Project Proposal and Feasibility Study

Smart Sole

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Calvin College Engineering 339/340

Senior Design Project

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Abstract

The Smart Sole team consists of a group of four engineers pursuing a Bachelor of Science in Engineering with an Electrical and Computer Concentration at Calvin College. They are expected to graduate in the Spring of 2017. The Smart Sole team originally set out to create a fitness tracking device that could be entirely powered by energy generated by piezoelectrics. That original goal was determined to be unfeasible after preliminary piezoelectric testing, so the scope of the product was modified. The team then decided to focus on making a fitness tracker that is more accurate and precise than comparable competition. This goal will be accomplished by integrating a piezoelectric comparator, an accelerometer, and GPS all into a standard running shoe. Communications to a mobile application will be done via Bluetooth. This will allow the exporting and storage of user data for easy viewing and access. The team will make sure that all features are implemented while preserving the comfort and aesthetics of the shoe. This document provides a proof of feasibility of the project. It also outlines the requirements, testing methods, and decision methodology employed by the Smart Sole team.

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1 Introduction

Initial inspiration for the Smart Sole team was found when observing a loss of energy in athletic activities. Using the global push for capturing renewable energy as a lens, the Smart Sole team saw athletic activities, such as recreational sports (Basketball, Soccer, Tennis, etc) and running, as having a great amount of mechanical energy that was underutilized. There is a lack of formal processes put in place to recapture this expended energy. The team decided to develop a method that would capture that energy and put it to use. The team decided to focus on running and walking as the primary athletic activities examined. The process of running/walking involves a person exerting energy in a constant manner over an extended period of time. Running/walking is also an activity that a large portion of the world's population participates in frequently. These factors combined make running the ideal focus as it is popular, providing a large potential user base, and mechanically ideal for energy harvesting, as it is continuous and steady. In addition to the harnessing and storing of energy, the team saw the potential to use the energy to power sensors that could be used for analysis to replace or augment analysis given by activity trackers. As the project progressed and feasibility of the energy recapture was called into question, providing an accurate fitness tracker became the primary focus of the team, with sustainability viewed as a secondary objective.

The Smart Sole Team consists of Nicholas Beezhold, Modeste Niragire, Garrett Schliebe, and Andrew Twining. They are all Senior electrical and computer engineering students at Calvin College. The team members all share a passion for innovation and being on the cutting edge of technology. They all will graduate from Calvin College in the Spring of 2017 with a Bachelor of Science in Engineering, Electrical and Computer Concentration.

The Smart Sole project is part of the senior design course offered by Calvin College to engineering seniors. This is a required course that is intended to offer students the opportunity to work on an extended project that will challenge their abilities and demonstrate how a project may develop and function in an industry working environment. This involves researching, designing, prototyping, and testing as well as developing a potential business plan and marketing strategy for the product. The course also encourages students to develop their project management skills as the extended nature of the project makes planning and accountability a necessity. The course is offered over two semesters as ENGR 339 and ENGR 340. It is ultimately concluded with the Senior Design Banquet where the final project is presented.

Calvin College is “a top-ranked liberal arts college in Grand Rapids, Michigan that prepares students to be Christ’s agents of renewal in the world”.[1] Calvin College was founded in 1876 as a school of ministry training for the Christian Reformed Church. It has now grown to be one of the top liberal arts colleges in the Midwest, with over 4,000 students. Calvin College believes in integrating the Christian faith with learning to equip students with the skills necessary to live as agents of renewal in the world.

[1] "Calvin College | Grand Rapids, Michigan." 2015. 12 Nov. 2016 <https://calvin.edu/>

2 Project Description and Requirements

2.1 Project Description

The Smart Sole team formed around a desire to recapture energy lost through athletic activities and use this energy to power a device that is useful to the athlete. After exploring many options, including pressure sensing soccer balls and energy harvesting basketball courts, the team settled on the activity of walking and running. Walking is an activity that most people do every day. Providing a product that is incorporated into daily life will increase the potential customer base and encourage a large portion of society to practice healthy fitness habits. The final proposed design by the Smart Sole team incorporates piezoelectrics and other additional hardware into a running shoe. This product will be able to be used as a fitness tracker that is comparable to other similar products on the marketplace.

Piezoelectrics are materials that convert mechanical pressure into electrical energy. By implementing piezoelectrics into the sole of running shoes, the user can capture energy with each step they take. Rectifying the voltage and storing it in a battery or capacitor provides power that is necessary to power additional on-board sensors. The data that is acquired by the sensors will then be sent to a mobile application that will be able to store and analyze the data. The piezoelectrics can also be used to track steps as they will produce a voltage after each step a user takes. Through the use of piezoelectrics and other current step tracking technologies, the Smart Sole team believes that they can produce a fitness tracker that is more accurate and precise than a device that uses an accelerometer alone.

A mobile application will be created to allow a user to interface with the hardware. The mobile application should be able to export data from the in-shoe hardware via Bluetooth. The application will organize and store the data in a way that is easy for the user to understand. Time permitting, additional features will be added within the mobile application. Some potential features that are being considered are GPS tracking, velocity tracking and analysis, pace analysis, and step pressure analysis. Including these additional features will allow a user to track their running/walking habits and may help them make changes to avoid injury. A depiction of the interaction between the hardware and software can be seen in Figure 1.

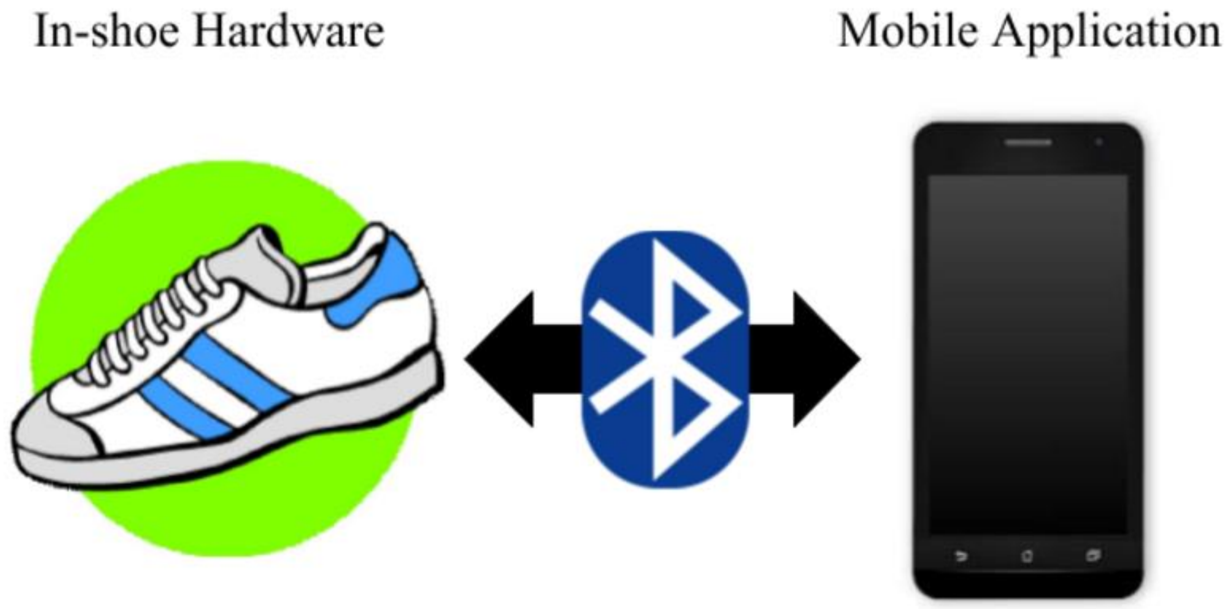

Figure 1: Simple Stylized System Diagram

2.2 Interface Requirements

The mobile application will provide a user-friendly interface that allows the end user to easily view data acquired by the device. The customer should be able to view current step count data as well as past archived step count data as desired. This data can be viewed in both a graphical format, comparing data taken from different times, as well as a raw data format. These two options will provide the user with an easy to understand visualization of their activities and allow them to explore the actual data further if they desire.

The insole hardware should require minimum manual maintenance performed by the consumer. The lifetime of the product should be at least two years without maintenance. This number is consistent with the warranty period of a Fitbit device.[2] A complete list of the interface requirements and their current status can be found in Table 1 below. Requirements are separated into hardware and software requirements and listed based on their perceived importance. They are each given a letter and number combination that represents the type of requirement and the importance.

[2] "Returns and Warranty - Fitbit." 12 Feb. 2016, https://www.fitbit.com/legal/returns-and-warranty. Accessed 10 Dec. 2016.

Table 1: Interface Requirements

	Requirement	Status
Software Interface	SI.1 The user interface of the mobile application should be intuitive and usable by any customer over the age of 8	In progress
	SI.2 The user should be able to view their step count data in raw data for and graphical form	In progress
	SI.3 The user should be able to view data from up to 90 days prior, assuming a usage of once per day	In progress
	SI.4 The application should provide some form of interactive achievements/statistics to encourage regular usage	In progress
Hardware Interface	HI.1 The user should only need to interface with the in-shoe hardware via the battery or battery charging device	Battery options currently being explored
	HI.2 The device should function without manual user maintenance for two years	Original goal subject to change based on durability research

2.3 Functional Requirements

The functional requirements for both the hardware and software were defined by the Smart Sole team. The goals of this project are to capture energy from kinetic motion, to power sensors for analysis, and connect and successfully send data to a phone application. Requirements were defined to help achieve these goals. The requirements were once again divided into hardware and software requirements. Some important aspects considered when developing these requirements were ergonomics (size and weight), power consumption, voltage and current levels, durability, reliability, functional capabilities, cost, security, safety, as well as many more. These aspects were all analyzed and condensed into a list of requirements that aims to address any functional concerns regarding the product. The list of requirements and their current status, in order of perceived importance, can be found in Table 2 (for hardware) and Table 3 (for software) below. The importance of each requirement is subject to change based on further research, and more requirements may be added if the team notices an area of the project that lacks definition. The requirements are each given a letter and number combination that represents the type of requirement and its importance.

Table 2: Hardware Functional Requirements

	Requirement	Status
Hardware Functionality	HF.1 The device shall be able to record and export step count data	Step count currently working with piezos
	HF.2 The device shall not cause any additional safety concerns such as cuts, blisters, electric shock, battery corrosion, or an thing else that might harm a user	In progress
	HF.3 The device should be designed to minimize power consumption to a level comparable to other similar products	Currently met
	HF.4 The device should be able to fit into a shoe without causing discomfort to a walker/runner	In progress
	HF.5 The device should be able to withstand standard running and walking practices with a two year lifetime of semi regular use	In progress
	HF.6 The hardware should be able to store data for exporting at a later time	Currently met
	HF.7 The components and design of the hardware should be selected in a manner to minimize the overall weight of the product	In progress
	HF.8 The cost of the product should be less than that of other comparable products on the market	In progress
	HF.9 The device should be water resistant and usable in wet and humid conditions	In progress
	HF.10 The device should use renewable energy sources whenever possible	Under cost benefit evaluation currently
	HF.11 The device should operate at low current levels of less than 15 mA as determined by the peak current consumption of Bluetooth LE	Currently met
	HF.12 The device should operate at a voltage level of 5V or below	In progress

Table 3: Software Functional Requirements

	Requirement	Status
Software Functionality	SF.1 The mobile application shall be able to export data from the Bluetooth processor in the hardware	In progress
	SF.2 The mobile application should have a idle mode that uses minimal processing power and phone resources	In progress
	SF.3 The mobile application should store user data for up to 90 days	In progress
	SF.4 The mobile application should be able used to store data during the run or after	In progress
	SF.5 The mobile application should be fun and easy to use	In progress
	SF.6 The mobile application should safe user data locally	In progress
	SF.7 The mobile application should be secure and prevent third party access of customer information	In progress

2.4 Performance Requirements

Step counting was the primary performance objective of the Smart Sole device, and distance tracking and route mapping were secondary stretch objectives. Preliminary research showed that step counters currently on the marketplace all have some level of error in step counting and distance tracking; however, different studies showed differing levels of error. A study performed by various medical researchers found that differences in mean step count ranged from -22.7% to -1.5% for wearable fitness trackers and -6.7% to 6.2% for mobile application fitness trackers.[3] Data obtained from this study can be found in Figure 2. The data displayed is for the 500 step trial. According to the researchers, findings were "mostly consistent" between the 500 step and 1500 step trial. The counters with the highest accuracy, the Fitbit One and the Fitbit Zip, are both clip-on devices. In general, clip devices were shown to be more accurate than other wearables.

