purpose I/O pins are used to communicate with subsystems when SPI, I2C, or interrupts are not needed. (Appendix G provides a list of individual microcontroller pins and the external devices and pins to which they are connected.) Assignments were made after considering the characteristics of the microcontroller pins, requirements of the external pins, and location of pins for ease of routing. The microSD card, MP3 decoder, accelerometer, and altimeter communicate with the microcontroller using an SPI interface. The PIC24 has three SPI units which can be remapped to various pins [9]. The microSD card has a dedicated SPI interface to the microcontroller for the MISO, CLK, MOSI, and CS. The MP3 decoder also has a dedicated SPI interface to the microcontroller. The SO, SI, SCLK, xCS, and xDCS were assigned near the reset and data ready pins. The altimeter and accelerometer share the last SPI interface from the microcontroller because they do not need constant communication. The SPI bus includes MISO, MOSI, and SCK. The altimeter chip select, data ready, input trigger, and power down pins were placed near one another. The accelerometer chip select and configurable interrupt pins were placed near one another. The microcontroller's dedicated I2C pins used LCD signals SDA and SCL. The PIC24 has five interrupt capable pins, and three interrupts are used in the final product. The INT pin for the coulomb counter allows instantaneous charge to be determined. The accelerometer's INT1 and INT2 interrupts are used to detect free-fall and the end of free-fall. Serial communication with the GPS uses remappable pins.

8.3 Summary

The main circuit design constraints of the Gauntlet are small size, low power consumption, and the ability to work at -20 °C. The main subsystems are the microcontroller, the power regulation and monitoring, the flash memory, the environmental sensors, the audio, and the user interface. The GPS, accelerometer, altimeter, and coulomb counter send information to the microcontroller, which processes it, stores some in memory, and sends some to the MP3 decoder which sends audio information to the user. Communication interfaces include SPI, I2C, interrupts, and general I/O.

9.0 PCB Layout Design Considerations

The Gauntlet utilizes a single PCB that is stored inside the forearm-mounted casing. Primary layout concerns for this PCB include the routing complexity of the microcontroller and noise reduction on the sensor traces, as well as ensuring that the PCB fits inside of the chosen packaging for the project.

9.1 PCB Layout Design Considerations - General

There are a number of important general considerations that must be taken into account. The PCB layout is separated into a number of functional groups, which include the battery charge, regulation, and monitoring group, the audio interface, the SD interface, sensors, and the core microcontroller. This provides isolation, which helps reduce noise in the PCB design. To minimize PCB production errors and noise problems, right and acute angles are avoided at all costs. Noise and thermal performance of certain components, particularly the inductor and IC in the boost-buck regulator circuit, are improved considerably through the incorporation of significant power and ground planes beneath and around those components. Additionally, the microSD card features a keep out region in which no traces can be routed [28]. This region is a relatively small region under the card, and has no impact on the placement of other system components. Finally, noise in the circuit needs to be decoupled from all ICs using decoupling capacitors.

9.2 PCB Layout Design Considerations – Packaging

In order to fit inside the chosen casing for this project, the board was limited to a maximum size of 126mm x 88mm, fitting snugly inside the case, which is 150mm x 100mm [23]. From this initial size small cutouts needed to be made from 2 of the corners to leave room for some plastic screw guides used to seal the casing [23]. Additionally, in order to mount the circuit board to the casing, four mounting holes are required on the PCB [23]. Due to the nature of the casing certain components that need to be accessible from the outside of the casing, such as the power switch, SD card, power barrel jack, and audio jack, must be placed on the right side of the PCB, where they can easily be machined to access the casing's exterior.

9.3 PCB Layout Design Considerations – Sensors

Aside from these general considerations, certain components, such as the accelerometer, needed to be positioned as close to PCB mounting points as possible, ideally within 1 inch. This is done to reduce the effects of PCB resonance on the sensor readings from the accelerometer [29]. Also, the Gauntlet system requires two separate grounds for analog and digital. The junction for these grounds needed to be placed as close to the MP3 decoder chip as possible, in order to provide latch-up immunity [30]. The MP3 decoder chip also requires a dedicated external 12MHz oscillator, which cannot be shared with the microcontroller as the decoder chip grounds the clocking signal when in reset mode [30]. Also, several of the sensor systems, such as the accelerometer and altimeter units, were unavailable in packages that could be easily hand soldered, so breakout boards were required for these systems. As a result, it was important to place these parts sufficiently far apart to prevent space conflicts between the boards.

9.4 PCB Layout Design Considerations - Microcontroller

The microcontroller utilized by the Gauntlet design is a PIC24FJ256GA006, which is being utilized in a 64-pin QFP package [9]. A vast majority of these pins are utilized by the Gauntlet design, and as such routing about the microcontroller was difficult. To ease the routing process, the microcontroller needed to have large amounts of board space allocated about it. Also, subsystems on the microcontroller needed to be positioned such that the number of electrical traces that must cross over one another to complete the layout design are minimized. Additionally, the PIC microcontroller has a flexible remappable peripheral structure [9], so rewiring of certain interfaces to improve routing on the board may be performed. For the Gauntlet design, the microcontroller is utilizing an 12MHz external crystal oscillator, so space must be allocated around the oscillator to minimize noise-related clocking errors. The chosen microcontroller has three sets of power and ground connections, as well as an additional decoupling capacitor connection pin, analog ground and power pins, and core voltage pin [9]. All of these are decoupled using decoupling capacitors placed as close to the microcontroller as possible. In spite of the fact that many of the microcontroller pins are being used, there are no noteworthy difficulties placing the decoupling capacitors close to the microcontroller pins. The microcontroller requires five pins for device programming. These pins are broken out as an onboard header, and the length of these traces needed to be minimized to mitigate programming errors.

9.5 PCB Layout Design Considerations - Power Supply

The power supply for the Gauntlet system consists of several components: the DC power barrel jack, the Li-Ion charger IC, the fuel gauge IC, and a buck-boost converter chip. The DC barrel jack needed to be located on the right side of the PCB, to allow for easy access to the exterior of the packaging. The Li-Ion charger IC requires input and output capacitors, as well as a programming resistor, to be located nearby [16]. Additionally, digital ground as well as the battery power and digital power planes needed to be located near the Li-Ion charger with vias to improve heat dissipation [16]. According to the device’s data sheet, the charger IC must be located as close to the battery as possible to minimize power losses [16]. Traces are fairly low resistance, however, so locating the charging IC within an inch of the battery leads should be sufficient for the purposes of this project.

In addition to the charger IC, the battery fuel gauge and the buck boost regulator ICs have a number of important layout considerations. In particular, a current sensing resistor with a Kelvin connection should be placed near the IC to provide accurate current readings for the IC [25]. Connections are also be minimized and a capacitor needed to be placed close to the device to ensure optimal performance [25]. The buck-boost regulator requires power and ground planes to be placed near the IC with vias to improve thermal dissipation [15]. Also, high current traces connected to the regulator do contain any bends to minimize noise and resistive losses [15].

10.0 Software Design Considerations

10.1 Memory Constraints

The PIC24F uses a modified Harvard architecture, which utilizes separate memories and busses for program space (implemented in Flash) and data space (implemented in RAM) [9].

Appendix H shows the memory maps for both. The variant of PIC used in the Gauntlet is able to store approximately 87,000 instructions in program space. This is plenty of room for the microcontroller's code. What is of primary concern is the data RAM – although there are 16 KiB of it available to the PIC24F, the first few KiB will be needed for the software stack. (The MPLAB IDE defaults to a stack size of 6 KiB; this is an appropriate maximum value given the functions which are called during operation.) This leaves a minimum of 10 KiB to store working variables, data structures, and the MP3 buffer for transferring audio from the microSD card to the MP3 decoder. Even if all of this space were used for sample buffering, just over a second of audio could be fully buffered at a bitrate of 64 kbps. This implies that reading samples from the microSD card and streaming them to the decoder is a critical microcontroller task.

10.2 External Interface Mapping

The PIC24F uses a remappable-pin design, allowing on-chip peripherals to choose from a good number of I/O pins. Appendix G shows a full table of pin mappings to the external peripherals. (It should be noted that these pin mappings were chosen for ease of circuit board routing, and not for their internal "port name" consistency or numerical order.)

10.3 Integrated Peripherals

In order to communicate with the off-chip sensors, the PIC needs to utilize three SPI interfaces, one UART interface, and one I2C interface. In addition, an onboard ADC in single-sample mode will be utilized to measure the battery voltage, and the timer subsystem will be needed to perform periodic tasks. Initialization of these peripherals is done though memory-mapped registers, which are described in Appendix I.

10.4 Application Code Organization

The Gauntlet, being a battery-powered device, is primarily interrupt-driven. When a timer, SPI, UART, or other interrupt is fired, the interrupt handler sets appropriate flags and wakes the microcontroller. The main loop reads these flags and takes the required action, going back to sleep only when a full loop is executed without any interrupt activity. A fuller description of the actions the main loop may take is described in Section 10.6.

10.5 Debugging Provisions

A PIC24F simulator was used for initial testing and debugging of newly written code. The PIC can also be operated using an in-circuit debugger, and debugging information during normal use is communicated on the character LCD.

10.6 Software Design Narrative

10.6.1 Input

The microcontroller takes input from five primary sources: the accelerometer, the altimeter, the battery, the GPS, and the pushbuttons. The accelerometer, altimeter, pushbuttons, and battery voltage are polled at regular intervals. The GPS and the charge counter both send data asynchronously to the PIC in the form of NMEA messages or pin interrupts. This implies some differences in the way the underlying hardware drivers work.

For the SPI-based input devices, the sensor SPI bus (clocked at 500 kHz) is utilized. Once a second, the altimeter is triggered to begin an acquisition/conversion sequence by the PIC. When the altimeter responds with a data-ready interrupt, the PIC's interrupt handler signals the main loop to 1) pull the altimeter's chip select low and 2) read the altitude by writing a read command and receiving a 15-bit value back. Using the table described in [31], this value is converted to an altitude in meters. The accelerometer, in contrast, will be set to perform its own sample buffering; no trigger is necessary. Approximately ten times a second, the accelerometer's chip select will be pulled low and the values of the X-, Y-, and Z-accelerations is read via the SPI interface.

The absolute battery voltage is read using a single ADC sample/conversion – a maximum 10-bit value of 0x3FF corresponds to the maximum battery voltage of 4.2 volts. The charge counter circuit works via an interrupt system. When a discrete quantity of charge equal to 1/100 of the battery's nominal capacity passes through the charge counter, an interrupt pulse is sent to one of the pins on the PIC. Another pin is pulled high or low depending on the polarity (i.e. charge or discharge) of the count. The interrupt handler then either adds or subtracts one from the charge count, which starts at 23436. This provides a fairly accurate estimate of the charge percentage remaining in the battery.

