

SMART INSOLE FINAL REPORT

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SMILE: Smart Machines Improving Life Enterprises

Abstract

Every year, 60 million Americans (25% of the US), suffer from flat feet. This deformity, also known as fallen arches, can limit daily activities and lead to pain in the ankles, knees, hips, and lower back, as well as the common injury known as shin splints. Current shoe insoles sold at local drugstores, however, have been proven to be ineffective on many occasions. A recent article published by the Journal of the American Medical Association concluded that lateral wedge insoles, the kind you can find for sale at stores across the country, do not reduce knee pain caused by osteoarthritis. Because custom orthotics from a podiatrist are so expensive -- some can cost upwards of \$400 -- the market for insoles can be very daunting to an average consumer, especially when their effectiveness is debatable.

Improving functionality, aesthetics, and maintaining the effectiveness of a custom orthotic at a quarter of the price, Team SMILE (Smart Machines Improving Life Enterprises) has developed MotionSoles . This design, featuring system of thin force transducers coupled with an array of small mechanical pins and covered by memory foam, maximizes comfort and effectiveness in correcting foot shape while keeping the consumers' pocket in mind. No longer will a user suffering from foot, ankle, knee, or some sort of posture-related pain be forced to shell out hundreds of dollars for a newfangled apparatus that may or may not reduce the pain. With Team SMILE'S MotionSoles, the user will be able to rest easy, with less pain in the body and the mind at ease.

1. Introduction

Every year, 60 million Americans suffer from flat feet (Brown). This deformity, also known as fallen arches, can limit daily activities and lead to pain in the ankles, knees, hips, and lower back, as well as the common injury known as shin splints. As a team, we at Team SMILE believe that that is a serious issue. When presented with a challenge by AT&T to contribute to AT&T's Internet of Things initiative to find new opportunities to collect and analyze data in innovative ways that will benefit our lives, this was one of the first things to come to mind.. Design categories for this competition were connected home, connected car, and wearables. By creating a solution Team SMILE is tackling a massive industry with a large consumer basis to improve the lives of millions.

To manage this project, Team SMILE is following a design process that includes 1) an Activity Network Diagram to maximize efficiency of project development over a time restriction, and 2) an Analytical Hierarchy Process to rank the most important needs of the product based on the consumer assessments

This project report will be organized and presented in the following manner to maximize readability and understanding of key concepts that drive Team SMILE's innovation.

1. SMILE's initial problem statement.
2. Gathering and Analyzing Customer Feedback
3. SMILE's revised problem statement
4. Gathering external data from literature and patents, and analyzing that data.
5. Generating and analyzing new product designs that address the team's problem statement and that is ultimately unique in the marketplace.
6. Analyzing the cost of the design
7. Explaining MotionSole, team SMILE's affordable custom orthotic

1.1 Initial Problem Statement

Team Smile is tasked with creating an economically viable device that will allow the user to interact with the technology and receive real-time information wirelessly, through an app for example. The device, or the information that it collects, should aim to improve the user's life in some way. The device must fall under one of the following categories: Connected Home, Connected Car, or Wearables. Team SMILE then decided to focus the problem statement to better define a specific problem. The redefined problem is to create a wearable device to reduce knee and ankle pain of the wearer.

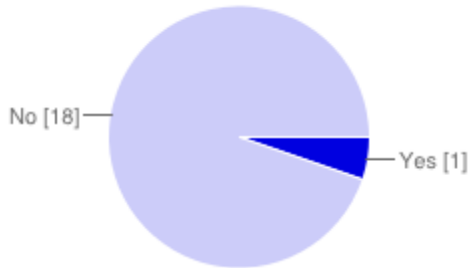
2. Customer Needs Assessment

Before the team could begin generating to solve the given problem, it had to first fully understand the potential market for a real-time adaptable insole. To do this, the team had to take into account the entirety of able-bodied the population: both young and old, male and female, athletic and non-athletic, all of whom, it goes without saying, spend at least some time on their feet, propelling themselves from point A to point B. The team, with this broad view in mind, conducted an online survey that determined what potential consumers looked for in an insole. The survey gathered data on whether or not the survey taker used insoles at all, and his or her openness to a "custom-tailored insole that dramatically reduces foot and knee pain." The survey also allows the taker to specify specific attributes one might look forward to in an insole, in addition to quantifying the importance of certain factors like cost or weight. The survey questions are listed in Appendix A. As it is made apparent in Figure 1, there is currently a large potential to create a market, due to the lack of consumers, but due to the potential usefulness to consumers because of the lack of products on the market. Figure 2 illustrates the important criteria for a custom orthotic insert/insole if they were to purchase one -- the most important is the comfort of the insert followed closely by the effectiveness of the product. Both criteria go hand-in-hand with one another, because the function of the smart insole, MotionSoles, is to make everyday life and athletic performance more comfortable and pain-free. To determine the how vital the weight will be to the success of the product, consumers were polled about that as

well. As seen in Figure 3, potential consumers are very clear as to their opinions on how much the insole should weigh, which is as little as possible. The information collected from the bar graph comparison of important features was compiled into a hierarchical list (Figure 4).