[3] Case MA, Burwick HA, Volpp KG, Patel MS. Accuracy of Smartphone Applications and Wearable Devices for Tracking Physical Activity Data. *JAMA.* 2015;313(6):625-626. doi:10.1001/jama.2014.17841

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From: **Accuracy of Smartphone Applications and Wearable Devices for Tracking Physical Activity Data**

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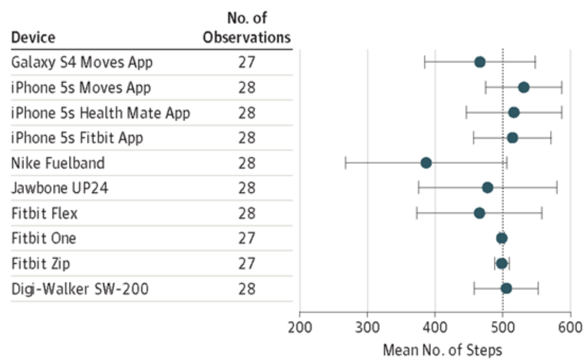

Figure Legend:

Device Outcomes for the 500 Step TrialsThe vertical dotted line depicts the observed step count. The error bars indicate ±1 SD.

Figure 2: Step Counter Accuracy

A group of engineers from universities in Sheffield, United Kingdom also performed similar research in 2015.[4] This group examined the step count detection accuracy of seven separate commercially available activity monitors. The devices used in this study were all different forms of wearables that are worn on various locations on the body such as the lower back (Movemonitor), waist (Fitbit One), legs (Tractivity and ActivPAL), or arms. This study also observed the effects that walking speed could have on the accuracy of a step count reading. This became another important factor that the Smart Sole team began to consider when developing performance requirements. The data for this research was provided in the form of mean percentage error (MPE). Mean percentage error is found by taking the mean of the summation of the error percentages for each trial. A graphical representation of the data can be seen in Figure 3. The error bars displayed on the graph represent plus or minus one standard deviation. The data showed that most fitness trackers, while accurate at a high speeds, struggled with accuracy at a low walking speeds.

[4] "Step Detection and Activity Recognition Accuracy of Seven Physical ...." 19 Mar. 2015, http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0118723. Accessed 11 Dec. 2016.

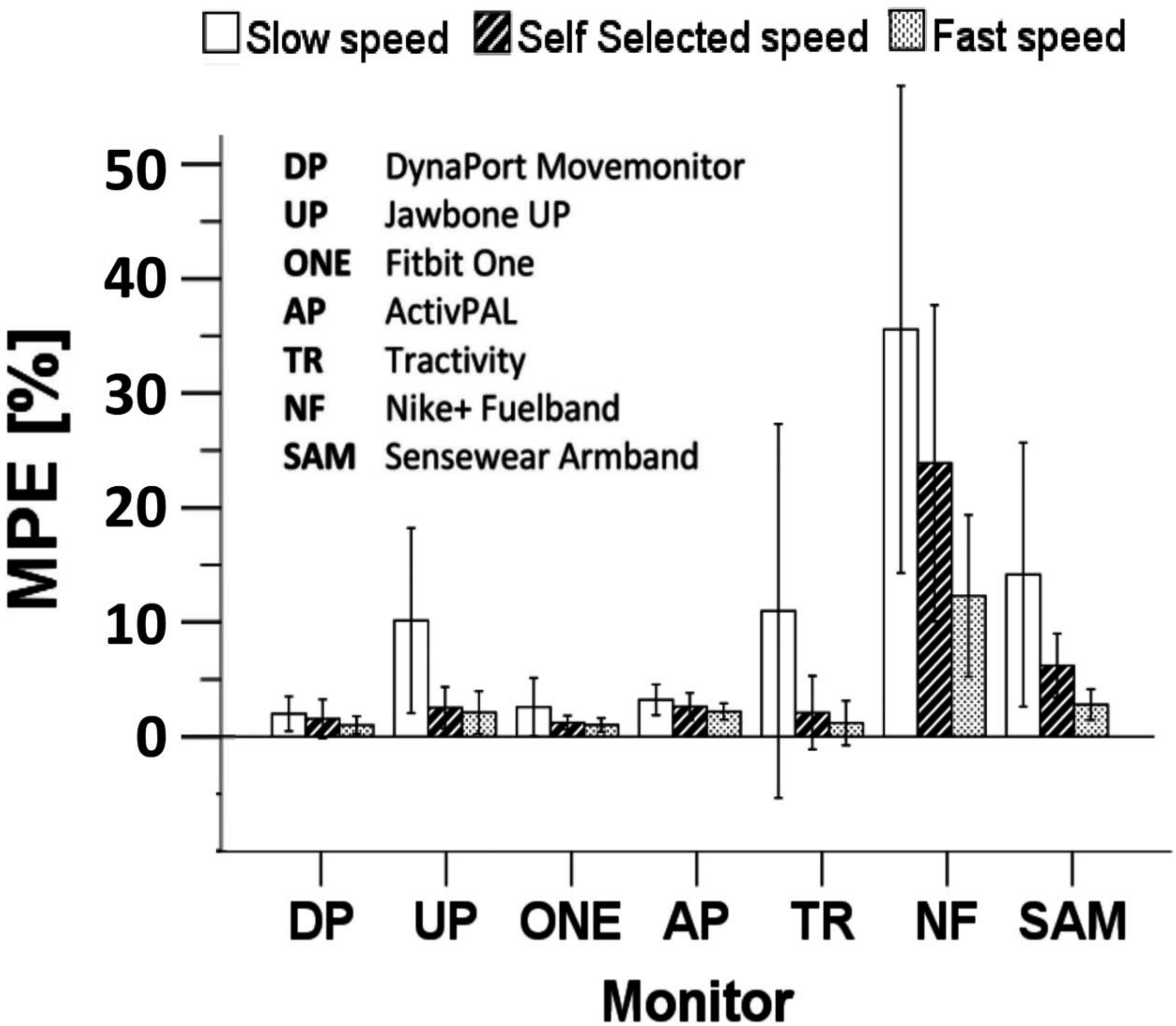

Figure 3: Step Counter Error at Varying Walking Speeds

Distance accuracy is also a problem seen in wearable devices. A study performed in 2015 by Dan Graziano of CNET found that distance tracking error ranged anywhere from 0.3% (calibrated Apple Watch) to 16% (Pivotal Tracker 1).[5] The full results can be viewed in Figure 4. These results are based on the average of three walks. The distance was calculated by the distance measuring functionality of a treadmill. Additional research performed on the accuracy of fitness trackers showed similar results.

[5] "How accurate is the Apple Watch's step counter and distance tracking ...." https://www.cnet.com/news/smartwatch-step-counter-and-distance-tracker-accuracy/. Accessed 11 Dec. 2016.

Activity trackers

Device	Steps	Distance (mi)	Difference*	Deviation*
Apple Watch (calibrated)	2,097 avg	1.003 avg	0.003	0.3%
Garmin Vivosmart	2,079 avg	1.01 avg	0.01	1%
Lifetrak Zone C410	2,120 avg	0.96 avg	-0.04	4%
iFit Active	2,166 avg	0.96 avg	-0.04	4%
Misfit Shine	2,102 avg	0.93 avg	-0.07	7%
Fitbit Charge	2,108 avg	0.91 avg	-0.09	9%
Apple Watch (out of the box)	2,107 avg	1.10 avg	0.1	10%
Pivotal Tracker 1	2,083 avg	0.84 avg	-0.16	16%

Figure 4: Distance Accuracy of Activity Trackers

The performance requirements that the Smart Sole team developed were based on the research outlined above. The Smart Sole product should provide a step count and distance monitoring accuracy that is, at the very minimum, comparable to the current leader of the market competition. This threshold was set at less than plus or minus 5% for step count and less than plus or minus 4% for distance (if applicable based on design decisions).

Additional performance considerations included power, charge time, standard deviation of error, and application performance. Although the Smart Sole design intended to use all renewable energy, the team found this unfeasible. Discussion of this begins in section 5.3.1 below. Battery and power requirements are dependent on the implementation of the system's power circuitry. Rechargeable batteries are seen as desirable as they have a longer lifetime and would not need to be replaced; however, requirements were developed for both options so the team would have objectives that were clearly defined when making a decision regarding the power supply circuitry. Requirements of the design option that is not used in the final product will be eliminated once the proper decisions have been made. Some additional performance options may be explored by the team if time permits. These include requirements such as run mapping accuracy (if GPS tracking is implemented) and calibration (if an accelerometer is implemented). The requirements are each given a letter and number combination that represents the type of requirement and its importance.

Table 4: Performance Requirements

	Requirement	Status
Hardware Performance	HP.1 Step count error should be less than +/- 5%	In progress
	HP.2 Distance tracking error should be less than +/- 4%	In progress
	HP.3 Step count and distance error should remain within 5% of the mean percentage error at all walking speeds (to reduce standard deviation)	In progress
	HP.4 The internal battery (if rechargeable) should be able to last at least 8 hours in use	In progress
	HP.5 The internal battery should charge from empty to full in under 2 hours (if rechargeable battery is used)	In progress
	HP.6 The rechargeable battery (if used) should last the lifetime of the product (~2 years)	In progress
	HP.7 The internal battery should last 1 year under normal operating conditions or be easily replaceable (if non-rechargeable battery is used)	In progress
	HP.8 The hardware should enter an idle low power mode if not in use to conserve battery life	In progress
Software Performance	SP.1 Data should be exported to the mobile application in less than 5 seconds	In progress
	SP.2 Application performance should be consistent with what is expected by users (verified through testing)	In progress

2.5 Environmental Requirements

One of the initial aims of the Smart Sole team was to produce a product that would have a minimal environmental impact. The team also hoped to promote sustainability by harnessing energy generated by the piezoelectrics. The initial primary environmental requirement was to use renewable energy as the primary source of power. This way, additional power is not needed to power sensors. By increasing the amount of energy the product generates, the need for a nonrenewable source of energy within the product decreases. The facilities and materials used to create the product should also be taken into account when considering sustainability. The facilities and materials used to produce the product should be carbon neutral and limit the amount of waste. This will be taken into consideration when developing a business plan and selecting vendors of the individual components. The electronic hardware used within the product should be recyclable at any electronic recycling center. The components should also be environmentally safe if a user unknowingly disposes of the product in the trash. A concise list of all the environmental requirements and their current status can be found in Table 5. The requirements are each given a letter and number combination that represents the type of requirement and its importance.