Once a second, the GPS sends NMEA sentences at 9600 baud to the microcontroller [32]. The UART handler needs to move these sentences to an internal buffer, and then notify the main loop when a buffer fills so that it can be parsed. The sentences are parsed for their latitude/longitude information, the current speed-over-ground, and the heading of the user. These values are then stored in fixed-point format for use by the calculation block.

10.6.2 MicroSD Interface

The 2GB microSD card was formatted with a FAT16 file system to allow it to be easily loaded with MP3 samples from a personal computer. Microchip [33] provides a FAT16 library for use with the PIC24F, so we decided to port this to our project to reduce development effort. This library provides stdio-type file operations, which are well worth the time and memory overhead to the Gauntlet.

10.6.3 Calculation/Processing

The calculation module encompasses the algorithms which combine sensor data to provide new information. This includes the calculation of the downhill velocity, the slope grade, the distance and direction to the last saved waypoint, and the distance and direction to the user-saved “safepoint.”

Calculation of the velocity is fairly straightforward. The GPS chipset can provide a birds-eye velocity reading, or XY velocity, once every second. The change in altitude over the previous second, or Z velocity, can then be combined with the XY velocity using the familiar Pythagorean theorem. Slope grade is calculated with the same input, but this time the quantity is the ratio of the Z velocity to the XY velocity.

Waypoint distance and direction calculation is significantly more involved. The microcontroller will start with the latitude and longitude (in degrees) and the altitude (in meters) of both waypoints. The approximate distance between two points (lat1, long1) and (lat2, long2), with a radius of the earth r, is equal to [r * acos(sin(lat1)sin(lat2) + cos(lat1)cos(lat2)cos(long1 – long2)) [34]. An accurate calculation, then, will require six trigonometric calculations, eight floating-point multiplications (four of these are to convert to degrees), and two floating-point additions and subtractions. Instead, a fixed-point approximation is used which utilizes multiple trigonometric lookup tables. After finding the horizontal distance, the vertical distance can be computed by simple subtraction and presented to the user.

To calculate the exact direction to a waypoint, a much more complicated function is needed – the bearing is given by atan2(sin(long2 – long1)cos(lat2), cos(lat1)sin(lat2) − sin(lat1)cos(lat2)cos(long2 – long1)) [34]. This is incredibly uC-intensive, so a simpler (arctangent) approach is used under the simplifying assumption that the earth is flat. This reduces the trigonometric requirement from seven calls to one (for the arctangent itself), and is close enough for the Gauntlet to navigate correctly up to distances of a few miles.

10.6.4 Action on Input

The microcontroller's reaction to the accelerometer data is simple. If all three axes of acceleration are sufficiently close to zero for a sufficiently long amount of time, the PIC should record a jump and note the time; otherwise, the PIC should stop a jump in progress and record the total airtime. If the magnitude of the acceleration spikes suddenly, the PIC should mark a crash condition. These conditions can then be communicated to the user.

Decisions on waypoint storage are distance-based. If the distance to the last saved waypoint (measured by the sum of the squares of each axis translation) is greater than a given threshold, a new waypoint is saved to persistent microSD storage. Depending on the time available to the PIC, an optimization routine may be implemented to search through the stack of waypoints, determine if the most recently added waypoint is within the threshold of a previously added waypoint, and reset the stack to that point to avoid directing the user in loops.

The reaction to battery information is primarily bookkeeping. If the analog reading and charge count have changed significantly, they are backed up to Flash. If the battery is dangerously low, the user is notified and nonessential circuitry is shut down. Since the Gauntlet can be charged while it is off (and therefore not receiving charge count information), the PIC will reset the charge count if the analog battery voltage is measured to be 4.20 volts.

Finally, and possibly most trivially, the PIC must react to user pushbutton input. This comes mainly in the form of changing the operating mode, updating the user menu, and writing new data to the LCD.

10.6.5 Output

Output to the user comes in two forms: the LCD display and the audio interface. The LCD display is trivial, as the interface to the LCD is a simple I2C system. The audio interface will therefore be the topic of discussion here.

The trigger for audio output is a user-configured timer. The mode of audio output (e.g. velocity, airtime, or slope grade) is also determined by the user. Once the audio trigger occurs, audio samples must be selected. The first audio sample (e.g. "Your current velocity is," or "The slope grade is") is determined by the audio output mode. Numeric values are parsed into their constituent components. For example, the number 362 would be parsed into 300 + 60 + 2, which is further subdivided into four audio samples: "three," "hundred," "sixty," and "two." (Because of the nuances of the English language, special cases are needed to avoid playing numbers like "ten-three" when "thirteen" is meant.) Finally, a unit of measure (e.g. "meters per second") is output.

The chosen samples are found on the microSD card through a table lookup of filenames. The available (512-byte) audio buffers are filled to capacity, and then the PIC enters a time-critical segment of code which feeds blocks to the MP3 decoder and read new blocks from the microSD card, stopping only when the samples are completed or the decoder indicates that it no longer has buffer space. The SPI interface used by the microSD card and the VS1011e is clocked at a very fast 1 MHz rate to avoid buffer underflow and, by extension, cracked and halting sound.

11.0 Version 2 Changes

We would make several changes to the Gauntlet in a second revision. The first changes deal with schematic errors: most notably, the audio oscillator component and the charge counter circuitry. A 12.288 MHz oscillator would be added to the PCB for the VS1011e, since that frequency provides the best performance [6]. The charge counter would be attached to the battery instead of the power rail, eliminating several of the problems we had over the semester. The PIC24F ENVREG pin would not be left floating – instead, it would be connected to power to allow the PIC24F to correctly power on. On a more minor note, a ground plane would be added to the buck-boost circuitry to reduce switching noise at higher current draws.

On a functionality level, the Gauntlet would utilize a Kalman filter for its altitude reading, combining input from the GPS and the altimeter to reach a nearly-noise free result. This would make our velocity calculation much better. We would research the PMB-648's static navigation mode in order to disable it and allow slightly more noisy waypoint updates at slow walking speeds. An optimal-path algorithm for emergency mode would search the waypoint list and eliminate loops in the user's path to guide them back to the safe point more quickly.

Finally, on a machining and packaging level, we would machine the package to fit the internal components more closely. This would include machining holes in the PCB to allow wires to travel from one side of the case to the other, as well as adding appropriate spacers to the mounting screws for the PCB. We would also seal the package to make it watertight and provide protection in the event of a fall into snow.

12.0 Summary and Conclusions

Team 3 accomplished the design, construction, and testing of a fully-functional GPS unit for skiers and snowboarders. During this process, we brainstormed and selected success criteria, analyzed design constraints for the device, researched possible constituent components, and designed the packaging for the device. We subsequently designed a schematic and used it to lay out a custom printed circuit board. Upon receiving and populating this PCB, we crafted low-level drivers, higher-level algorithms and control software, and a user interface for the Gauntlet to satisfy all of the success criteria. Parallel to the completion of the product, we analyzed the device's safety and reliability, as well as ethical and environmental concerns, and we researched possible patent liabilities we might encounter during the manufacture of the Gauntlet.

During this process, the team learned multiple useful computer and electrical engineering concepts: how to design a circuit for maximum reliability and safety, how to correctly design a digital system, how to test and debug embedded systems during manufacture, and how to best ensure that the manufacture of a product is legal and ethical. Overall, we have each learned how to take a digital embedded system from an initial concept to a working reality.

13.0 References

[1] V. Blake, “Flaik skis its way to a design award,” The Australian, Jun. 3, 2008. [Online]. Available: http://www.theaustralian.com.au/news/flaik-skis-its-way-to-a-design-award/story-0-1111116516898. [Accessed: Feb. 1, 2010].

[2] “SCP1000 Series (120 kPa) Absolute Pressure Sensor,” VTI Technologies. [Online]. Available: http://www.sparkfun.com/datasheets/Components/SCP1000-D01.pdf. [Accessed: Jan. 31, 2010].

[3] “MP3H6115A Series Datasheet,” Freescale Semiconductor, 2009. [Online]. Available: http://www.freescale.com/files/sensors/doc/data_sheet/MP3H6115A.pdf. [Accessed: Jan. 31, 2010].

[4] “BMA150 Data Sheet,” Bosch Sensortec, May 30, 2008. [Online]. Available: http://www.bosch-sensortec.com/content/language1/downloads/BMA150_DataSheet_Rev.1.5_30May2008.pdf. [Accessed: Jan. 31, 2010].

[5] “ADXL345,” Analog Devices, Jun. 2009. [Online]. Available: http://www.analog.com/static/imported-files/data_sheets/ADXL345.pdf. [Accessed: Jan. 31, 2010].

[6] “VS1011e – MP3 Audio Decoder,” VLSI Solutions, Oct. 6, 2009. [Online]. Available: http://www.vlsi.fi/fileadmin/datasheets/vlsi/vs1011.pdf. [Accessed: Jan. 31, 2010].

[7] “STA013 MPEG 2.5 Layer III Audio Decoder,” STMicroelectronics, Feb. 2004. [Online]. Available: http://www.st.com/stonline/books/pdf/docs/6399.pdf. [Accessed: Feb. 1, 2010].

[8] “GPS Comparison Table,” Parallax, Inc., 2010. [Online]. Available: http://www.parallax.com/ProductInfo/Accessories/GPSComparisonTable/tabid/831/Default.aspx. [Accessed: Jan. 29, 2010].

[9] “PIC24FJ256GA110 Family Data Sheet,” Microchip Technology, Inc., Dec. 10, 2009. [Online]. Available: http://ww1.microchip.com/downloads/en/DeviceDoc/39905d.pdf. [Accessed: Feb. 3, 2010].

[10] “XMEGA A1 Microcontroller,” Atmel, Jan. 2010. [Online]. Available: http://www.atmel.com/dyn/resources/prod_documents/doc8067.pdf. [Accessed: Feb. 3, 2010].

[11] A.S. Brooks. “Route based on distance.” U.S. Patent 7 627 423, Dec. 1, 2009.

[12] K. Tomizawa. “Navigation device, method, and program.” U.S. Patent 7 565 240, July 21, 2009.

[13] "Flaik Armband for Ski Adventurers," Tuvie. [Online.] Available: http://www.tuvie.com/flaik-armband-for-ski-adventurers/. [Accessed: Mar. 30, 2010].

[14] United States Department of Defense, "MIL-HDBK-217F: Military Handbook on Reliability – Prediction of Electronic Equipment," Dec. 1991. [Online]. Available: https://engineering.purdue.edu/ece477/Homework/CommonRefs/Mil-Hdbk-217F.pdf. [Accessed: April 8, 2010].

[15] "LTC3440 Micropower Synchronous Buck-Boost DC/DC Converter," Linear Technology, 2001. [Online]. Available: http://cds.linear.com/docs/Datasheet/3440fb.pdf. [Accessed: Feb. 18, 2010].