Table 5: Environmental Requirements

Requirement	**Status**
E.1 The insole hardware should be powered via piezoelectric power generation	Unfeasible, requirement will be adjusted to a more realistic threshold based on testing data
E.2 The vendors of components used in the Smart Sole product should incorporate sustainability practices into their business model	In progress
E.3 Smart Sole facilities used for production should minimize energy usage and waste in an attempt to remain carbon neutral	Business plan in development
E.4 The electronics used in the product should be disposable at any electronic recycling center	Currently met
E.5 The product should be trash safe	Currently under investigation

2.6 Project Deliverables

In addition to all of the requirements established for the functionality of the Smart Sole product, a list of deliverables was also generated. These deliverables are listed below along with their status in Table 6.

Table 6: Project Deliverables

Deliverable	**Status**
Final PPFS	Completed 12/12/16
Final Report	In progress
Working Prototype	In progress
Mobile Application	In progress
Design Notebook	In progress
Team Website	Under maintenance
Software User Guide	In progress

3 Scope and Constraints

The Senior Design course offered by Calvin College is a two semester course; therefore, the total scope of the project is limited by the time available. Furthermore, although Calvin College provides excellent facilities for design work, there is certain equipment that will not be available for use, thus limiting the scope. The scope of the project is also limited by the available budget. Each senior design team had a budget of approximately $500 to spend on components, travel, and any other expenses associated with the project. If addition money is needed, that money would have to be acquired via fundraising or a third-party sponsor. These are the main constraints of the project from a high-level management perspective.

The biggest constraints of this project, from a functional perspective, are space, comfort, component resilience, budget, and power. The size of the shoe limits the number of components the team can fit into the shoe. This limits the size of the components that will be used as well as their arrangement within the shoe. In addition, the comfort of the user must be considered. Comfort is crucial as uncomfortable shoes can lead to injuries and other safety concerns. Furthermore, a customer is less likely to use a product that they consider to be uncomfortable or inconvenient. The additional components must therefore be small and not add points of pressure on the user's foot that would cause pain or discomfort.

Another problem to consider is the resilience of the components. As the components are stepped on repeatedly over time by a user's foot, the mechanical stress has the potential to cause damage. The components the team picks must be able to handle the oscillatory impact over a long period of time. With unlimited money, the team has the potential to get the smallest military grade components that can handle high levels of stress; however, the team budget is finite. The cost of higher quality components would transfer over to the consumer as a higher sale price.

Finally, the system’s power budget must be considered. If renewable energy is selected as the main source of energy, all components used for analysis and performing the vital functions of the product must be low power. Even if an internal battery is selected, low power components should be considered to reduce the need for frequent battery replacement or charging (if the selected battery is rechargeable).

4 Project Management

4.1 Team Organization

The team consists of four members: Nick Beezhold, Garrett Schliebe, Andrew Twining, and Modeste Niragire. All of the members are Electrical and Computer Engineering Majors. In addition, the team has one business minor and a math minor. The project is divided into four roles, including hardware, software, project management, and energy capture. In addition, each team member will do research when necessary. Research will not be confined to the head of the section which relates to the research. Each team member is in charge of a one of these roles in the project; however, this does not limit that member to working solely on the role they are in charge of. Each team member is expected to contribute to any role, as needed.

Nick Beezhold is in charge of project management. He is responsible for assigning responsibilities to the members of the team, setting goals and creating a schedule, as well as tracking the team's progress. In addition, Nick will handle all of the budgeting and the business plan. He will also assist in the research and design of the hardware portion of the project.

Garrett Schliebe will be in charge of the software portion of the project. This includes designing and coding an app for the iPhone that will collect the data from the hardware through Bluetooth. The data will be stored, and the app will display various measures. In addition, Garrett is the team webmaster.

Andrew Twining will be in charge of the hardware portion. He will be responsible for researching and designing the circuitry to capture and store the energy from the piezoelectrics. He will design hardware to implement both the comparator and additional sensors, such as the accelerometer and Smart GPS. He will also assist in implementing the Bluetooth interface.

Modeste Niragire will be in charge of the energy capture portion of the lab. This includes researching and choosing the piezoelectrics used to generate the power. He will also determine the power storage solution and the necessary energy needed to power the devices. Finally, Modeste will be in charge of integrating the hardware into the shoe in a way that is ergonomic.

Additional contributors to the team include the team advisor, Mark Michmerhuizen, and the industrial consultant, Eric Walstra. Mark Michmerhuizen is an Electrical and Computer Engineering Professor at Calvin College and brings both industry experience as well as project management advice to the team. Eric Walstra is an Engineering Manager at Gentex and has more than 15 years of industry experience. A meeting with Eric Walstra was held on November 3 to discuss the project and risks involved. Figure 5 shows the roles of the project supervisors throughout the semester.

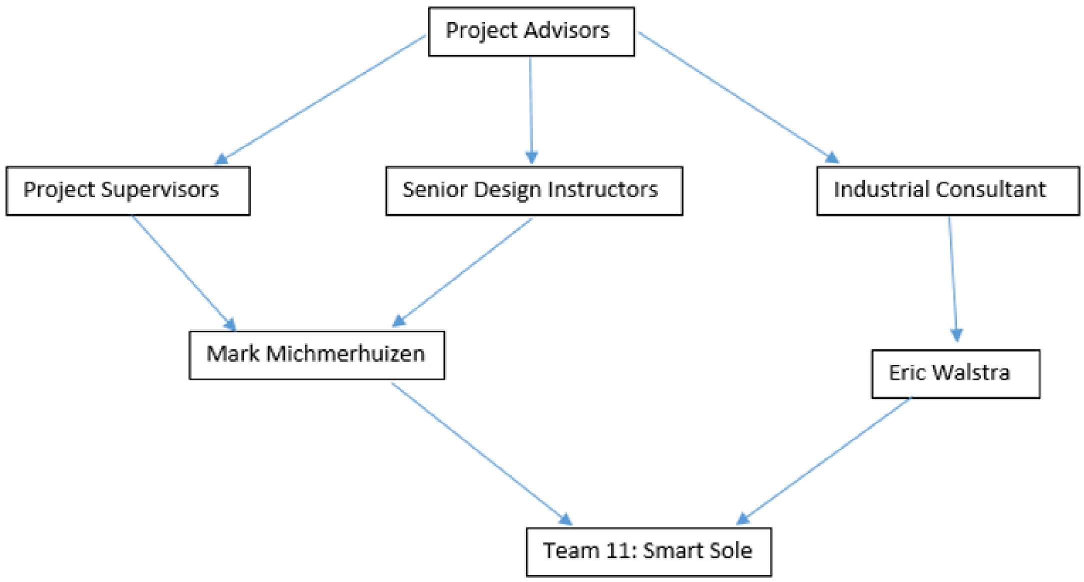

Figure 5: Project Supervisors

Team meetings are held on a weekly basis, with additional meetings during Senior Design class time occurring approximately once a week. These meetings typically include project research time, project planning, and project work days to generate required documents. All team documents are held in a shared folder on Google Drive. This includes meeting minutes, research notes, presentations, schedules, testing results, and any other document or information relevant to the team. The folder is currently only shared between team members and the project supervisor Mark Michmerhuizen. Additionally, the final three weeks of lab time for a required computer engineering course were utilized to design portions of the step count module.

4.2 Schedule

Nick is in charge of maintaining the schedule and adjusting goals and deadlines weekly based upon the realized progress of the project. An action item list is used to to organize project deliverables, and is provided in Appendix B. A work breakdown schedule was created to assist in determining what jobs and tasks needed to be done, how long these tasks would take, and when they should be completed. The complete work breakdown schedule is included in Appendix A. The preliminary research is 100 percent complete, while product design is estimated at five percent complete based upon the completion of the comparator circuit. Design research is ongoing and the progress cannot be accurately estimated. A table of schedule highlights is provided below in Table 7. This table includes both past and future milestones.

Table 7: Schedule Highlights

Project Milestone and Description	Date
Define and Propose the Project	September 14, 2016
Complete Project Feasibility Research	October 19, 2016
Post Website	October 26, 2016
Determine and Order Piezoelectrics for Testing	November 17, 2016
Step Count Module Prototype	December 8, 2016
PPFS Final Draft	December 12, 2016
Finish Prototype and Begin Testing and Troubleshooting Prototype	March 17, 2017
Consider Additional Hardware Features	April 14, 2017
Develop Technical Documentation	May 2, 2017
Senior Design Project Presentation and Banquet	May 6, 2017

An order of tasks was determined by taking into account both time, risk, importance, and whether one task was a prerequisite for other tasks. For example, research is required before piezoelectrics can be ordered. Included in the weekly meetings is a discussion about whether the team is on schedule or if adjustments should be made. Some deadlines are static, such as the first major developmental requirement and the final PPFS, due on December 12. Most deadlines, however, can be adjusted, as long as the project is completed in a timely matter. It is a priority to stay on schedule and not have to constantly readjust goals. It is for that reason that scheduling takes place, in order to avoid delays in the project.

As research and design advances, reevaluations will occur more frequently to determine if deadlines are still realistic. This will occur because one part of the project may have more problems or take longer than anticipated. Originally, each team member spent approximately five hours each week on research, design, and documentation and assignments. As the semester has moved forward, the amount of time spent by each team member has increased, particularly in design decisions, testing, and construction. The amount of time spent working on the project is expected to significantly increase in the spring semester. Creating the iPhone app and using the Bluetooth processor for the step count module are expected to require a substantial amount of time. Both require a large amount of coding, as well as further research to make informed decisions on how they should be implemented.

4.3 Budget

The budget is maintained by Nick. He is responsible for ensuring that the team remains on budget and that there are adequate funds for each area of the project requiring them. In group meetings, Nick discusses with each team member materials that will be required for their portion of the project, based upon their research and design. He then determines if the proposed materials are appropriate in relation to the budget or if there may need to be a change. The $500 budget provided by the Engineering Department is expected to be sufficient in funding the project; however, due to uncertainties, the team has planned to design a product that shall cost well under the $500. This will provide the team with a rainy day fund needed in the event of unforeseen costs. Major costs of the project include the piezoelectrics, Smart Bluetooth, and Smart GPS. Current expenditures have totaled $56.95, which includes $19.00 for a set of piezoelectrics, $20.00 for Bluetooth LE, and $17.95 for separate shipping of the two products. A more detailed developmental budget is included in section 7.2.

Each time a team member proposes a material to be purchased, Nick reviews the budget and determines whether the purchase is appropriate in relation to the budget. The budget is updated each time permission is given to purchase an item. A comparison of the estimated budget and actual costs is done once a week. While budget issues are not expected to arise, due to the lower cost of the product, the rainy day fund is there to use if necessary. Outside funding will only be sought if a major issue arises and there appears to be no resolution to staying under budget.

4.4 Method of Approach

The team started this project by identifying the objectives of the design. This involved determining a set of requirements that would provide identifiable objectives for the team. After establishing the purpose of the project and defining the problem, the alternative solutions to the problem were considered. The proposed solutions revolved around several ideas. First, that the shoe can be used to generate power that can subsequently be used to power the sensors such as an accelerometer and Bluetooth. Second, the shoe should be able to export information to portable electronics such as an iPods and cellphones through an application. When conducting research, there is immense concentration on satisfying the requirements of generating constant and uninterrupted energy and transferring information from the sensors to the user through the app. For energy generation, the use of piezoelectric devices was heavily relied on. It is known that with this technology, electrical energy can be converted from kinetic motion. The key research questions of this project were where and how should the piezoelectric devices be implemented to perform the work effectively; however, based on initial testing of piezoelectric materials, generating enough energy to power the sensors was ruled unfeasible.

As a team working together to accomplish a common goal, good communication amongst members is crucial. Most research and design work for the project is done on the individual or small group level, so holding weekly team meetings gives an opportunity for individuals to update the other members of the team. In the status update meetings, the current status of the project is evaluated by highlighting what has been done and what tasks should be priorities. The team has established a Facebook group and mobile group message as the primary way of communicating, but interpersonal email is also used, especially for communicating with the project advisor.

The team understands that to achieve the project goals, they must make sure that fundamental principles of teamwork are fully followed. Those principles include cooperation with each other, dedication and commitment to the objectives, and effective communications. The team believes that we are agents of God's renewal, and we must ensure that we approach this project with kindness, honesty, and an appreciation of God's creation.

4.5 Task Specification

The Smart Sole team is currently working to develop an accurate list of tasks that must be completed in order to produce a prototype that is functional and marketable. The current work breakdown structure can be found using the link below:

https://app.asana.com/0/204429740631370/list

The full work breakdown structure, in text form, can also be found in Appendix A: Work Breakdown Structure. Dates of tasks are subject to change and represent estimates of the overall project timing. Additional tasks may be added in the future as necessary if timing estimates change.

5 Designing the Project

5.1 System Design and Architecture

The system design proposed by the Smart Sole team consists of two primary blocks: the in-shoe hardware and the mobile software. The basic overall block diagram of the system can be seen in Figure 6.

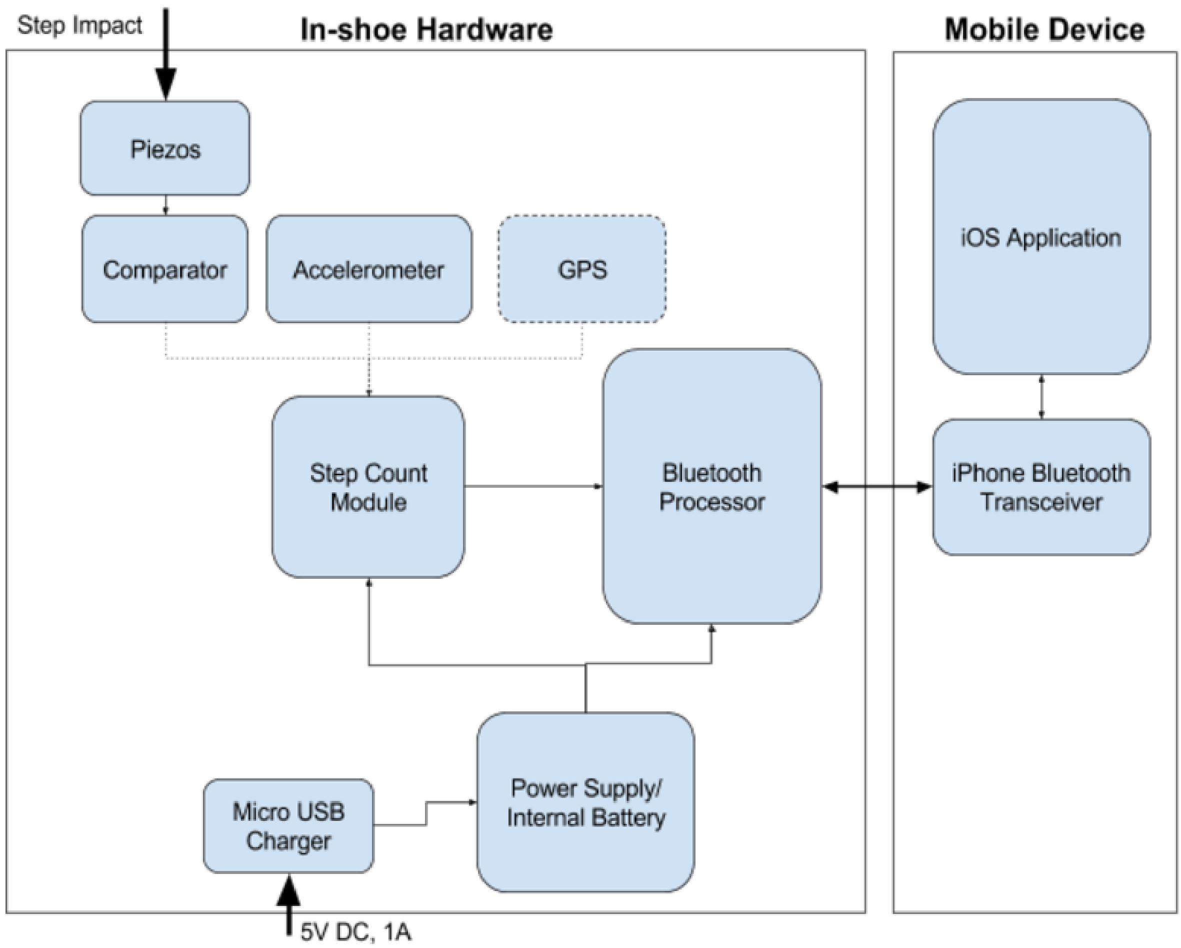

Figure 6: System Block Diagram

The in-shoe hardware will consists of three main circuits. These circuits include the power circuit, the Bluetooth and processor, and the step counting module. The power of the system will likely be supplied by a rechargeable battery (hardware has yet to be selected). The team plans to use a battery that will be rechargeable via any standard Micro USB charger. The Bluetooth LE processor will act as the communications device as well as the system processor. This will prevent the need for a secondary processor, thus reducing the monetary cost as well as the power cost. Bluetooth LE will be used as it is a lower energy alternative to standard Bluetooth, making it an attractive option for our product. The currently proposed system for the step counting module includes a three part step counting system that will use multiple sensor inputs to more accurately determine step count. These three circuits within the step count module (indicated by the dotted line in Figure 6) are the comparator circuit, the accelerometer circuit, and the GPS circuit. The feasibility of in-shoe GPS is still currently being examined (indicated by the dotted border in Figure 6). Later implementations may include the GPS function as part of the mobile application. A more detailed block diagram architecture of the hardware can be seen below in Figure 7.

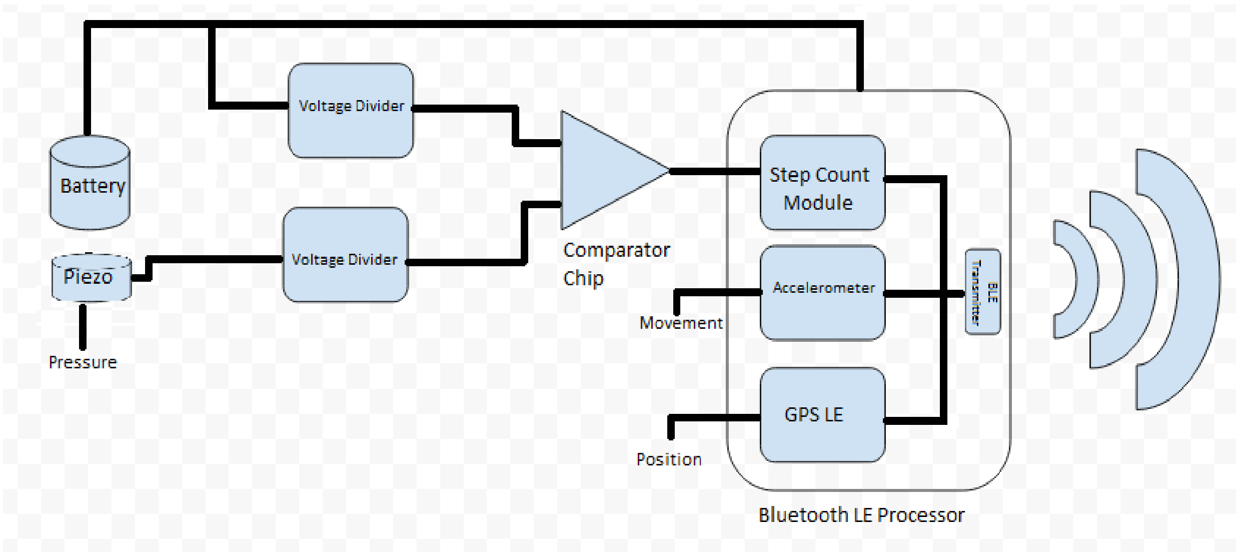

Figure 7: Detailed Hardware Block Diagram

Currently the comparator circuit has been constructed and verified for feasibility. An Arduino with a Bluetooth shield was used as a microprocessor; however, a new Bluetooth processor must be found for the final design as the Arduino board is too large to fit within a shoe.

The mobile application used to hold and display the step count data will be designed using Apple's Swift developer. The basic architecture of the application can be seen in Figure 8.

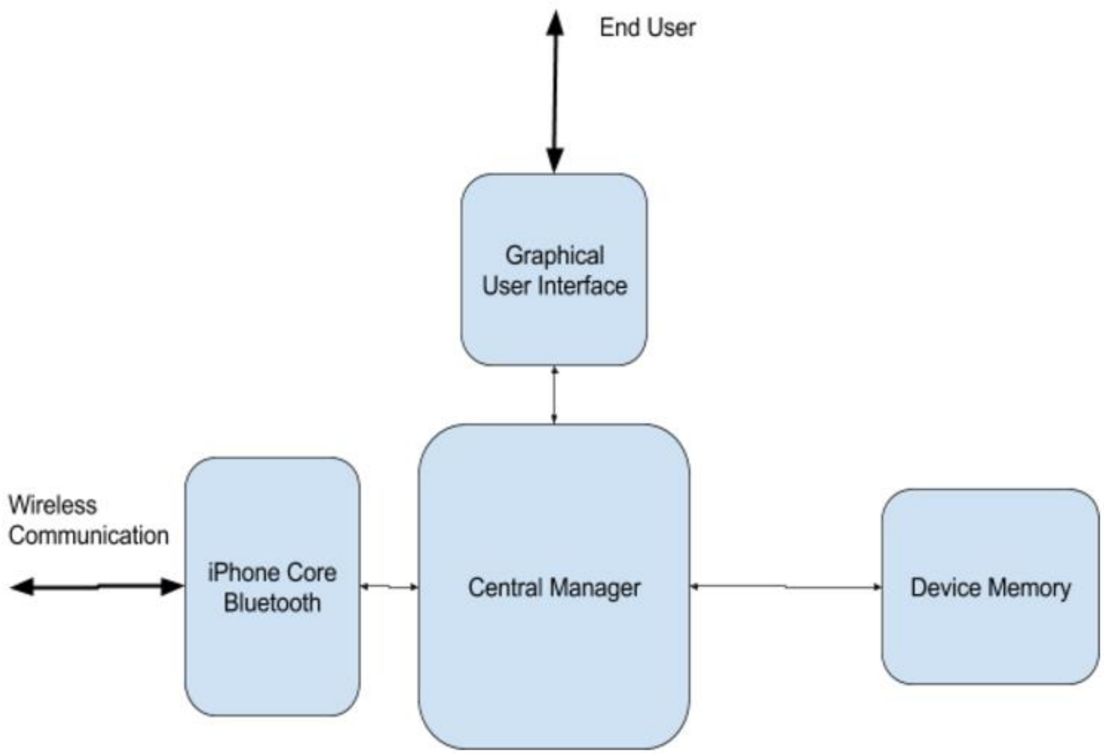

Figure 8: Basic Software Block Diagram

Currently the software development is still in the research phase, so design characteristics are not definitive. More information will be put forward regarding the mobile application when it becomes available.