[16] "Microchip MCP73811/2 Simple, Miniature Single-Cell, Fully Integrated Li-Ion / Li-Polymer Charge Management Controllers," Microchip, June 25, 2007. [Online]. Available: http://ww1.microchip.com/downloads/en/DeviceDoc/22036b.pdf. [Accessed: Feb. 18, 2010].

[17] RoHS Guide.com, "RoHS Compliance FAQ," *RoHS Guide: FAQ on RoHS compliance*, 2010. [Online]. Available: http://www.rohsguide.com/rohs-faq.htm. [Accessed: Apr. 15, 2010].

[18] Hoag, Hannah, "The missing greenhouse gas," *Nature Reports Climate Change*, July 10, 2008, [Online]. Available: http://www.nature.com/climate/2008/0808/full/climate.2008.72.html. [Accessed: Apr 15, 2010].

[19] Buchmann, Isidor, "Recycling batteries," *Battery University.com*, July 2003, [Online]. Available: http://www.batteryuniversity.com/partone-20.htm. [Accessed: Apr 16, 2010].

[20] Garmin Ltd., "Foretrex 301," [Online], Available: https://buy.garmin.com/shop/shop.do?cID=144&pID=30025. [Accessed February 8, 2010]

[21] S. Fallon, "The Flaik Armband Tracks Your Airtime on the Ski Slopes," [Online], Available: http://gizmodo.com/5012805/the-flaik-armband-tracks-your-airtime-on-the-ski-slopes. [Accessed February 9, 2010]

[22] OKW Enclosures, Inc., "OKW Ergo-Case Enclosures," [Online], Available: http://www.okw.co.uk/products/okw/ergo.htm. [Accessed February 9, 2010]

[23] OKW Enclosures, Inc., "ERGO CASE M," [Online], Available: http://www2.okw.com/okw-static/drawings-pdf/00006701.pdf. [Accessed February 10, 2010]

[24] "585460 Li-Polymer Battery Packs Specification," UnionFortune, Mar. 16, 2006. [Online]. Available: http://www.sparkfun.com/datasheets/Batteries/UnionBattery-2000mAh.pdf. [Accessed: Feb. 18, 2010].

[25] "LTC4150 Coulomb Counter / Battery Gas Gauge," Linear Technology, 2003. [Online]. Available: http://cds.linear.com/docs/Datasheet/4150fc.pdf. [Accessed: Feb. 18, 2010].

[26] "POLSTAR PMB-648 GPS module," Parallax. [Online]. Available: http://www.parallax.com/Portals/0/Downloads/docs/prod/sens/PMB-648_Specification_V0.1.pdf. [Accessed Feb. 18, 2010].

[27] "NHD-C0220BiZ-FSW-FBW-3V3M COG (Chip-on-Glass) Liquid Crystal Display Module," Newhaven Display International, Nov. 20, 2009. [Online]. Available: http://www.newhavendisplay.com/specs/NHD-C0220BiZ-FSW-FBW-3V3M.pdf. [Accessed: April 3, 2010].

[28] Kyocera-Elco. "MicroSD Card Connector", [Online], Available: http://www.kyocera-elco.com/prdct/pdf/5138.pdf. [Accessed February 25, 2010].

[29] Analog Devices. "ADXL345 Datasheet", [Online], Available: http://www.sparkfun.com/datasheets/Sensors/Accelerometer/ADXL345.pdf. [Accessed February 24, 2010].

[30] VLSI Solutions. "VS1011e MP3 Audio Decoder Datasheet", [Online], Available: http://www.vlsi.fi/datasheets/vs1011.pdf. [Accessed February 24, 2010]

[31] "Air Pressure and Altitude Above Sea Level," The Engineering Toolbox, 2005. [Online]. Available: http://www.engineeringtoolbox.com/air-altitude-pressure-d_462.html. [Accessed: March 22, 2010].

[32] "NMEA Reference Manual," SiRF Technology, Inc., Dec. 2007. [Online]. Available: http://www.sparkfun.com/datasheets/GPS/NMEA%20Reference%20Manual-Rev2.1-Dec07.pdf. [Accessed: March 20, 2010].

[33] "Implementing File I/O Functions Using Microchip's Memory Disk Drive File System Library," Microchip Technology, Inc., 2008. [Online]. Available: http://ww1.microchip.com/downloads/en/AppNotes/01045b.pdf. [Accessed: March 23, 2010].

[34] "Calculate Distance, Bearing, and More Between Two Latitude/Longitude Points," Movable Type Scripts. [Online]. Available: http://www.movable-type.co.uk/scripts/latlong.html. [Accessed: March 24, 2010].

Appendix A: Individual Contributions

A.1 Contributions of George Hadley:

Over the semester, I completed the Preliminary PCB Layout Narrative and Patent liability analysis homework assignments, which forced me to be well versed in issues related to the placement of the Gauntlet's components as well as infringement issues related to the Gauntlet's operation. I also brought a number of valuable skills to the team, including prior embedded system design experience, printed circuit board layout experience, soldering and physical construction experience, and video filming/editing experience. Additionally, I provided many of the tools the team used to excel in these areas, which included a cordless power drill, cordless rotary tool, video camera, and a book on programming the PIC24 microcontroller in C.

Over the course of the semester, my previous experience with PIC microcontrollers was very valuable to the success of the project. I provided consultations on the design of the system, including helping to select the PIC microcontroller after discovering that trigonometric functions could be implemented on the microcontroller using libraries provided by microchip. A second very valuable contribution I provided to the team regarding the microcontroller was the suggestion to check the microcontroller silicon errata to ensure that the peripheral pin selections we made did not result in unforeseeable errors. As it turned out, there was a problem that rendered one of the three sets of programming pins on the microcontroller inoperable, which we avoided, while another team had to redesign due to this problem. When it was discovered that the MP3 decoder chip did in fact require an oscillator, it was my suggestion to clock the PIC off of a 12MHz external clock that could be shared with the decoder IC. While this approach had to ultimately be abandoned, the 12MHz crystal oscillators ordered were used for both the microcontroller and MP3 decoder IC.

Additionally, due to previous hobby electronics projects, I had previous PCB layout experience that I brought to the team. Design and layout of the PCB was an area in which I had major responsibilities. I explored the PADS PCB layout program, figuring out the initial approach for making custom footprints, which I wrote up as a tutorial to share with the rest of the class. Using this knowledge, I designed footprints for all of the parts needed for the Gauntlet. Jacob discovered additional features of the PADS layout software, and I implemented these to perfect the footprints for the PADS PCB. Jacob, Kelli, and Sean were very helpful in arranging most of the PCB components into unions, at which point I ran the autorouter and proceeded to tweak the output from the autorouter to complete the PCB design for the Gauntlet.

When the PCB arrived, I was in charge of all of the soldering for the Gauntlet, particularly parts that were more difficult to solder by hand. These included the microcontroller, mp3 decoder IC, analog comparator IC, charge counter IC, and buck-boost converter IC, as these came in QFP and SSOP packages. When problems arose related to the microcontroller and audio decoder ICs, I was in charge of performing the fly-wiring on the chips, which was extremely difficult in most cases. Once the PCB was fully constructed, I was responsible for machining the case to ensure parts fit within the Gauntlet casing. This included carefully drilling holes for the audio jack and DC power jack in the back of the case, drilling mounting holes for the screws to fasten the power switch to the back of the case, adding eyelets to the bottom of the case to allow straps to be connected to the case, and machining holes and cut-outs on the top of the case to allow pushbuttons and the LCD display to be accessible from the outside of the case.

At the end of the semester, my considerable previous experience in video filming and editing, due to some previous video projects, allowed the team to create a professional looking video. I performed all of the filming needed for the project and, once that was done, took care of capturing all of the footage to an external hard drive. Finally, all of the footage was edited together using Final Cut Pro, based on suggestions the team provided for the film.

A.2 Contributions of Sean Ma:

At the beginning of the semester, I was mostly a contributor to discussions and conceptual ideas. I learned PADS so that I could support the team when we needed to construct the PCB, but most of the work ended up going to George and Jacob. I was able to contribute ideas and such, and did some rerouting of traces with Kelli so that our PCB was more consistent. I also was the main person in charge of researching the microSD card and how to interface with it so that we could use it for persistent storage.

One of my biggest contributions in the early weeks was in determining the packaging. I was in charge of the packaging homework, and so I did some research into enclosures that we could use, and found the OKW Ergo-Case. Seeing the case as the best example of a wearable plastic enclosure, I ordered a free sample of one and an eyelet set, so that we could attach the straps. I also worked on the CAD of the first product model. I created a model of the Ergo Case in AutoCAD using a CAD sheet that I had requested from OKW Enclosures, Inc., and added the main user interface to the case, as well as the Power Jack and Headphone Jack. The CAD model that I had created was eventually used as our main model for the final product, and the result was very close to what I had envisioned in the early weeks.

When the PCB came in after Spring Break, I began to focus on my main specialty: software. Jacob and I worked together to create a basic skeleton of what we wanted the Gauntlet to actually do in software. We also worked together on the GPS navigation algorithms. After deciding that we would need some of our own fixed-point notation variable types, I helped come up with exactly how we would implement that, and wrote the parser that we would use for translating NMEA sentences from the GPS into information that we would eventually use for the final calculations. I also found Microchip's FAT16 library so that we could easily interface with the SD card when the time came to use it. My netbook also became our main interface with the SD card, since I had most of the drivers installed to read it already, and I added the mp3 files of my voice to the SD card that we used to talk to the user. Toward the end of the semester, I helped Jacob write the Menu System user interface.

I also did a lot of debugging on the main code when problems came up. I helped Jacob write a lot of the main code, and then I focused on fixing certain problems that came up, such as fixing the I2C interface when it wasn't appearing correctly on the oscilloscope, correcting the navigation algorithm when latitude and longitude were switched, fixing some of the functions when an incorrect number was displaying on the LCD, and some bugs in the Menu System once it was implemented.

Apart from the main responsibilities given to me, there were some more minor jobs that I had a hand in. I was responsible for the Ethics and Environmental Analysis, which I was able to do some research into when the time came, concluding that our product was mostly "green", as far as electronics go. I helped Kelli write much of the User Manual, and in the process determined how our Menu System should work. I also made the Team Logo one night in Photoshop, which we eventually used on the poster.

A.3 Contributions of Jacob Champion:

My design component homework, the design constraints narrative, required me to research and select components for the Gauntlet. My specific areas of research included the selection of our accelerometer (the ADXL345), our altimeter (the SCP1000-D01), and our GPS (the PMB-648). I balanced cost, utility, and ease of use for each of these selections; the accelerometer and altimeter were finally chosen because they are both SPI-based -- and therefore can be multiplexed if the microcontroller has a limited number of SPI connections -- and they are available in easy-to-solder breakout boards. Upon receiving the altimeter and GPS, I used a Texas Instruments MSP430 and a serial connection to test their functionality and ensure that the microcontroller at the heart of our project would be able to communicate with them properly.