5.2 Design Criteria

5.2.1 Hardware Design Criteria

When designing the hardware, the team considered a number of factors. Three main sections were developed that contained these individual factors. The sections considered were renewable energy considerations, power management considerations, and user considerations. Renewable energy considerations include sustainability and the feasibility or impact of the renewable energy aspect of the project. Power management considerations concern intelligent distribution of power and minimization of power consumption. Finally, user considerations include any impact on the user during usage and both appearance and functionality. These design criteria are not for specific components but are instead intended for use when examining features on a macro level. The following descriptions are meant to give further insight as to how blocks of the overall block diagram were selected. In addition to the following categories, design norms played a big part in decision making. These design norms are discussed in further detail in Section 5.5.1. All criteria are given a weight out of 5 with 1 being the least important and 5 being critical.

Renewable Energy

Power output is an important factor for the product, because the more power available, the more analysis that can be performed and given to the user. The team gave this a weight of 4 out of 5 because the power issue is the foundation of many of our issues for this project.

Development Time

Development time is the amount of time it takes to create the product. This determines whether various parts of the project are feasible and whether the entirety of the project can be completed in the scope of the class. This criterion was given a weight of 3.

Capability

Capability is an important criterion for the team. Capability determines whether the product has the ability to gather energy and use the energy. The product must be capable of performing the tasks that are required of it; therefore, the team assigned this criterion a 4.

Availability

Availability is the ability to acquire all necessary parts and pieces for designing the energy harvesting component. The team assigned a 3 to criterion because, without access to needed hardware, the functionality of the final product could be hindered.

Ease of Building

Ease of building is determined by how difficult the system examined will be to develop. This criterion was not especially important because difficulty is expected. As long as feasibility is assured, difficulty can be negotiated. The team gave this criterion a 2.

Renewability

Renewability is whether or not the primary source of energy is derived from renewable locations. While the project could be powered by a number of other sources, the team desired renewable energy as a key source of power; therefore, the criterion received a 3.

Cost

Cost is the monetary cost to the team and the effect that it has on the budget. With a limited amount of money available, smart decisions must be made and cost analysis must be considered. Maintaining a less expensive production cost can be done through the use of inexpensive parts. The team assigned a 3 for this criterion because, while important, the team does not expect to go over budget.

Power Management

Power management is an ability to power all necessary components efficiently. This includes any additional sensors. By adding more analysis, the product increases in value to a potential consumer; therefore, a 5 was assigned to this criterion.

Feasibility

Feasibility is whether the added sensors will be able to be added or not. This is dependent on power and size considerations. It was given a 5 because if the project is possibly unfeasible, then there should be less consideration of it.

Comfort

Comfort is determined by how noticeable the hardware will be to the user when it is implemented inside or on the shoe. The team desires to make the hardware unnoticeable or as close to unnoticeable as possible. The team gave this consideration a 4.

Aesthetics

Aesthetics are how the shoe hardware makes the product look. Although not needed for functionality, it is needed for marketing and sales of the product, which generate revenue. Therefore, the team gave the consideration a 3.

Product Longevity

Product longevity determined by how long the hardware will last before it becomes unusable due to physical wear. The team desires the product to be long lasting so that the user can enjoy use it for a long time without having to have it replaced. It also will make the product more reliable; therefore, a 4 out of 5 was assigned.

Transferability

Transferability is whether the hardware is built into one pair of shoes or if it can be transferred to another shoe (e.g. an insole). This allows the product independence from any particular housing and makes the product interchangeable amongst shoes. The team assigned a 2 because, while it would be a nice addition, it is unnecessary for the first functional prototype.

Cost to User

Cost to user is how much the user will need to pay to offset the additional features added. To increase demand, the team wants the product to be as inexpensive as possible. Therefore, a 4 was given as a designated weight.

The final considerations, along with decision matrices, can be viewed below in Section 5.4.1.

5.2.2 Application Design Criteria

When creating a mobile application for our product, a mobile operating system on which to implement the software had to be selected. The criteria used for selecting a mobile platform on which to create the application were divided into two sections: considerations for the developer and considerations that would affect the end user. Developer considerations included any factors that would impact the research, design, and production of the mobile application. End user considerations included any impacts that the decision may have on the finalized product seen by the end user such as the functions available or the compatibility with the user's personal mobile phone. All application design criteria, including design norms, were given a weight out of 5 with 1 being the least important and 5 being critical.

Developer Considerations

Ease of Use

Ease of use of the programming software is one of the first developer consideration criterion established. Ease of use includes the difficulty of working with the language, the ease of obtaining the proper software to write the application, and the ability to add more features without having to completely rewrite the code. Ease of use is given a weight of 2 as it is important to consider but could be sacrificed assuming the person implementing the software is experienced in coding and able to learn quickly.

Development Time

Development time is considered when selecting the appropriate design. Development time includes the time to design, code, and implement the application on a mobile device. The time that the design takes to be implemented is important because the team is working on a strict deadline that cannot be adjusted if the design does not go as planned. Development time is therefore given a weight of 4 out of 5 as it is a crucial factor to consider but not the most important.

Feasibility

Feasibility of the software used to design the application is the next criterion considered. If the software is incapable of meeting the project requirement, it should not be considered as a viable option. Feasibility is given a weight of 4 since it is necessary to achieve the team's desired results.

Availability

Availability of software is the next criterion that was considered. The software that is used has to be easily acquired by the team. All platforms considered have free downloadable software; therefore, this criterion is given a weight of 3. This factor also included the availability of all equipment necessary to test the application.

Hardware Compatibility

Hardware compatibility is considered the most important consideration for the mobile application design. If the software is incompatible with the hardware, the product is completely non-functional. The product must be functional before any other requirements can be met regarding the application. Because compatibility is essential to accomplish all other requirements, it is deemed the most important criterion and given a weight of 5 out of 5.

Cost

Cost is the last developer consideration that was examined when selecting an alternative. One of the goals of the Smart Sole team is to create a product that is affordable and comparable to other similar products on the market. To achieve this goal, the cost of designing the mobile application must be kept to a minimum, Primary cost factors for the application were the cost of the design software, the labor cost of designing and implementing the application, and cost of the materials necessary to test the product. Cost is given a weight of 3 as the cost of the app development would be mostly fixed with the exception of labor to update and maintain the app.

User Considerations

A goal of the Smart Sole team is to create a product that is marketable and desirable to a wide consumer base; therefore, it is important to consider the needs of the end user when developing the product. Two primary needs were considered that fell under this category: functionality and compatibility.

Functionality

Functionality includes the ability of the application to perform all functions desired by the user. Functionality is defined as meeting the requirements for the application set by the Smart Sole team. Functionality also includes designing the application so that additional features based on potential customer feedback can be implemented in the future. Functionality is considered the most important user consideration and is therefore given a weight of 5 out of 5.

Compatibility

The final factor examined is compatibility with whatever mobile devices our target market may own. Our product is not useful if the consumer is unable to download the mobile application to their device. This factor is given a weight of 4 as it is important for us to keep our prospective market as large as possible.

Design norms are also considered when selecting the mobile operating system to program on. Design norms considered when proposing and selecting design criteria and alternatives can be found in Section 5.5.

5.3 Design Alternatives

5.3.1 Hardware Design Alternatives

One of the goals of the Smart Sole team was to increase the amount of energy captured through the running or walking process while still having a comfortable, marketable product. Smart Sole found through previous research that two different methods have been used for the energy capturing process. The first method uses a high powered generation device. Researchers Jingjing Zhao and You Zheng found they were able to harness an average power of 4 mW at 1 Hz (about walking speed) with this device. This gave them about 50 mW to work with. They determined that low power sensors could be added to provide additional data. The second method used a more comfortable mesh insole design. The same research team found that the more comfortable device could only give an output of 30 μW. They concluded that combining the power and comfort of the two prototypes would be the best way to approach the problem.[6] Originally, team Smart Sole intended to draw from the two prototypes in their own design and herald the work of Zhao and Zheng; however, after reconsidering the amount of energy available and the potential cost, the team decided an internal battery was a better option for a power source. The piezoelectrics were found to not provide enough power. The team will still use piezos in its

[6] Zhao, Jingjing, and Zheng You. "A Shoe-Embedded Piezoelectric Energy Harvester for Wearable Sensors." *Sensors* 14.7 (2014): 12497-510. *ProQuest.* Web. 13 Nov. 2016.

step count module as a pressure sensor and potentially as a way to harness small amounts of power to extend the product's battery life.

5.3.2 Application Design Alternatives

One of the goals of the Smart Sole team was to make the final mobile application reach as large a consumer base as possible. Android OS and the Apple iPhone iOS were selected as possible platforms in which to develop the application. Android phones accounted for approximately 85% of all smartphone sales in the first half of 2016 with Apple selling the second most at approximately 13%.[7] This totals approximately 98% of the smartphone market. These sales have remained relatively stable for the past three years making Android OS and iOS the best design alternatives for reaching as large a market as possible. Furthermore, sales of Microsoft's Windows phone and other smart phones have been declining for the past two years. These phones also make up only approximately 2% of the market, making them unacceptable alternatives based on the team's desire to market to a large consumer base.

Programming in a language that is usable by both applications was another option that was considered. This can be achieved by using Oracle ADF Mobile, which used a Java and HTML5 based framework.[8] Oracle ADF Mobile has the ability to develop programs for both Android phones and iPhones; however, the development of these applications requires a developer certificate. Since the members of the Smart Sole team are not certified developers, this option was deemed unrealistic. Furthermore, none of the team members are familiar with programming in Java, making it necessary to learn a completely new language if Oracle ADF Mobile was selected as the development option.

5.4 Design Decisions

5.4.1 Hardware Design Decision

When creating the hardware for our product, multiple designs and components had to be considered. This decision was based on a variety of factors (Table 8, Table 9, and Table 10). Criteria were weighted on a scale of 1-5 with 5 being the most important. The solutions were given a number from 1-10 based on preliminary research, with 10 being the best. Ideally, after looking at the design matrix, the team would use a piezoelectric generator because of its ability to get the most renewable energy. It would also use a step counter and Bluetooth LE to send the data. It would also use a piezoelectric mesh based on comfort

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[7] "Mobile OS market share 2016 | Statista." 2016. 13 Nov. 2016 <https://www.statista.com/statistics/266136/global-market-share-held-by-smartphone-operating-systems/>

[8] "Building Mobile Applications with Oracle ADF ... - Oracle Help Center." http://docs.oracle.com/cd/E18941_01/tutorials/buildmobileappscontent/adfmobiletutorial_1.html. Accessed 10 Dec. 2016.

factors; however, some of these decisions conflict. The piezo mesh is unable to generate enough energy to power all the sensors. The Smart Sole team intended to find a compromise. Through the team's research, it was determined to be unfeasible to utilize the piezos to completely power the system. In addition, the step count may not be enough analysis to give to the customer to distinguish the Smart Sole product, so a decision was made to focus on performance over renewability.