I assisted the team in designing the analog and power circuitry for the Gauntlet. This specifically included designing and choosing components for the LCD backlight controller so that the PIC24F did not need to source 20 mA out of a control pin (which would have put it severely out of tolerance) as well as choosing essential components such as the DC barrel jack, the headphone jack, and a high-quality inductor for the buck-boost converter. I researched the lithium polymer battery we selected and discovered that it would require protective circuitry to prevent an undervoltage condition. I then assisted the team in designing an analog shutdown for our buck-boost converter in an undervoltage situation to prevent user injury. During the PCB layout portion of our project, I assisted George in creating accurate part footprints for our components. I also assisted with a cleanup of the PCB layout -- which rearranged our power circuitry, our audio converter, and the sensor layout -- to facilitate debugging and reduce noise.

My primary responsibility for the Gauntlet was embedded software. I used references such as the PIC24F datasheet, manual, and online tutorials to begin writing a basic polling loop for the microcontroller. I researched and chose the peripheral initializations, which included UART, SPI, I2C, and interrupt-based communication, and mocked up the overall software framework for the Gauntlet with stub functions that could be implemented one at a time to enable functionality. I wrote the audio driver for the Gauntlet, which takes numbers and phrases off of the microSD card, queues them in play order, and streams them as quickly as possible to the MP3 decoder while still allowing the user to interact with the UI. I also successfully enabled the accelerometer after a prolonged debugging period, which allowed the Gauntlet to make airtime measurements. This process involved hardware debugging for the SPI interface, followed by manual testing and tweaking of freefall and activity interrupt parameters to ensure that jumps were correctly recognized by the microcontroller. I used an online altitude table and a cubic regression function to allow the microcontroller to convert the pressure reading from the

SCP1000 into an altitude measurement, which is saved with a GPS waypoint to provide an overall picture of a user's path. During our microSD integration phase, I discovered and fixed bugs in Microchip's SD library which prevented the microcontroller from correctly formatting and reading the 2 GB microSD card.

Sean and I both contributed equally to the GPS communication and navigation portions of the assignment. Completing these PSSCs involved engineering and implementing a trigonometric lookup table to convert a difference in latitude and longitude into a distance measurement as quickly as possible. This allowed the Gauntlet to efficiently store waypoints to a persistent stack file we created, which automatically saves and maintains the path the user has taken to his or her current location. We also created the final user interface for the Gauntlet, which is a menu-based system that allows the user to easily change preferences and operating modes while also providing useful information about the user's activities.

A.4 Contributions of Kelli Hacker:

During the conception and early design portion of the project, I focused on the audio circuitry and found an appropriate chip for coulomb counting. I researched several different chips that fit our constraints of purpose, size, cost, and operating conditions. I found a variety of text to speech and decoding chips and researched their constraints and sound quality. After comparing several candidates, I selected the VS1011E, a well-documented chip which can decode MP3 and several other formats, and it does not need an external digital to analog converter or audio amplifier. I also looked at documentation from other teams who used coulomb counters and found the fuel gauge that we used in our design.

I was responsible for writing the Hardware Design Narrative and created the preliminary schematic in PADS Logic. I collaborated with my teammates to get the information for the narrative, and created a spreadsheet to keep track of pin assignments as they were made. This spreadsheet was updated throughout the semester as changes were made and was extremely useful in several different stages of design. I completed the preliminary schematic, and was a significant contributor as changes were made throughout the semester.

While the PCB was being designed, I assisted in the grouping of parts into functional blocks and the placement of blocks to ease routing. Jacob, Sean, and I spent many hours rearranging the PCB to create cleaner routes and large power traces, in addition to uniform ground planes. I found a PCB layout guide for the MP3 decoder which led us to arrange passives and traces carefully and to isolate the circuit as much as possible from other parts to avoid noise entering the circuit.

Once the PCB arrived, I helped check it for obvious errors and connectivity issues. George soldered the surface mount parts, but I assisted by organizing all the passive components and keeping track of schematic connections while he put them on the board. I helped test and debug most major functional blocks of the circuit, including power, microcontroller, and audio circuitry. When we discovered issues with our fuel gauge, I worked with a circuit on a bread board to test our circuit design. I determined that the individual circuit design did not appear to be a problem once one connection was fixed, because the circuit worked on the bread board. Then I did connectivity checks on every connection in the circuit on the PCB, but did not find any specific errors. I was also involved in several testing and debugging sessions with the fuel gauge circuit until the problem was resolved.

Once most of the hardware was assembled and tested, I became involved in full system tests and debugging. I helped find a few minor software issues and tried to learn how the software worked. I helped with the initializations of the MP3 decoder and helped test its functionality. Sean and I developed a menu system for our project to make it more user-friendly and wrote most of the first draft of the user manual. I helped test the GPS location and navigation algorithms and helped film and edit two different versions of our PSSC video.

I also wrote the Safety and Reliability Analysis paper and researched several different components which are most likely to lead to system failure. I analyzed these components in the reports and calculated their Mean Time To Failure. I also completed a FMECA analysis of our system.

I made a few contributions to packaging. I added buckles and adjustable elastic straps to the Gauntlet casing to make it wearable. I also determined that the SPI bus header was interfering with the GPS, and I trimmed the header. After a few adjustments of wires inside the case, I was able to close the case.

Appendix B: Packaging

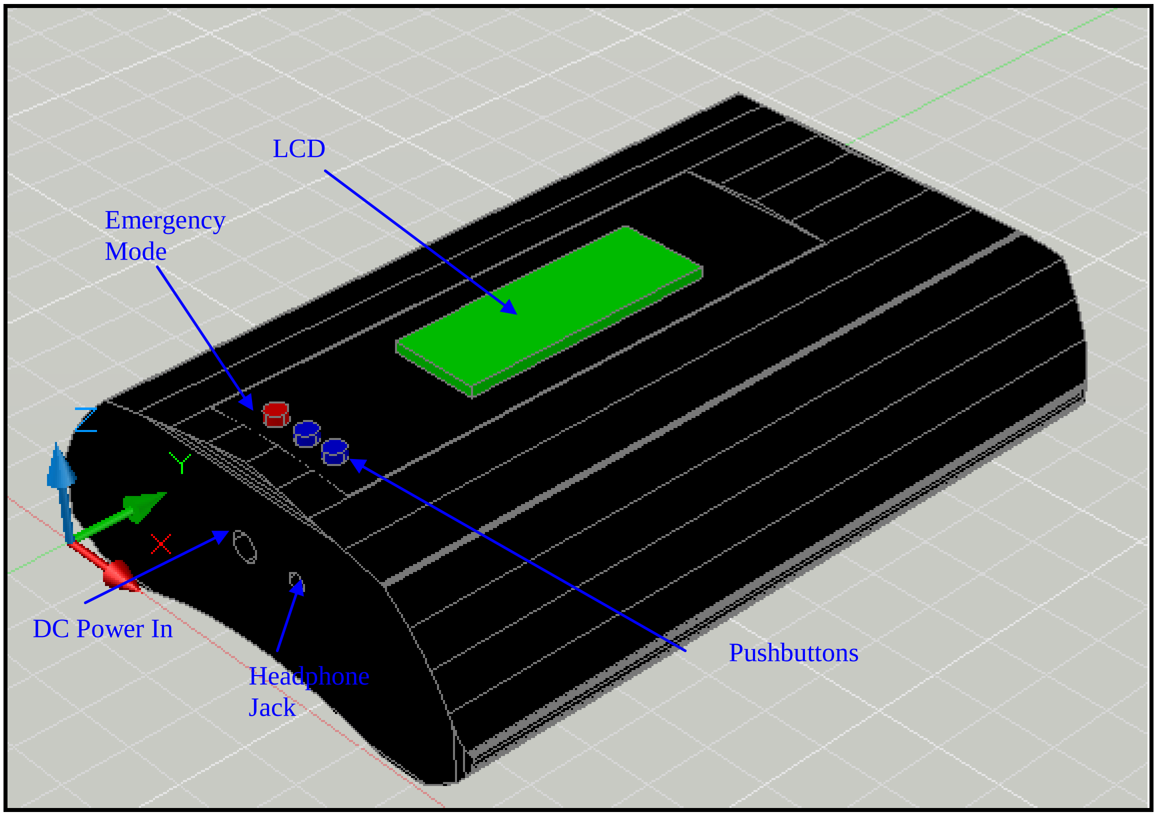


Figure B-1: Gauntlet Package Design (Isometric)

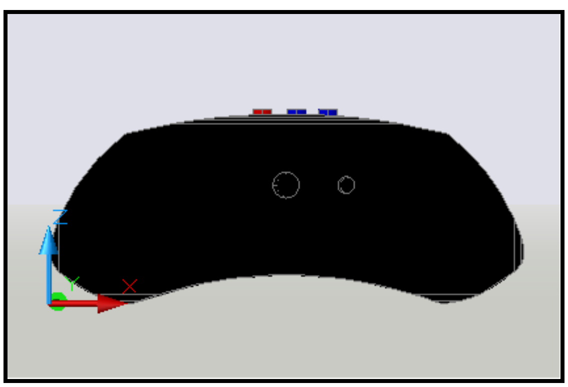


Figure B-2: Gauntlet Package Design (Front)

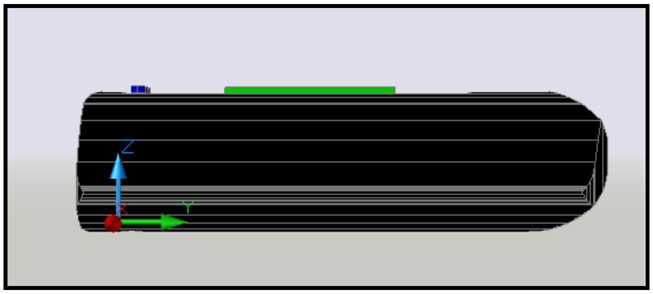


Figure B-3: Gauntlet Package Design (Side)

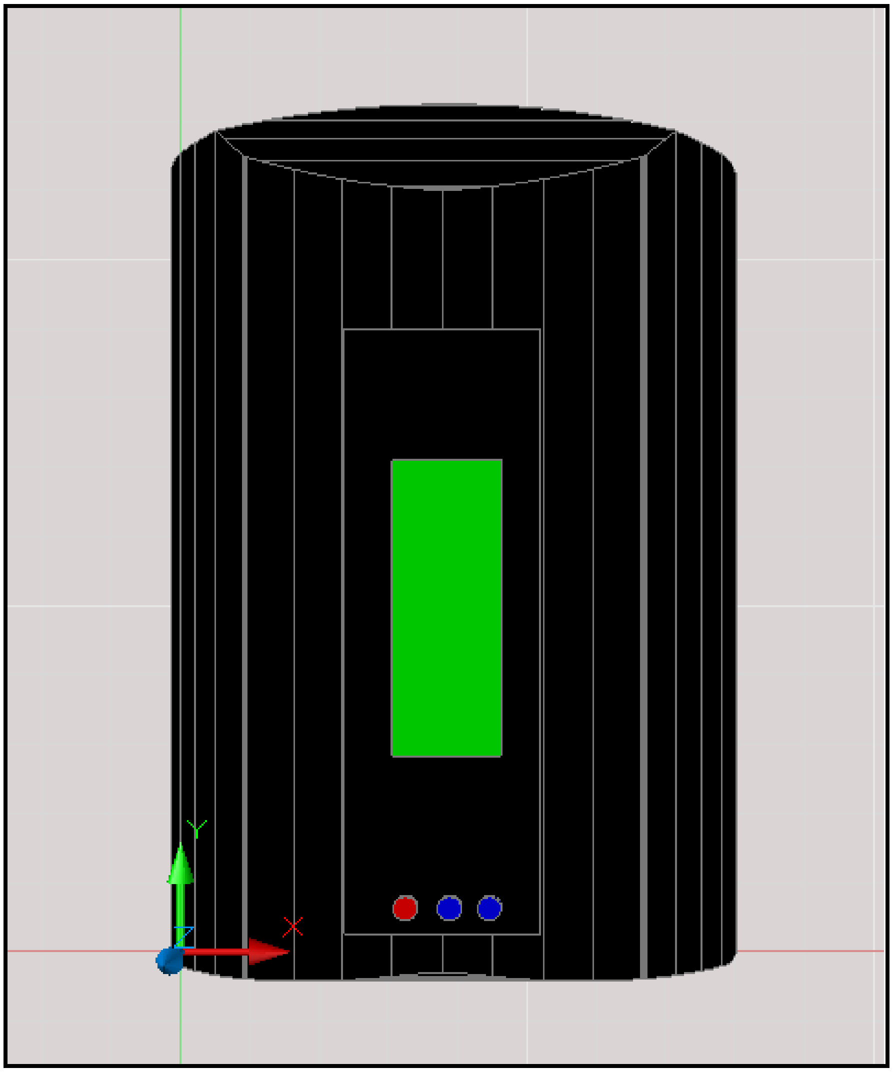


Figure B-4: Gauntlet Package Design (Top)

Figure B-5: Final Packaging (Isometric)

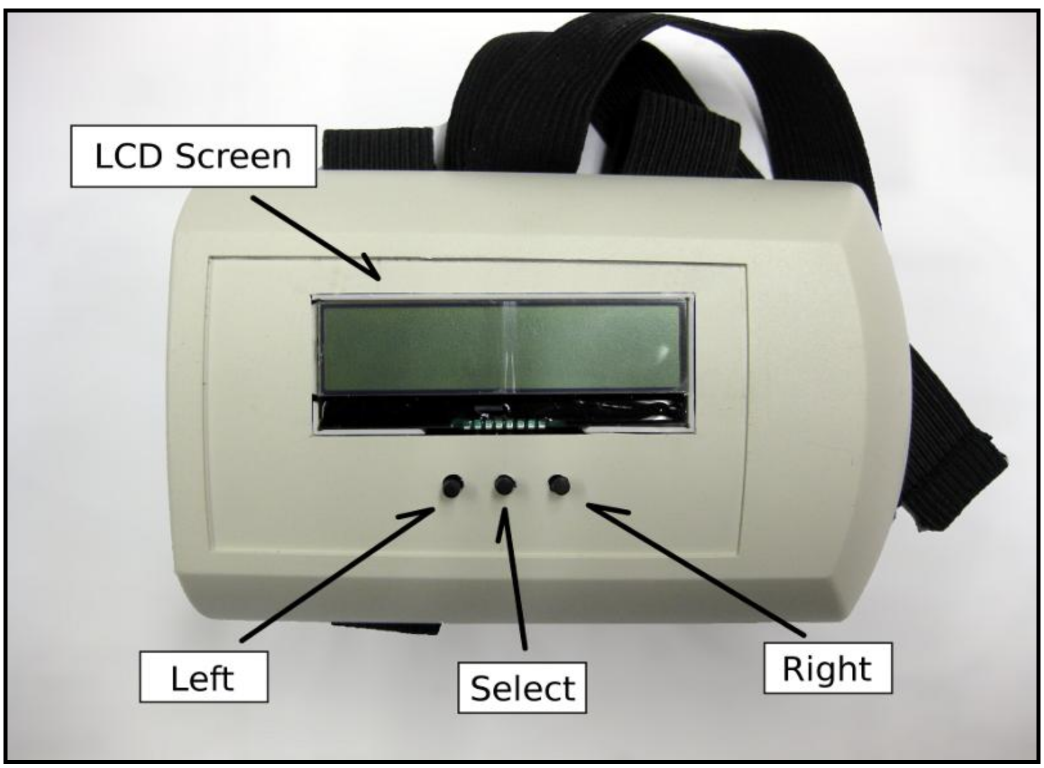


Figure B-6: Final Packaging (Top)