Table 8: Renewable Energy Decision Matrix

		Weight	**Piezo Generator**	**Piezo Mesh**	**Piezo Generator w/ battery**
Renewable Energy Considerations	Power Output	4	7	6	9
	Development Time	3	8	4	6
	Capability	4	7	7	10
	Availability	3	7	4	7
	Ease Building	2	8	5	8
	Renewable	3	10	10	2
	Cost	3	7	4	5
	Stewardship	4	8	6	6
	Total		200	152	176

Table 9: Power Management Decision Matrix

		Weight	BLE, Step count	BLE, Step count, Accelerometer	BLE, Step count, Accelerometer, GPS
Power Management Considerations	Analysis Power	5	5	7	9
	Development Time	2	3	5	6
	Capability	3	7	7	7
	Availability	4	7	7	7
	Ease Building	2	8	6	5
	Feasibility	5	9	7	4
	Cost	4	8	6	5
	Stewardship	4	8	7	7
	Total		205	192	184

Table 10: User Decision Matrix

		Weight	Generator Built in	Insole Generator	Mesh Insole
User Considerations	Comfort	4	4	4	9
	Aesthetics	3	7	7	7
	Product Longevity	4	6	6	8
	Transferability	2	0	7	8
	Cost to user	4	8	7	5
	Trust	4	4	7	8
	Caring	4	4	5	9
	Integrity	4	7	7	7
	Total		153	179	221

Initial testing has shown that the power generation capabilities of the piezos is limited to the microwatt scale; therefore, large scale energy generation is impractical without adding a large amount of piezos and causing discomfort to the wearer. To offset the lack of renewable energy, the team intends to then focus on functionality by adding more step counting and analysis power. The team has therefore tentatively decided to implement a step count module that will feature a comparator, an accelerometer, and GPS. The team hopes that the increase in step counting methods will lead to increased accuracy at a slight cost increase. The high accuracy will make the Smart Sole product competitive on the fitness tracker marketplace.

5.4.2 Application Design Decision

When creating a mobile application for the product, a mobile operating system in which to implement the software had to be selected. This decision was based on a variety of factors (Table 11). Criteria were weighted on a scale of 1-5 with 5 being the most important. The solutions were given a number from 1-10, with 10 being the best. The design norms considered for software were also included in the decision matrix. The design norms were all weighted the same as they are all equally important to the decision.

The design norms not listed were also considered when making the decision; however, they were not as applicable as the others and were therefore not included in the decision matrix.

Table 11: Mobile App Decision Matrix

		Weight	Swift (iPhone)	Android Studio	Both
Developer Considerations	Ease of Use	2	4	6	3
	Development Time	4	6	7	1
	Capability	4	8	8	9
	Availability	3	4	6	5
	Hardware Compatibility	5	8	8	8
	Cost	3	8	3	3
End User Considerations	Functionality	5	8	8	8
	Compatibility	4	9	8	10
Design Norms	Transparency	4	9	9	9
	Integrity	4	10	10	10
	Caring	4	9	9	9
	Trust	4	8	8	10
	Total		360	355	342

Ease of Use

Based on preliminary research, Android has more free resources readily available to aid an app designer. For this reason, Android was given a higher score than iOS for ease of use. Both design softwares take time to learn; therefore, the scores were given in the middle of the total range. Designing an application for both platforms would involve learning two separate languages and would be the most difficult to implement, giving it the lowest score. Programming in a common language was another potential option; however, it was later be ruled out due to feasibility (see the end of this section).

Development Time

Development time of both Android and iOS depends mostly on the difficulty of the language. Because Android was found to be easier to use, it was given a higher score than iOS. Implementing the application for both platforms was given a score of 1, the lowest value, because it would take twice as much time in development and testing than just choosing one (assuming the programming will not be done through a common language as noted later).

Feasibility

Both Android and iOS devices are able to host applications that perform the same (or very similar) functions. For this reason, both Android and iOS were given the same score for capability. If there are any differences, implementing an application on both platforms would allow the team to provide the most completely capable software, giving the option of both the higher score.

Availability

Both Android and iOS have software available for download that can be used to design applications. The difference between the alternatives comes from the availability of equipment necessary for testing. All the members of the Smart Sole Team have Apple iPhone, so no further smart phone would need to be purchased if the app was developed for iOS. If the app were to be developed for Android, a smartphone for the purpose of testing would have to be added to the team's budget. Apple's iOS was given a higher score.

Hardware Compatibility

Both Android and iOS will be able to support the Bluetooth transmission the team hopes to implement. All alternatives were given the same score for hardware compatibility.

Cost

Because iOS Swift is available for free download and the smart sole team has iPhones, using the iOS alternative would reduce the cost for testing and implementing the application. If the Android platform were to be used, an Android smartphone would need to be added to the budget giving the Android alternative a lower score. Because cost of the iOS implementation is minimal, the alternative of doing both was given the same score as the cost of implementing Android.

Functionality

The requirements specified for the mobile application were created independent of the mobile operating system on which they would be implemented. It is assumed, due to the maturity of the operating systems proposed as alternatives, that both platforms would be capable of supporting an application that meets all the defined requirements. All alternatives were therefore given the same score for functionality under these assumptions.

Compatibility

The score given for compatibility was based primarily on the ownership statistics of iPhones and Android devices. Because Android devices are purchased at a higher rate, Android was given a higher score. The option of both was given a perfect score as approximately 98% percent of new smartphone purchases are Androids or iPhones.[2]

Based on the results obtained from the decision matrix (Table 4), a decision was made by the team to move forward with the iOS Swift development of the application. The Android option was also determined to be a suitable backup because of the small gap in score. This alternative would be selected if further research determined that iOS would be too difficult to implement. Both alternatives would be implemented if the iOS application is able to be developed quickly, as time was the limiting factor that helped eliminate the option of both.

5.5 Design Norms

Design norms are the guiding principles in making decisions within the design process. While the team gave thought to all design norms, a few specific design norms were key in multiple decisions and were worth mentioning in greater detail. Design norms were looked at from a hardware and software standpoint.

5.5.1 Hardware Design Norms

Trust

The Smart Sole product must be trustworthy and dependable. It should be made to go beyond its design parameters. It should be reliable and functional after many uses. This product will be used on a regular basis by everyday exercisers through walking or running, so the shoe should be designed and constructed to the highest standards of accuracy and safety.

Integrity

The product must be carefully designed and constructed to be ergonomic, comfortable, and useful. It must work for the users, making their exercising experience successful and at the same time providing accurate information about their performance. It must also be intuitive to use and accomplish its purpose with a minimum amount of effort by the user.

Caring

This product must be pleasing and meet the user expectations, especially regarding safety. The project will take into account the method of use and how often it will be used. The final design is helpful whether in use or under maintenance.

Stewardship

Calvin College is a Christian institution that values the call of stewardship and taking care of God's creation. The team sees the energy crisis as a motivating push to move towards renewable energy. The final design must promote smart and faithful energy usage. It must put sustainability at the forefront of the product.

5.5.2 Application Design Norms

Transparency

The design norm of transparency states that a design should be understandable to a user. The design should avoid deception while being constant and reliable. This design norm is important for application design because feedback and the ability to provide updates are essential to creating an app that is useful and respected. The user should be able to understand all functions of the mobile application. If anything is unclear, the user should be able to communicate with the designers to have it resolved. The data acquired through the app should not be shared with any third parties without the consent of the user.

Integrity

The design norm of integrity states that a design should be complete and function properly. This design norm is important because a user will expect an application that functions properly, is able to maintain the data it collects, and is continuously improving. By allowing user feedback and app support, this design norm can be upheld throughout the life of the product.

Caring

The design norm of caring states that a design should take into account the effects that it has on individuals. The design should also address a problem and better the lives of its users. The application should be designed in a way that allows a user to easily track his/her activity. Through this tracking of activity and data, a consumer is able to make changes in their life involving fitness. This will lead to a healthier and more fulfilling life.

Trust

The design norm of trust states that a design should be trustworthy and avoid conflicts of interest. One of the ways that trust is maintained through our mobile application is the confidentiality of data. Data collected through the app will not be sold or provided to any advertisers or other third parties. The app will also not access unnecessary data from a user's device such as contacts or Facebook profile information without first having the consent of the user.

6 Integration and Testing

Testing of the Smart Sole product will be done step-by-step to ensure each individual component is functioning properly. This will help prevent loss in capital by not assembling a final project until the feasibility of all individual components has been verified. Testing of the hardware will be divided into three primary phases: component validation, system validation, and product validation. A semi-functional prototype of the Smart Sole product will be developed to test the functionality of the software. This will be done to allow software testing to occur simultaneously with hardware testing.

6.1 Component Validation

Component validation includes any testing done on individual components or small subsystems of the overall project. This phase of testing is currently underway. Smart Sole plans to test the piezoelectrics to determine what voltage levels are outputted under normal walking conditions. Testing will continue with a testing of the piezos integrated with the step count comparator circuit to verify the accuracy of the designed circuit. The Bluetooth Low Energy (BLE) element will be tested to verify that connectivity works and at what distances it is able to send data to the application. Some additional testing plans that are being developed include accelerometer testing, GPS testing, and battery testing. All current tests under development are listed in Table 12. Specific testing procedures will be posted to the team website once they are standardized.

Table 12: List of Component Validation Tests

Component/Subsystem	Projected Completion	Status
Piezoelectrics	1/31/17	High priority. Samples are currently in and being tested
Comparator	12/9/16	Completed. Voltage levels will be adjusted based on piezo testing
Accelerometer	3/17/17	Low priority
GPS	Unknown	Tentative
Battery	1/31/17	In progress
Bluetooth LE/Processor	1/31/17	In progress. Capabilities verified

6.2 System Validation

System validation involves testing the larger systems that will make up the Smart Sole product. This includes the step count module, the power supply circuit, the Bluetooth/Application communication, and the ergonomics and housing. The step count module testing will begin when the testing is complete for the comparator, accelerometer, and GPS. This testing will focus on integrating the three components together to find out what data constitutes a step. The power supply circuit testing method is currently under development. The Bluetooth communications testing is similar to the testing performed in the component validation step; however, this step of testing will incorporate the mobile application into its methods. Finally, housing will be made for the shoes to hold the hardware. The unit will be tested by multiple users for the sake of comfort and ergonomics. All current tests under development are listed in Table 13. Specific testing procedures will be posted to the team website once they are standardized.

Table 13: List of System Validation Tests

System	Projected Completion	Status
Step Count Module	Tentative	Dependent on the testing of the three individual step count systems
Power Supply	3/15/17	Low priority
Communications	Tentative	Dependent on the Bluetooth testing
Housing	Tentative	Dependent on the development of all the hardware systems

6.3 Product Validation

Product validation involves all testing that will be done on a final, completed prototype. This includes any testing that will be done to ensure that the product meets the requirements that were initially set by the Smart Sole team. These tests include step count and distance accuracy, environmental validation, and durability validation. Step count and distance monitoring will be tested to ensure that measurements meet the requirements set by the team. Environmental validation includes weather testing and testing on various running surfaces. The product should be able to remain functional under adverse conditions such as rain, as the goal was to create a product that can be used outdoors. Finally, a test of the component's resilience against impact and physical stress will be conducted within the housing. This will be done to see the long term impacts that usage can have on the longevity of the hardware. All current tests under development are listed in Table 14. Specific testing procedures will be posted to the team website once they are standardized.

Table 14: List of Product Validation Tests

Testing	Projected Completion	Status
Step Count Accuracy	Tentative	Dependent on System Validation
Distance Accuracy	Tentative	Dependent on System Validation
Environmental Validation	Tentative	Dependent on System Validation
Durability Validation	Tentative	Dependent on System Validation

7 Business Plan

7.1 Marketing Plan

While a step counting device is an interesting idea, fitness tracking devices have been around for many years. They have become very popular only within the past few years though, thanks in part to the rise of smartwatches and the rising awareness of the benefits of exercise. Many new devices come out each year, most with similar features and accuracy. The Smart Sole device provides the same functionality but at a cheaper price, a more accurate measurement of step count, and no requirement to wear a watch or wristband as most other devices require.