Appendix C: Schematic

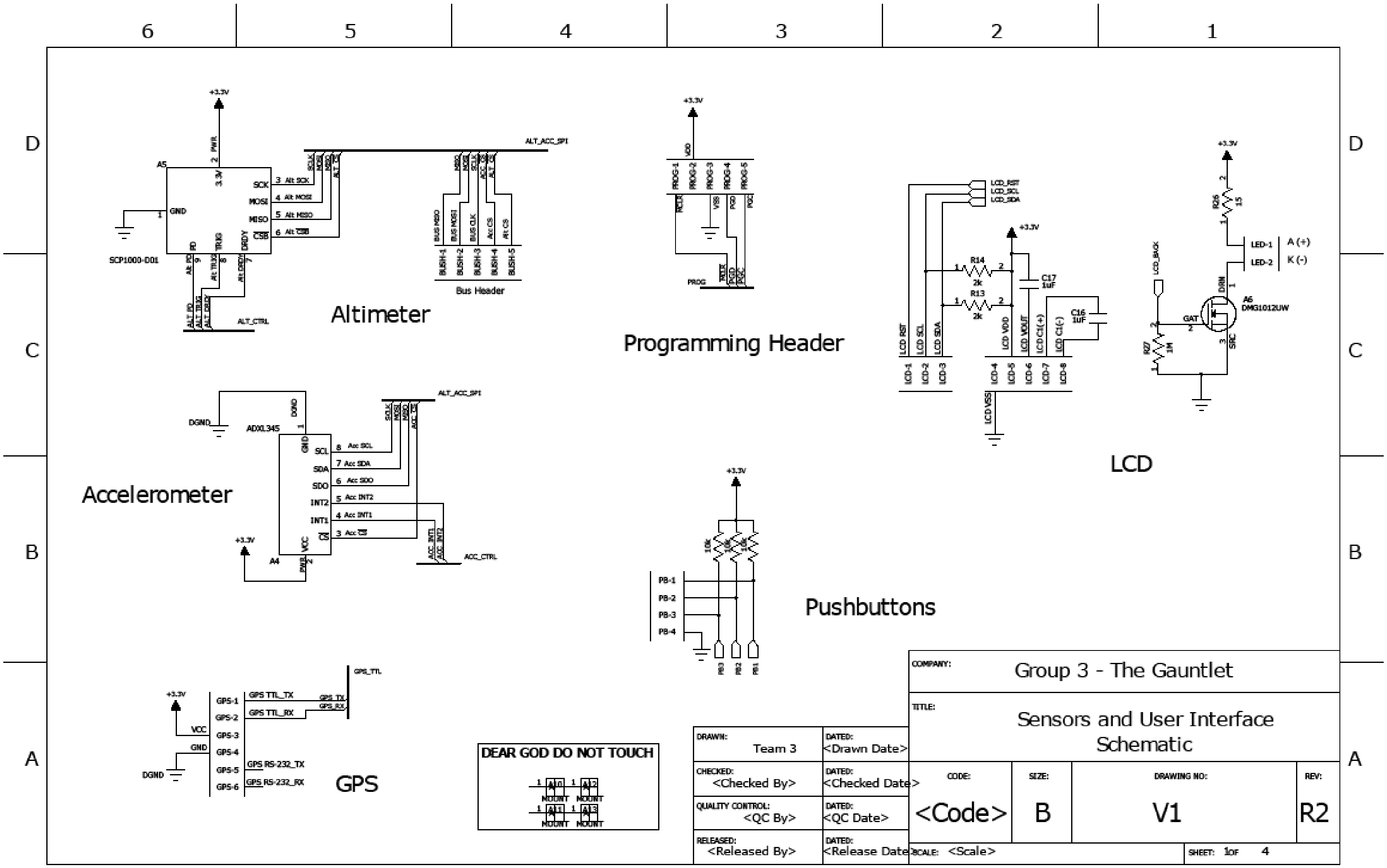


Figure C-1: Sensor and User Interface Schematic

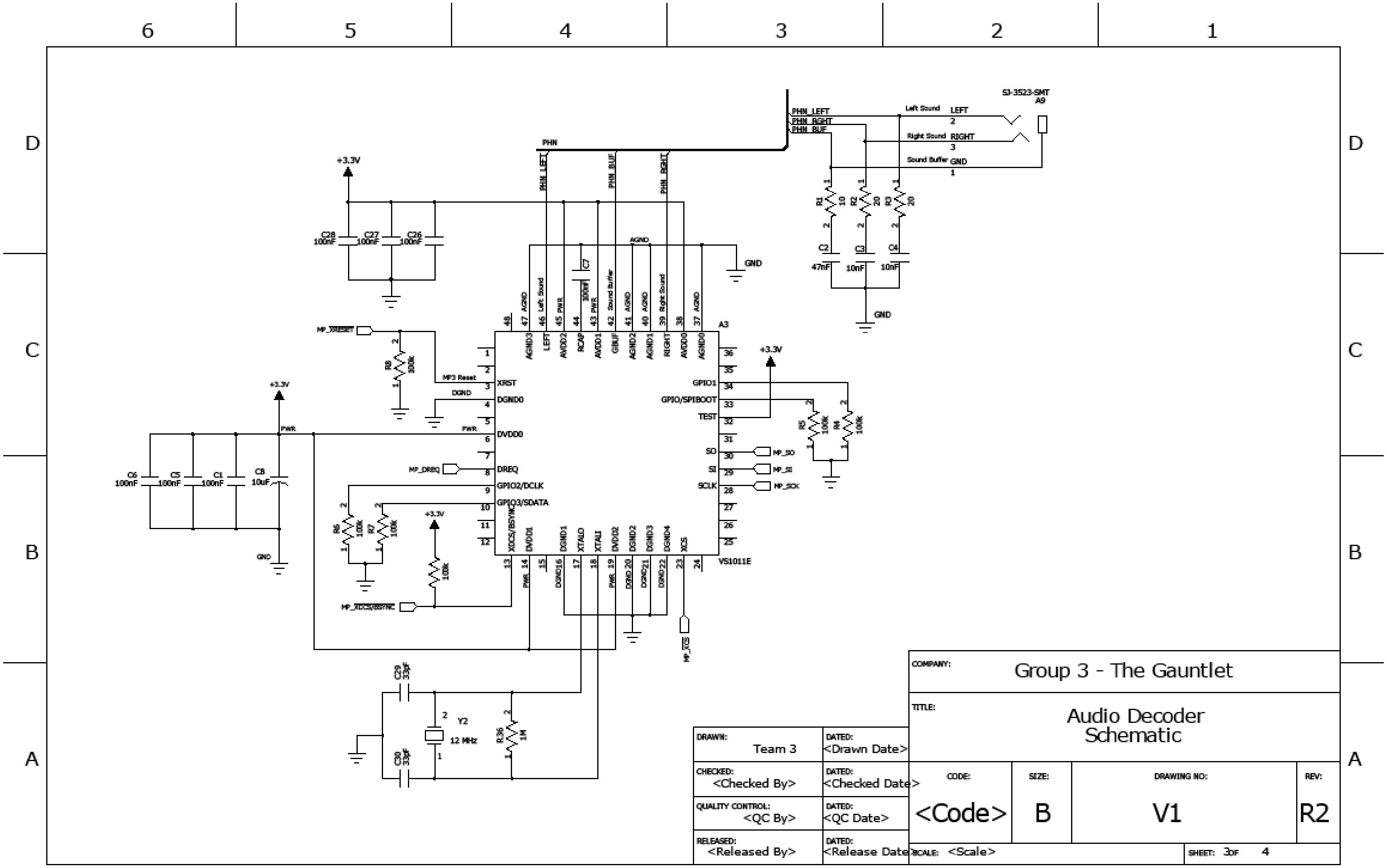


Figure C-2: Audio Decoder Schematic

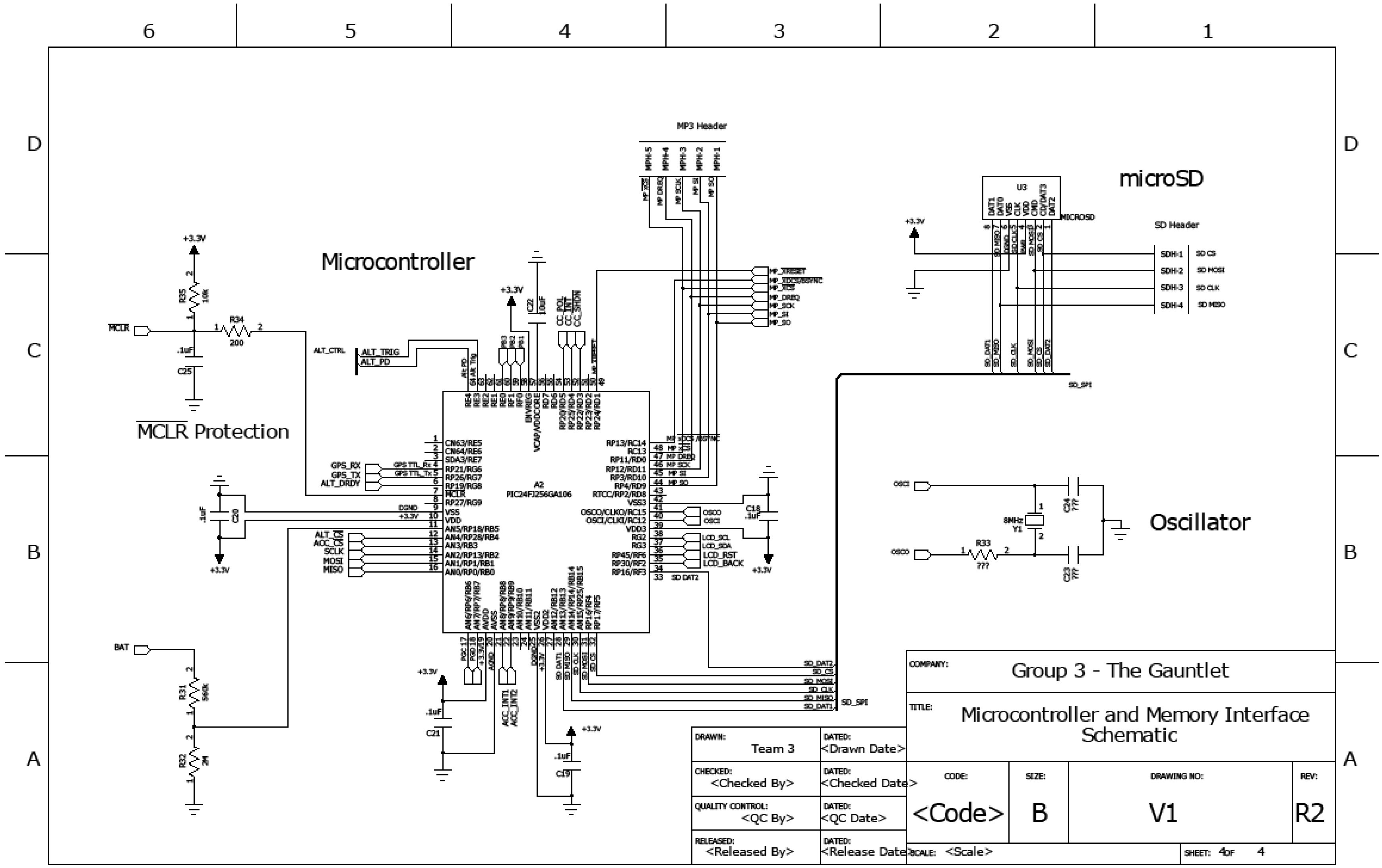


Figure C-3: Microcontroller Schematic

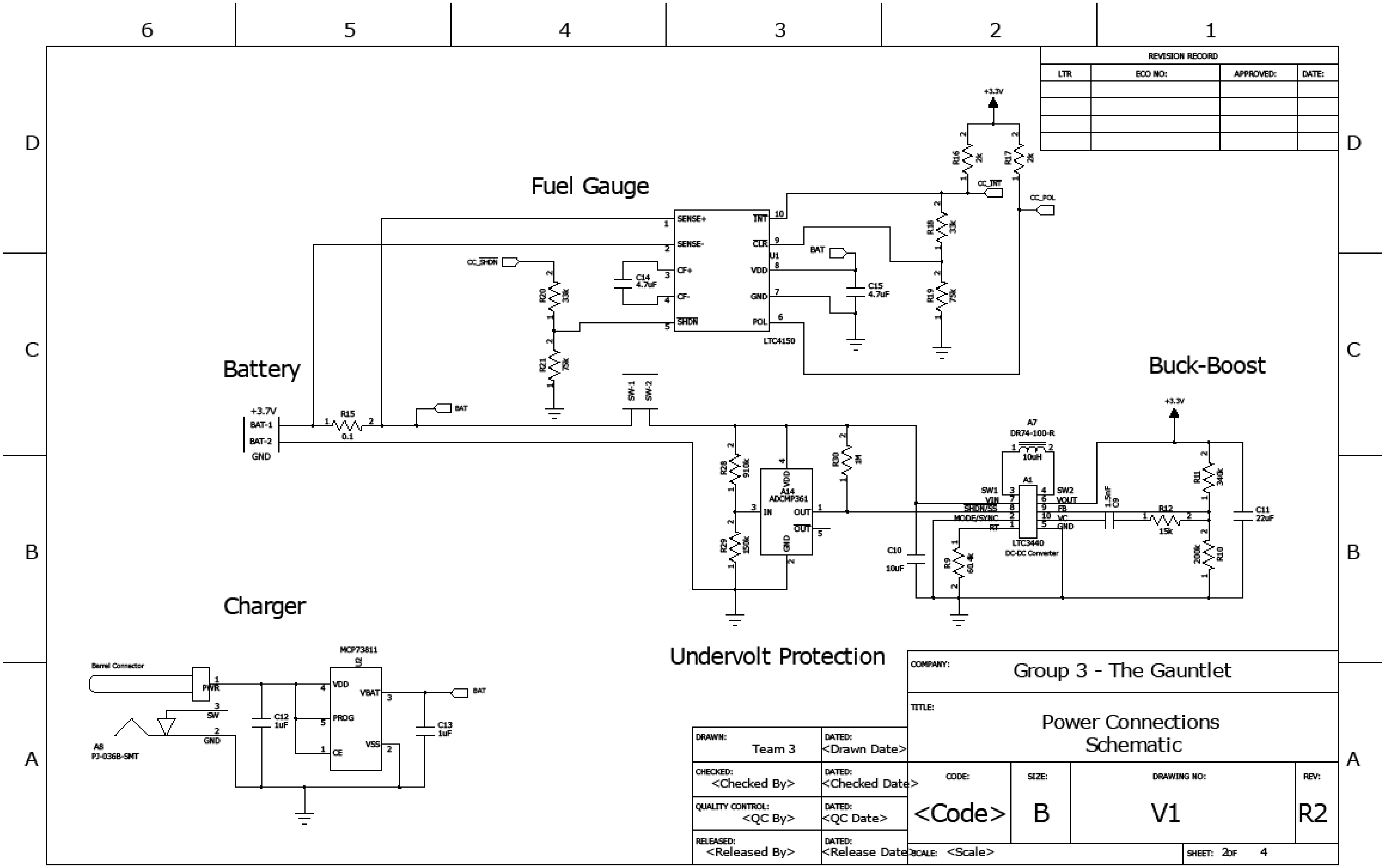
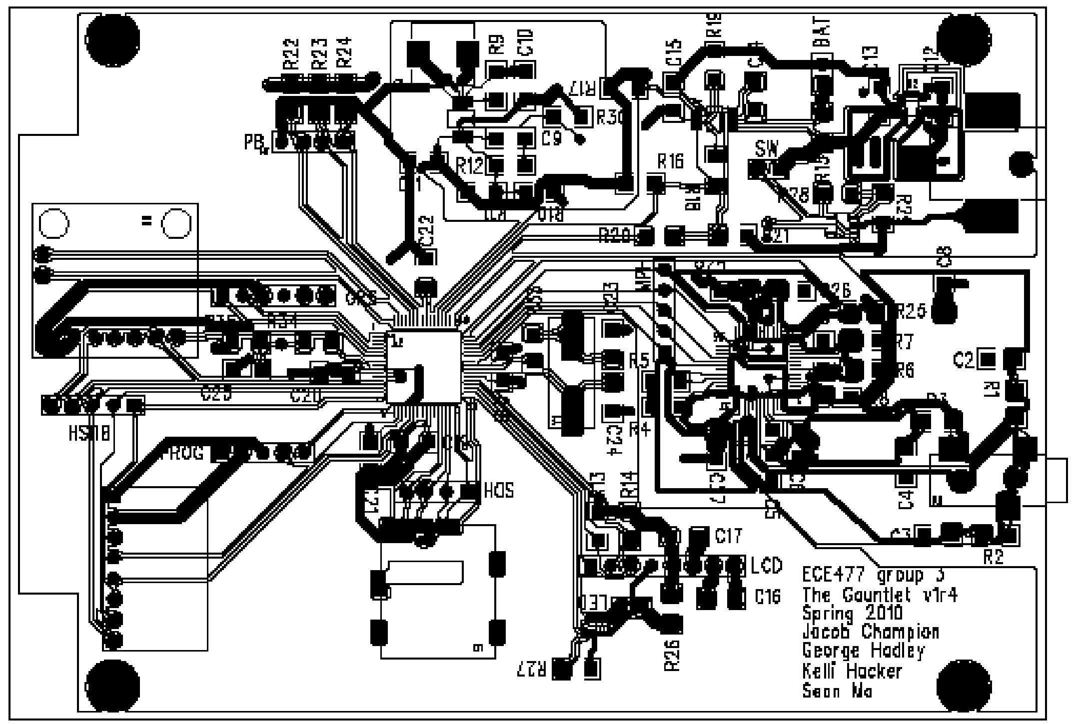