7.1.1 Competition

Many companies produce a variety of fitness trackers. The four main competitors in the fitness tracker market include Fitbit, Garmin, Misfit, and Apple. Each of these companies, with the exception of Apple, release a wide variety of fitness trackers.

Fitbit offers sports watches and wristbands starting as low as $100. The Fitbit Flex 2, released in the fall of 2016, is the cheapest product, starting at $100 and offering basic activity tracking.[9] It does, however, require the user to wear the fitness band.

Garmin offers sports watches at prices ranging from $100 to over $450. The cheapest model Garmin offers is the Garmin vivofit® 3, which starts at $100, offers basic fitness tracking and can connect to a capable smartphone.[10] The vivofit® 3 is a fitness band with a small display screen.

Misfit offers cheaper wristbands in general, with models starting at $100. The Misfit Ray costs $100 and is a waterproof wristband that provides basic fitness tracking features.[11] The Misfit Ray is compatible with the Misfit smartphone app.

Apple's Watch offers fitness tracking apps, but this comes at the price of the Apple Watch itself. The price of an Apple Watch starts at $370. The Apple Watch Series 2 comes with built in GPS and a display.

[9] "Fitbit Flex 2™ Fitness Wristband." https://www.fitbit.com/flex2. Accessed 12 Dec. 2016.
[10] "vivofit 3 | Garmin | Fitness Tracker." https://buy.garmin.com/en-US/US/into-sports/health-fitness/vivofit-3/prod539963.html. Accessed 12 Dec. 2016.
[11] "Misfit Ray Premium Fitness + Sleep Tracker - Misfit." https://misfit.com/products/misfit-ray/. Accessed 12 Dec. 2016.

It is also waterproof.[12] The user's smartphone is not needed for fitness tracking. Third party apps may be used with the Apple Watch.

Because most fitness trackers can have step counting error of ten percent or greater, the Smart Sole hopes to reduce the error to within five percent through the use of piezoelectrics. None of the fitness tracking companies offer reliable fitness trackers for less than $100. The Smart Sole shall cost under $100 (see Section 7.3) while offering similar tracking capabilities and more accuracy. Table 15 provides a summary of Smart Sole and its competitors.

Table 15: Summary of Smart Sole and Competitors

Product	Features	Price
Smart Sole	Basic step counting, waterproof, smartphone app	$65
Fitbit Flex 2	Basic fitness tracking, waterproof, smartphone app	$100
Garmin vivofit® 3	Basic fitness tracking, waterproof, display, smartphone app	$100
Misfit Ray	Basic fitness tracking, waterproof, smartphone app	$100
Apple Watch Series 2	Advanced fitness tracking, waterproof, built in GPS, display, smartphone app	$370

7.1.2 Market Survey

The market for Smart Sole is large and growing. The fitness tracking industry is expected to grow from $2 billion, in 2014, to $5.4 billion by 2019.[13] Fitness trackers are becoming popular among all age groups, especially the millennial generation. Prospective customers include those both with and without smart watches. Many customers with smart watches do not have a need for a stand-alone fitness tracker, as the watch provides tracking abilities. However, some customers still desire a stand-alone tracker that is more rugged or suitable in conditions that could ruin a smart watch. The other set of customers, those currently without a smartwatch, desire a cheaper product.

[12] "Apple Watch Series 2 - Apple." http://www.apple.com/apple-watch-series-2/. Accessed 12 Dec. 2016.
[13] "Fitness tracker market to top $5bn by 2019 - Wareable." 26 Mar. 2015, http://www.wareable.com/fitness-trackers/fitness-tracker-market-to-top-dollar-5-billion-by-2019-995. Accessed 11 Dec. 2016.

7.2 Cost Estimate

Bringing the Smart Sole product to the market would entail some additional costs and require further design to improve comfort and aesthetics. The costs of Smart Sole can be broken up into development costs and production costs.

7.2.1 Development

Development costs consist of preliminary research, design, and testing. In addition, if the product was taken to the market, other costs would be incurred such as the use of Calvin's facilities, which previously have not been taken into consideration.

Preliminary research costs include all of the time taken among the four team members to research project feasibility, which includes researching piezoelectrics, Smart Bluetooth, potential components and devices which would be used, and other early project-related research. This includes the selection of piezoelectrics. Preliminary research does not include design costs, which in many cases might be considered a type of research. Preliminary research only includes the time spent determining project feasibility and all aspects related to that. Because it is hard to break up time researching app design, the development of the app is included in the design costs. Most research has been completed, and it's reasonable to assume that no more feasibility research will be conducted. Based upon research already done, it is estimated that between the four team members, roughly 30 hours of preliminary research was done. The team values their time at a rate similar to that of an entry level engineer. The compensation cost for an entry level engineer is based upon the cost to the company, not simply the salary of the engineer. Typically, the actual cost of an engineer can be estimated to be around double or slightly more than double that of their salary. This is because besides the engineer's salary, other benefits such as health and life insurance, retirement, holiday pay, education, traveling, and many more factors must be accounted for. In addition, there exist other costs in an organization, such as non-revenue generating departments like management, finance, customer service, quality, and human resources. Organizations must also pay for property, plant, equipment, and utilities. All of these variables factor into the cost per employee. With this in mind, a $70 thousand salary equates to about $35 per hour. A suitable cost to the company based upon this is $80 per hour. Therefore, a total of $1600 was spent on research.

Design costs primarily consist of engineering design time, which is also the bulk of the total time spent on the project. One other design cost is the cost of making the first prototype and any refinements made before moving the product towards production. The design time is difficult to estimate, as most will be performed during the second semester. A conservative estimate is 15 weeks spent on design, with the majority of the time coming from February and March, and a smaller amount coming from December, January, and April. Most of April, however, will be dedicated to testing and refining. Assuming each member spends 15 hours a week on design, a total of 900 hours will be spent on design, which equates to $72,000 in design costs. The cost of making one product has a minimal impact on this design cost. Because the first prototype product will always cost more than the production cost, a total of $100 is assumed for the design of the first prototype. This brings the total design costs to $72,100.

Testing costs include the time taken to test the hardware, piezoelectric generation, app, and complete prototype. In addition, fixed testing costs include the equipment used to test the product. This includes a Fluke Multimeter, oscilloscope, function generator, power supply, and miscellaneous costs related to testing. These include probes, breadboards, and jumper wires. The costs for the following equipment are: $400 for a Fluke Multimeter, $520 for a basic Tektronix oscilloscope, $300 for a Keysight (Agilent) function generator, $200 for an Instek power supply, and $100 for probes, a breadboard, and jumper wires. The amount of time spent testing the product is difficult to estimate, as it is unknown how many product revisions will occur. A tentative estimate is 20 hours of testing, resulting in $1600 of costs. Total testing costs therefore come to $3120.

Additional costs include facility costs, which includes the previously unaccounted costs of using Calvin's facilities for development and business functions. A small office in Kentwood with utilities included can be rented for $450 a month. With 8 months of rental for development and testing, the cost is $3,600.

Total development costs come to $78,820, which is rounded up to $80,000 to account for unforeseen issues or costs.

7.2.2 Production

Production costs are the other types of costs associated with bringing the product to the market. Production costs can be broken down into both fixed and variable costs.

7.2.2.1 Fixed Costs

Fixed costs include property and equipment, general and administrative expenses, and marketing costs.

Property costs include the cost of renting facilities for business administration and troubleshooting. The same facility used in development will be used afterwards and rented for $450 a month, or $5400 annually.

Equipment used in development, such as the oscilloscope, function generator, multimeter, and power supply can be used during production, if troubleshooting is necessary. Therefore, the only equipment costs include annual replacements of damaged components.

General and administrative expenses are expected to be $1600 a week, or $83,200 annually.

Marketing costs are expected to be online marketing at a cost of $40,000 a year.

The total fixed costs are therefore $128,600 annually.

7.2.2.1 Variable Costs

Variable costs include component costs, labor costs, and shipping costs. The components and their estimated prices are included in Table 16. Purchasing components in bulk, in contrast to just one for the prototype, will lead to substantial savings in variable costs. Most retailers provide costs for a single unit and bulk purchases. Some bulk purchases only go up to 100, and it's possible that purchasing in even larger amounts would result in even lower unit costs, although at diminishing returns. The price of purchasing in bulk is used in the analysis. A three-axis accelerometer rated up to 16 g was chosen from Mouser. Although a single unit costs $2.93 alone, the unit cost is $1.64 when over 5000 are purchased[14]. The Bluetooth LE chosen costs only $9.82 when bought in orders of 500 or more[15]. Smart GPS is included in Table 16 for reference, but currently is only a potential component addition, and not included in the total cost. An objective is to use the GPS found in the user's smartphone instead, in order to save a significant amount per unit by taking advantage of hardware already available.

[14] "MC3635 mCube | Mouser." http://www.mouser.com/ProductDetail/mCube/MC3635/?qs=xIT89idmjZlQ0wKEjJ43VQ%3D%3D. Accessed 12 Dec. 2016.

[15] "Panasonic Bluetooth / 802.15.1 Modules | Mouser." http://www.mouser.com/search/refine.aspx?Ntk=P_MarCom&Ntt=104335429. Accessed 12 Dec. 2016.

Table 16: Component Costs

Component	Price	Number	Cost
Accelerometer	$1.64	1	$1.64
Piezoelectrics (2)	$20.00	1	$20.00
Bluetooth LE	$9.82	1	$9.82
Comparator	$0.20	1	$0.20
Small Components	$0.02	20	$0.40
Smart GPS*	$15.00	1	$15.00*
Total			**$32.06**

Labor and assembly of Smart Sole will be outsourced due to the lack of resources and quantity to allow assembly to be performed on such a small scale basis. The total hourly cost of labor to the company is $100 per hour. A Smart Sole can be assembled and packaged in 2 minutes, meaning 30 Smart Soles can be manufactured per hour. This equates to a labor cost of $3.33 per unit.

Shipping costs are expected to average $1.50 based upon a mix of bulk shipping to distributors but also direct shipping from the business. Adding all of these individual costs results in a total variable cost of $36.89 per Smart Sole unit.

7.3 Summary of Financials and Profitability

Based upon the total variable costs, it has been determined that the Smart Sole will sell for $65. This is a 76 percent markup. This is a moderate markup, and it is essential to maintain a lower price point to beat the competition. Although there is a moderate gross margin, the product still must sell a high volume to recoup both the development costs and the fixed costs in production. The volume of the product sold is expected to increase for the first three years, due to increased product awareness, and then taper off due to improved alternative products and models. At this time it is expected a newer revision will be released. The profitability looks at only the first generation Smart Sole product. The business becomes profitable after two years; however, the total investment is not recovered until the third year. A summary of the profitability of Smart Sole is provided in Table 17.

Development costs are included as fixed costs in the first year only.

Table 17: Profitability of Smart Sole for Five Years of Operation

Year	Volume	Revenue	Fixed Costs	Variable Costs	Profit
1	3000	$195,000	$208,600	$110,670	($124,270)
2	5000	$325,000	$128,600	$184,450	$11,950
3	10000	$650,000	$128,600	$368,900	$152,500
4	9000	$585,000	$128,600	$332,010	$124,390
5	6000	$390,000	$128,600	$221,340	$40,060

8 Conclusion

The Smart Sole team set out to create a fitness tracker that functioned on renewable energy and would be able to compete with similar fitness trackers on the market. After researching and testing, the team determined that it was unfeasible to power the device solely on energy generated through the use of piezoelectrics. Basic design decisions were made and development of circuitry and software is currently ongoing. The primary objective that remains for the Smart Sole team is to develop an algorithm that uses multiple feedback methods including the piezos, an accelerometer, and GPS to provide as accurate and precise of a step count and distance measurement as possible. If such an algorithm is developed, the Smart Sole team believes that their product will be competitive on the fitness tracker marketplace. One more focus of the Smart Sole team will to design the product in a way to encourage development of additional features. The mobile application will be designed in such a way that it allows for expandability to potentially incorporate other features that may be seen on a product such as a Fitbit. The team has determined that the current project, with the requirements that they currently have defined, is feasible.