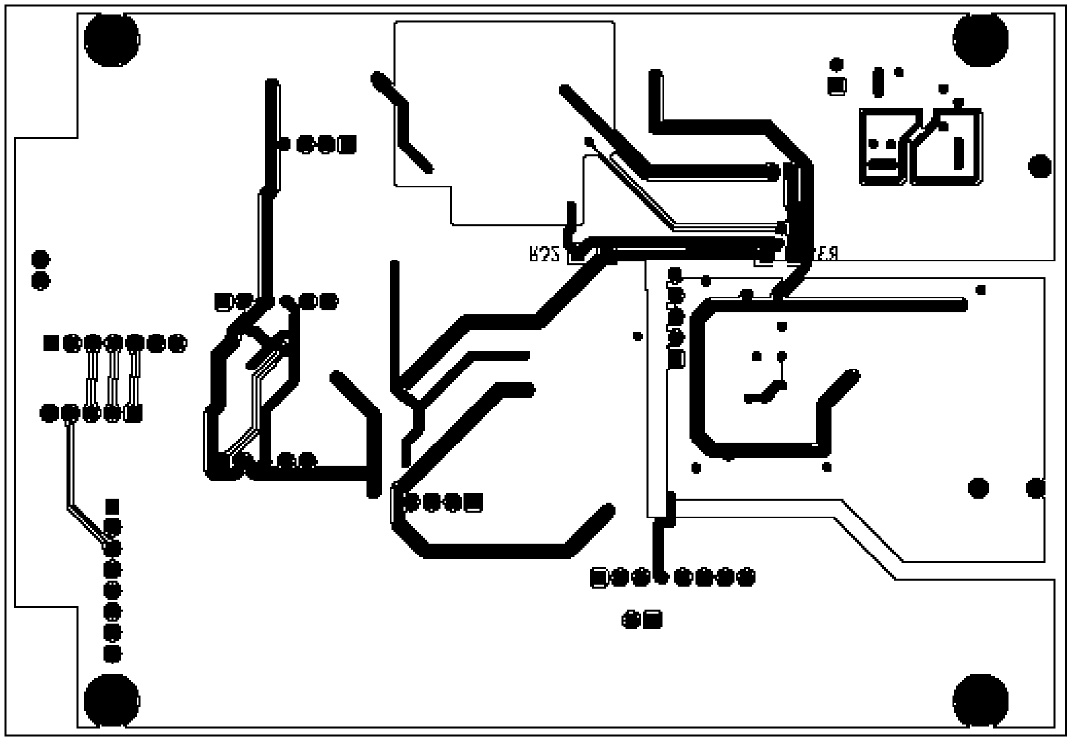
Figure C-4: Power Schematic

Appendix D: PCB Layout Top and Bottom Copper



gauntlet_final_beta.pcb - Fri May 07 13:18:23 2010

Figure D-1: Top Copper



gauntlet_final_beta.pcb - Fri May 07 13:20:08 2010

Figure D-2: Bottom Copper

Appendix E: Parts List Spreadsheet

Vendor	*Manufacturer*	*Part No.*	*Description*	*Unit Cost*	*Qty*	*Total Cost*
Sparkfun	Union Battery	PRT-08483	2000 mAh Lithium Polymer Battery	$16.95	1	$16.95
Parallax	Polstar	PMB-648	GPS Module	34.99	1	34.99
Sparkfun	VTI	SCP1000-D01	SPI Pressure Sensor + Breakout Board	34.95	1	34.95
Sparkfun	Analog	ADXL345	SPI 3-Axis Accelerometer + Breakout	27.95	1	27.95
Sparkfun	VLSI	VS1011E-L	MP3 Streaming Decoder	19.95	1	19.95
Microchip	Microchip	PIC24FJ256GA106	16-bit 32 MHz Processor	3.98	1	3.98
Digi-Key	AVX Corporation	045138008010890+	MicroSD Connector	3.86	1	3.86
Radio Shack	SanDisk	P-SDU2GB-FS/BB	2GB MicroSD Card	12.99	1	12.99
Linear	Linear	LTC3440EMS	600mA Buck-Boost 3.3V Regulator	3.24	1	3.24
Linear	Linear	LTC4150IMS	Battery Monitor/Fuel Gauge	2.45	1	2.45
Microchip	Microchip	MCP73811T	LiPo Battery Charge Management IC	0.63	1	0.63
Digi-Key	Newhaven Display	NHD-C0220BiZ-FSW-FBW-3V3M	3.3V 20x2 Character LCD	10.52	1	10.52
Digi-Key	Analog	ADCMP361	Analog Comparator	1.53	1	1.53
Digi-Key	C&K Components	L201011SS03Q	On/Off Slide Switch	2.22	1	2.22
Digi-Key	Stackpole Electronics	CSR 1/2 0.1 1% I	0.1Ω Sense Resistor	0.84	1	0.84
Digi-Key	Abracon Corporation	ABLS-12.000MHZ-B4-T	12 MHz Oscillator	0.41	2	0.82
Digi-Key	Panasonic	EVQ-11A09K	Pushbutton	0.14	3	0.42
OKW	OKW	Ergo-Case M	Package/Eyelets/Straps	30.28	1	30.28
Various	Various	-	Generic Passive Components (Resistors, Capacitors)	-	-	20.00
				TOTAL		**$228.57**

Appendix F: FMECA Worksheet

Power Subsystem						
Failure No.	**Failure Mode**	**Possible Causes**	**Failure Effects**	**Method of Detection**	**Criticality**	**Remarks**
A1	Power rail = 0 V	Short, disconnect in power supply circuit	Nothing turns on or operates	Observation	Low	
A2	Power rail > 3.3 V	Buck-boost failure, short to battery	Damage to components throughout circuit, loss of functionality	Observation	Medium	Specific damage to circuitry is unpredictable, likely not repairable
A3	Battery undervoltage	Analog comparator fails, excessive noise on buck-boost output, charger fails	Possible battery explosion	Observation	High	
A4	Battery overvoltage	Charger fails and short circuits	Possible battery explosion	Observation	High	

Microcontroller Subsystem						
Failure No.	**Failure Mode**	**Possible Causes**	**Failure Effects**	**Method of Detection**	**Criticality**	**Remarks**
B1	Microcontroller receives < 3.3 V	Bypass capacitor shorts	Microcontroller will not operate, no functionality	Observation	Low	
B2	External oscillator fails	Failure of individual components	No audio output, errors more likely in LCD communication	Observation	Low	Internal oscillator takes over if external signal is missing
B3	Microcontroller stuck in loop	Loss of communication with sensors	Loss of functionality	Observation	Low	Loss of functionality, but repairable
B4	SPI or I2C Pins stuck at 0 or 1	Software bug, internal microcontroller error	Loss of communication with sensor / LCD / audio	Observation	Low	
B5	Interrupt pins stuck	Software bug, internal microcontroller error	Loss of free-fall, battery information	Observation	Low	
B6	Altimeter CS or Accelerometer CS stuck	Software, internal microcontroller error	Loss of communication with 1 device	Observation	Low	
B7	Pushbuttons pins stuck at 1	Software bug, internal microcontroller error	Loss of communication with user, device set at defaults	Observation	Low	Very little loss of functionality
B8	Pushbuttons stuck at 0	Software bug, internal microcontroller error	Constant change of settings, loss of functionality	Observation	Low	

Audio Subsystem						
Failure No.	**Failure Mode**	**Possible Causes**	**Failure Effects**	**Method of Detection**	**Criticality**	**Remarks**
C1	MP3 decoder receives < 3.3 V	Bypass capacitor shorts	Audio does not operate	Observation	Low	
C2	MP3 decoder chip damaged	Decoder receives ESD, output capacitors short	Audio does not operate	Observation	Low	Repairable
C3	SPI pins stuck at 0 or 1	Shorted trace, internal error	Loss of communication with microcontroller, loss of new audio	Observation	Low	
C4	Audio output pins stuck at 1 or 0	Internal error, shorted trace	Loss of audio, possible annoying audio output	Observation	Low	Volume is a different function, so no extra loud noises should be emitted