9 References

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Appendix A: Work Breakdown Structure

My Tasks in Calvin College Senior Design Team 11

Printed from Asana

- ☐ 1.1 Hardware — due May 5
  Design and implement the hardware associated with our project
  - ☑ ~~1.1.1 Research~~ — due December 9
    This task includes all research and research related work that need to be done to make informed decisions when prototyping and testing. Research can be broken down into mechanical and electrical considerations.
    - ☑ ~~1.1.1.1 Electrical Research~~ — due December 9
      This sub-task includes all research regarding electronics and their implementation in our project.
      - ☑ ~~1.1.1.1.1 Component Analysis~~ — due December 9
        This task includes researching and choosing component for our design. May include some library research as well as preliminary ordering and testing of parts. Dependent on 1.1.1.1.2 Power Generation, 1.1.1.1.3 Step Counting, and 1.1.1.1.4 Wireless Communication as well some dependencies on 1.1.1.2 Mechanical Analysis.
      - ☑ ~~1.1.1.1.2 Power Generation~~ — due November 25
        This task includes researching power generation capabilities as well as the materials and products that would be most effective.
      - ☑ ~~1.1.1.1.3 Step Counting~~ — due November 25
        This task includes research into step counting circuits as well as low power data storage options.
      - ☑ ~~1.1.1.1.4 Wireless Communication~~ — due November 25
        This task includes researching low power wireless communication methods.
    - ☐ 1.1.1.2 Mechanical Research — due December 9
      This task includes researching all mechanical topics that must be taken into consideration for our design.
      - ☐ 1.1.1.2.1 Stress/Impact Analysis — due November 25
        The goal of this task is to perform research regarding stress/impact and the effects that it will have long term on our product.
      - ☐ 1.1.1.2.2 Ergonomic Considerations — due November 25
        This task includes taking into account user comfort as our product should feel like a standard running shoe.
  - ☐ 1.1.2 Product Generation — due May 5
    This task includes using research to generate possible prototype ideas as well as testing and implementing said ideas. Dependent on 1.1.1 Hardware Research.
    - ☐ 1.1.2.1 Product Testing — due April 21
      This task includes testing our prototype(s) for functionality and comfort. This task will be ongoing as long as necessary in multiple stages. Full test plan will be generated.
      - ☐ 1.1.2.1.1 Prototyping — due March 24
        This task involves implementing research to create and a design a prototype of our product. May later be divided into further sub-tasks once research is complete. Dependent on 1.1.3 Hardware Research.
        - ☑ ~~1.1.2.1.1.1 Comparator Design~~ — due February 3
          Design the comparator component of the device hardware
        - ☐ 1.1.2.1.1.2 Accelerometer Design — due April 3
          Design the accelerometer hardware components of the step count module.
        - ☐ 1.1.2.1.1.3 GPS System Design — due April 3
          Design the GPS component of the step count module (if necessary)
        - ☑ ~~1.1.2.1.1.4 Bluetooth and Processor Design~~ — due February 3
          Design the Bluetooth circuit and all circuitry associated. May undergo changes as the requirements are modified
      - ☐ 1.1.2.1.2 Test Plan Generation — due March 24
        This task involves the creation of a test plan to effective and efficiently test all aspects of our prototype design. Dependent on 1.1.3 Hardware Research.

- [ ] 1.1.3 Hardware Budget Analysis — due May 5
  This task includes budgeting the design and development of our prototypes as well as budgeting and analyzing long term options covered in our business plan. This data will be used along with 1.2.3 Software Budget Analysis to help generate a business plan and a overall project budget for the year.

- [ ] 1.2 Software — due May 5
  Generate the software associated with our project including a mobile application and a team website.
  - [ ] 1.2.1 Mobile Application — due April 28
    This task involves the generation of the mobile application for our product including data acquisition and storage as well as possible GPS applications.
    - [x] ~~1.2.1.1 Research~~ — due November 25
      This task includes research how to design and create an effective mobile application.
    - [x] ~~1.2.1.2 Requirement Definition~~ — due December 9
      This task includes defining functions and user interface that is relevant for our mobile application. This includes functional definitions as well as providing an easy to use interface. Dependent on 1.2.1.1 Research.
    - [ ] 1.2.1.3 Application Development — due April 28
      This task involves the actual creation and design of the mobile application. This includes coding and testing. This task is dependent on both 1.2.1.1 Research and 1.2.1.2 Requirement Definition.
  - [ ] 1.2.2 Website Design — due May 5
    This task involves designing and maintaining a team website that meets the requirements laid out by the engineering department.
    - [ ] 1.2.2.1 Research — due May 5
      This task involves performing any research necessary to design a professional website. This task is continuously ongoing as necessary and can be performed simultaneously with the other tasks in this branch.
    - [x] ~~1.2.2.2 Design Implementation~~ — due December 9
      This task involves creating the interface as well as the content associated with the website.
      - [ ] 1.2.2.2.1 Content — due December 9
        The purpose of this task is to implement all of the required content onto our website. Can be performed simultaneously with 1.2.2.2.2 Interface.
      - [x] ~~1.2.2.2.2 Interface~~ — due December 9
        The purpose of this task is to make our website attractive and easy to use. Can be performed simultaneously with 1.2.2.2.1 Content.
    - [ ] 1.2.2.3 Website Upkeep — due May 5
      This goal of this task is to maintain the website and update the content and interface as necessary as the project continues. Can be performed at the same time as other website tasks.
  - [ ] 1.2.3 Software Budget Analysis — due May 5
    This task includes budgeting the design and development of our prototypes as well as budgeting and analyzing long term options covered in our business plan. This data will be used along with 1.1.3 Hardware Budget Analysis to help generate a business plan and a overall project budget for the year.

- [ ] 1.3 Business Plan — due April 7
  Manage all task associated with marketing and planning or project. Current due date is subject to change based on requirements
  - [x] ~~1.3.1 Executive Summary~~ — due December 9
    This task includes developing the finalized business plan as well as recording and presenting any material that a executive would find important when considering our project. This includes the PPFS. Dependent on 1.3.2 Marketing and Sales and 1.3.3 Financial Projection.
    - [x] ~~1.3.1.1 Business Plan~~ — due December 9
      This task includes any business related research and decisions that will go into the final PPFS. The primary focus of this task is on business related issues and not technical design ideas.
    - [x] ~~1.3.1.2 Design Plan~~ — due December 9
      This task focuses on the design and engineering aspects that must be included in our executive summary. This information will be simplified and condensed for corporate purposes.

- [x] ~~1.3.2 Marketing and Sales~~ due December 9
  This task includes taking information gathered through market analysis and applying it to develop a market and sales strategy. Dependent on 1.3.4 Market Analysis.
  - [x] ~~1.3.2.1 Marketing Strategy~~ due December 9
    The purpose of this task is to create a plan to promote our product based on data found through market research and analysis.
  - [x] ~~1.3.2.2 Sales Strategy~~ due December 9
    This task is to develop a plan to strategically distribute and sell our product in the most effective way possible.
- [ ] 1.3.3 Financial Projection due April 7
  This task includes developing a big picture financial projection of our products including cost and revenue analysis against market trends to show profitability.
  - [ ] 1.3.3.1 Financial Data due April 7
    This task involves acquiring data regarding market projections, general sales trends, and any other information essential to developing an accurate financial projection for our overall project.
- [x] ~~1.3.4 Market Analysis~~ due November 25
  This task involves performing research regarding the market for our product which will be used to help develop a potential business plan and product strategy.
  - [x] ~~1.3.4.1 Industry Outlook~~ due November 25
    The goal of this task is to generate an outlook on the revenue that could potentially be generated in the market we are entering. The primary purpose is to determine the future potential profitability of our product based on industry trends.
  - [x] ~~1.3.4.2 Target Market~~ due November 25
    The goal of this task is to find a target demographic/market that we would like to sell our product to. This will have a major impact on our marketing strategy.
  - [x] ~~1.3.4.3 Pricing~~ due November 25
    This task involves doing the research necessary to determine the selling price of our product. This will involve taking into account cost of materials as well as performing an economic analysis to determine a price to maximize profit. This task will be ongoing as materials used may change.
  - [x] ~~1.3.4.4 Competitive Analysis~~ due November 25
    This task involves analyzing and finding potential competition that our product may have and ensuring that our product will be able to compete in a competitive market.

- [ ] 1.4 Project Management due May 5
  This task includes all functions associated with managing personnel, scheduling, and finances. This task will be ongoing throughout the entirety of the project.
  - [ ] 1.4.1 Team Organization due May 5
    Includes general team and work organization tasks including the WBS, meeting minutes and team documentation.
    - [x] ~~1.4.1.1 Work Breakdown Structure~~ due October 31
      Generate a basic WBS to divide tasks and assign due dates.
    - [ ] 1.4.1.2 Meeting Minutes due May 5
      Keep a good record of team meetings and member contributions to increase accountability and meeting effectiveness.
    - [ ] 1.4.1.3 Documentation due May 5
      Keep an organized and easy to access set of research notes and other documentation.
  - [x] ~~1.4.2 Scheduling/Gantt Chart~~
    Create a basic schedule of tasks to better manage team time and organize due dates. Incorporated within WBS and subject to change.
  - [ ] 1.4.3 Financial Management due May 5
    Manage costs of materials and other group functions. Dependent on 1.1.3 Hardware Budget Analysis and 1.2.3 Software Budget Analysis. This task is ongoing throughout the project.

Appendix B: Action Items

Date	Task	Due Date	Description	Status
9/14/16	Objectives and Requirements	**9/23/16**	Create a list of project objectives and requirements to begin to define the scope of the overall project	Completed 9/22
9/23/16	Project Website	**10/26/16**	Generate a project website with basic team and project information	Completed 10/24
9/23/16	Website Upkeep		Keep the team website up to date with the lastest information and documentation	Yearly ongoing task
10/3/16	WBS	**10/12/16**	Generate a work breakdown structure to define and identify project tasks that must be completed	Completed in Asana 10/11
10/4/16	PPFS Outline	**10/5/16**	Generate a basic outline for a PPFS	Complete
10/10/16	Project Brief	**10/17/16**	Generate a project brief for review by the industrial advisor	Completed 10/16
10/10/16	Team Photos	**10/26/16**	Take team photos for use in presentations and on the team website	Completed 10/23
10/31/16	Project Poster	**11/4/16**	Create the initial team project poster for use at Calvin engineering day	Completed 11/3
11/6/16	PPFS Rough Draft	**11/14/16**	Generate a rough draft of the PPFS based on information and projections currently availible to the team	
11/14/16	PPFS	**12/12/16**	Finalize the rough draft of the PPFS	Ongoing
11/30/16	Oral Presentation 2	**11/7/16**	This presentation will focus on feasibility and project projections. Sub-tasks: - powerpoint presentation - presentation rehersal	12/4 - Power Point outline completed

Legend	
	Completed
	In Progress, Low priority
	In Progress, High priority