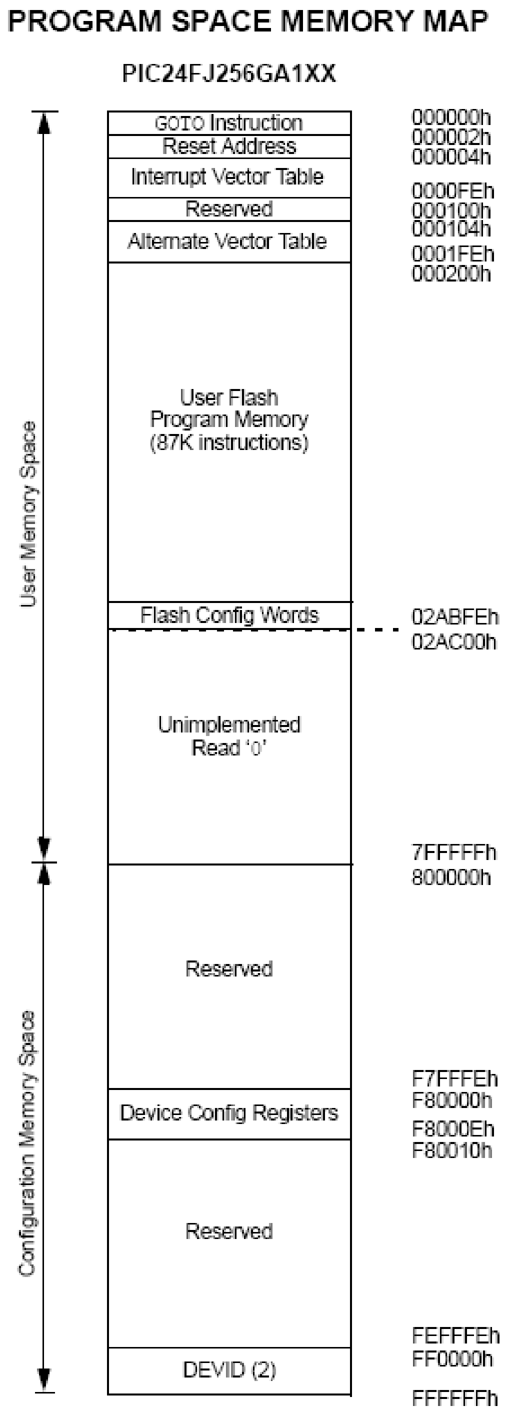
Sensors and User Interface Subsystem						
Failure No.	**Failure Mode**	**Possible Causes**	**Failure Effects**	**Method of Detection**	**Criticality**	**Remarks**
D1	Pushbutton stuck high	Switch shorted	Loss of communication with user, device set at defaults	Observation	Low	Very little loss of functionality
D2	Pushbutton stuck low	Switch broken	Constant change of settings, loss of functionality	Observation	Low	
D3	SCL or SDA pins stuck at 1 or 0	Short or disconnection of SCL or SDA pins, internal error	LCD does not change, has random values	Observation	Low	

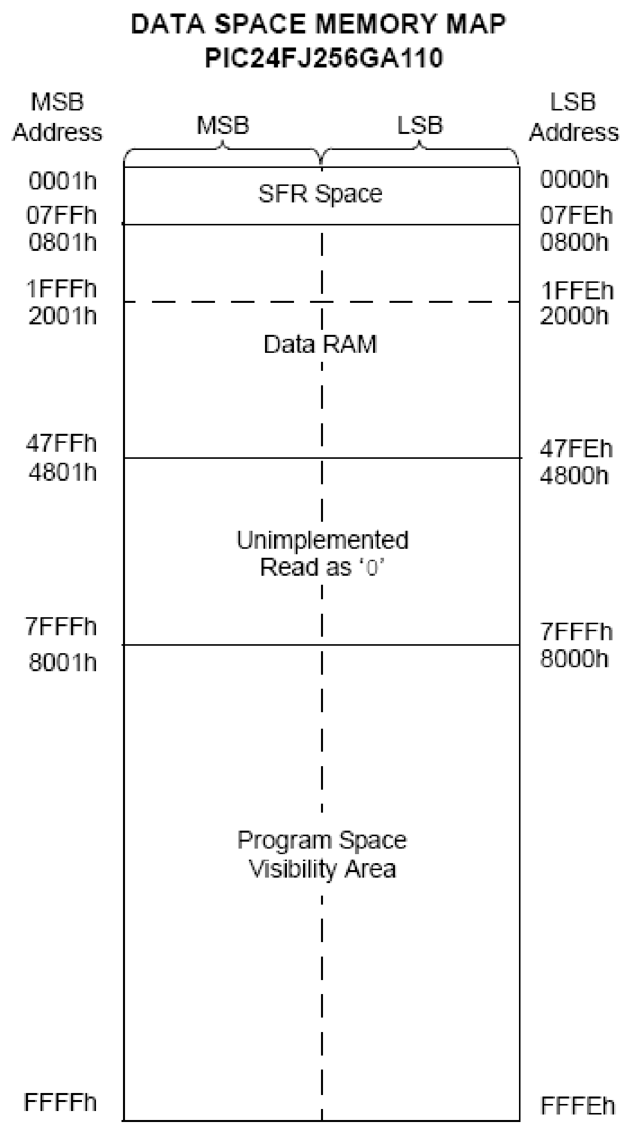
Appendix G: Pin Assignments

Microcontroller Pins	Pin#	Connect to External Device			
RP21/RG6	4	GPS TTL_Rx	GPS 2		
RP26/RG7	5	GPS TTL_Tx	GPS 1		
RP19/RG8	6	**Alt DRDY**	Alt 7		
\MCLR	7	Program - Header	Pheader 1		
VSS	9	DGND			
VDD	10	3.3V			
AN5/RP18/RB5	11	Battery			
AN4/RP28/RB4	12	Alt \CSB	Alt 6		
AN3/RB3	13	Acc \CS	Acc 3		
AN2/RP13/RB2	14	Alt SCK	Alt 3	Acc SCL	Acc 8
AN1/RP1/RB1	15	Alt MOSI	Alt 4	Acc SDI	Acc 7
AN0/RP0/RB0	16	Alt MISO	Alt 5	Acc SDO	Acc 6
AN6/RP6/RB6	17	PGC, header	Pheader 4		
AN7/RP7/RB7	18	PGD, header	Pheader 5		
AVDD	19	3.3V			
AVSS	20	AGND			
AN8/RP8/RB8	21	**Acc Int1**	Acc 4		
AN9/RP9/RB9	22	**Acc Int2**	Acc 5		
VSS2	25	DGND			
VDD2	26	3.3V			
AN13/RB13	28	SD DAT1	SD 8		
AN14/RP14/RB14	29	SD MISO	SD 7		
AN15/RP29/RB15	30	SD CLK	SD 5		
RP10/RF4	31	SD MOSI	SD 3		
RP17/RF5	32	SD CS	SD 2		
RP16/RF3	33	SD DAT2	SD 1		
RP30/RF2	34	LCD BACK	LCD "4"		
RPI45/RF6/INT0	35	LCD RST	LCD 1		
SDA1/RG3	36	LCD SDA	LCD 3		
SCL1/RG2	37	LCD SCL	LCD 2		
VDD	38	3.3V			
OSCI/CKLI/RC12	39	XTAL IN			
OSCO/CLKO/RC15	40	XTAL OUT			
VSS	41	DGND			
RP4/RD9	43	MP SO	MP 30		
RP3/RD10	44	MP SI	MP 29		
RP12/RD11	45	MP SCLK	MP 28		
RP11/RD0	46	MP DREQ	MP 8		

RC13	47	MP \xCS	MP 23	
RPI37/RC14	48	MP \xDCS/BSYNC	MP 13	
Rp24/RD1	49	MP \xRESET	MP 3	
RP22/RD3	51	CC \SHDN	CC 5	
RP25/RD4	52	**CC \INT**	CC 10	
RP20/RD5	53	CC POL	CC 6	
RF0	58	PB 1	Pushbutton	
RF1	59	PB 2	Pushbutton	
RE0	60	PB 3	Pushbutton	
RE3	63	Alt Trig	Alt 8	
RE4	64	Alt PD	Alt 9	

Appendix H: PIC24F Memory Map





Appendix I: PIC24F Register Initializations

Only applicable initialization registers and configuration bits are shown here.

Timer Subsystem

PR1	The timer period (user-configurable)	
T1CON	The timer control register	
	TON	1 (enabled)
	TSIDL	0 (continue operation in IDLE)
	TGATE	0 (no gated time)
	TCKPS<1:0>	11 (1:256 clock prescaler)
	TSYNC	0 (no external synchronization)
	TCS	0 (internal clock)

ADC Subsystem

AN1CON1	Control Register 1	
	ADON	1 (enabled)
	ADSIDL	1 (disable in IDLE mode)
	FORM<1:0>	10 (unsigned fractional output)
	SSRC<2:0>	111 (automatic conversion after sample)
	ASAM	0 (automatic sampling off)
AN1CON2	Control Register 2	
	VCFG<2:0>	000 (use Vdd and Vss as ref)
	CSCNA	0 (use CH1SA bits for channel select)
	SMPI<3:0>	0000 (interrupt after every conversion)
	BUFM	0 (buffer is 16 bits)
	ALTS	0 (use single multiplexer)
AN1CON3	Control Register 3	
	ADRC	0 (use system clock)
AD1CHS	Channel Select	
	CH0NA	0 (use VR- for negative input)
	CH0SA<4:0>	00101 (use AN5 for positive input)
AD1PCFG	Port Configuration	
	PCFG<15:0>	0xFFDF (enable AN5)

UART System

U1MODE	Mode Register	
	UARTEN	1 (enabled)
	UFRZ	0 (enable in debug mode)
	USIDL	0 (continue in IDLE mode)
	IREN	0 (disable IrDA
	RTSMD	1 (simplex mode)
	ALTIO	0 (use normal pins)
	UEN<1:0>	00 (use only U1TX and U1RX)
	WAKE	1 (wake-up enabled)
	LPBACK	0 (loopback disabled)

	ABAUD	0 (no auto-baud rate)
	RXINV	0 (RX idle state is 1)
	BRGH	0 (low speed baud)
	PDSEL<1:0>	00 (8-bit no parity)
	STSEL	0 (one stop bit)
U1STA	Status and Control	
	UTXISEL<1:0>	00 (transmission interrupt when buffer has space)
	UTXINV	0 (TX idle state is 1)
	UTXBRK	0 (sync break disabled)
	UTXEN	1 (transmit enabled)
	URXISEL<1:0>	00 (interrupt when single character received)
U1BRG	Baud Rate Generator	
	BRG<15:0>	0x0019 (9600 baud; 0.16% error)

SPI System

SPIxSTAT	Status Register	
	SPIEN	1 (enabled)
	SPISIDL	0 (disable in IDLE mode)
SPIxCON1	Control Register 1	
	DISSCK	0 (internal clock enabled)
	DISSDO	0 (SDOx pin enabled)
	MODE16	1 (Communication is 16-bits wide)
	SMP	1 (input sampled at end of clock)
	CKE	0 (negative clock edge for output)
	SSEN	0 (slave select not used)
	CKP	1 (high idle clock)
	MSTEN	1 (master)
	SPRE<2:0>	prescaler (different for different modules)
	PPRE<2:0>	prescaler (different for different modules)
SPIxCON2	Control Register 2	
	FRMEN	0 (framing disabled)
	SPIFSD	0 (frame sync disabled)
	SPIBEN	0 (enhanced buffer mode disabled)

I2C System

I2C1CON	Control Register	
	I2CEN	1 (enabled)
	I2CSIDL	1 (disable in IDLE mode)
	A10M	0 (7-bit addressing)
	DISSLW	1 (slew rate control disabled)
	SMEN	0 (disable SMBus thresholds)
	ACKDT	0 (negative ACK)
I2C1BRG	Baud Rate Generator	
	BRG<15:0>	0x0012 (400 kHz)