Figure 1. Available Market for the Product

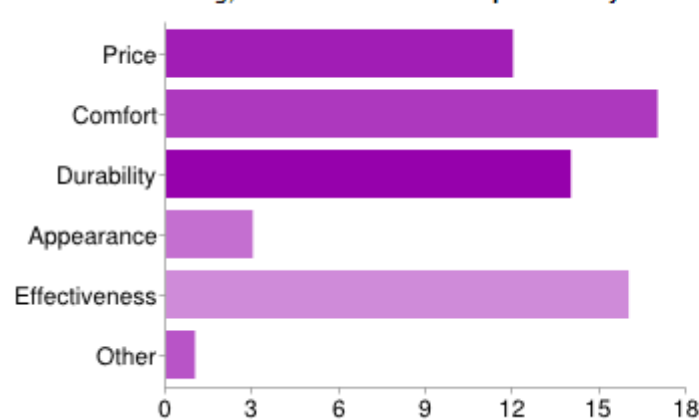
Do you currently use an insole or orthotic?



| | | |
|-----|----|-----|
| Yes | 1 | 5% |
| No | 18 | 95% |

Figure 2. Important Qualities in an Insole

Out of the following, which are the most important to you in an insole? (Select all that apply)

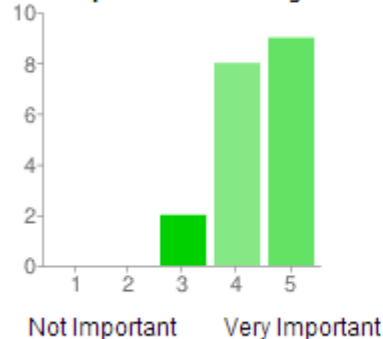


| | | |
|---------------|----|-----|
| Price | 12 | 63% |
| Comfort | 17 | 89% |
| Durability | 14 | 74% |
| Appearance | 3 | 16% |
| Effectiveness | 16 | 84% |
| Other | 1 | 5% |

People may select more than one checkbox, so percentages may add up to more than 100%.

Figure 3. Importance of the Insole's Weight

How important is the weight of the insole?



| | | |
|--------------------|---|-----|
| 1 - Not Important | 0 | 0% |
| 2 | 0 | 0% |
| 3 | 2 | 11% |
| 4 | 8 | 42% |
| 5 - Very Important | 9 | 47% |

Figure 4. Hierarchical Customer Needs List Obtained from Surveys

- | |
|---|
| <ol style="list-style-type: none"> 1. Weight 2. Comfort 3. Effectiveness 4. Durability 5. Price 6. Appearance 7. Odor Protection (Other) |
|---|

1. Weighting of Customer Needs

Once the survey had been conducted and the necessary data to ascertain customer needs had been gathered, the team began to analyze the data it had collected. To do this, the team needed some sort of system or chart that would categorize and weigh the different customer needs according to their relevance and overall importance. The system in mind was an Analytical Hierarchy Process, better known as an AHP. The AHP is a quick, convenient matrix that makes pairwise comparisons with each attribute, so as to determine which attribute, out of all of them, is the most important, which is the second most important, and so on. The following figure (Figure 5) shows the AHP the team used to analyze the data from the survey. The accompanying figure, Figure 6, creates a hierarchical comparison based on the information collected from the AHP, placing both effectiveness and comfort above weight and price.

Figure 5. AHP Pairwise Comparison Chart to Determine Weighting for Main Objective Categories

| | Appearance | Weight | Price | Comfort | Durability | Effectiveness | Odor Protection | Total | Weight |
|-----------------|------------|--------|-------|---------|------------|---------------|-----------------|--------|--------------|
| Appearance | 1.000 | 0.111 | 0.167 | 0.111 | 0.143 | 0.125 | 0.333 | 1.990 | 0.017 |
| Weight | 9.000 | 1.000 | 0.500 | 0.250 | 0.333 | 0.250 | 5.000 | 16.333 | 0.141 |
| Price | 6.000 | 2.000 | 1.000 | 0.333 | 0.500 | 0.333 | 5.000 | 15.167 | 0.131 |
| Comfort | 9.000 | 4.000 | 3.000 | 1.000 | 0.500 | 0.500 | 9.000 | 27.000 | 0.233 |
| Durability | 7.000 | 3.000 | 2.000 | 2.000 | 1.000 | 0.500 | 7.000 | 22.500 | 0.194 |
| Effectiveness | 8.000 | 4.000 | 3.000 | 2.000 | 2.000 | 1.000 | 8.000 | 28.000 | 0.242 |
| Odor Protection | 3.000 | 0.200 | 0.200 | 0.111 | 0.143 | 0.125 | 1.000 | 4.779 | 0.041 |

Figure 6. Weighted Hierarchical Customer Needs List Obtained from Focus Group and Individual Interviews

- | |
|---|
| <ol style="list-style-type: none"> 1. Effectiveness (0.242) 2. Comfort (0.233) 3. Durability (0.194) 4. Weight (0.141) 5. Price (0.131) 6. Odor Protection (0.041) 7. Appearance (0.017) |
|---|

3.0 Revised Problem Statement

With this new data in mind, the team realized that the in the smart insole must also be able to provide the benefits and comforts a normal insole. The most important attributes that consumers identified was the comfort and

effectiveness of the insert, . The team also discovered that appearance was unimportant, which makes sense, since the insole will be by nature almost never seen by others, and that price wasn't very important, which indicated that many users were willing to pay a high dollar for some sort of improvement in their walking experience.

4.0 External Search

In order to design a functionally more effective and more reasonably priced foot-shape corrective device, Team SMILE needed to gain a full understanding of the current products on the market. Background research was done to explore the variety and effectiveness of current products on the market, due to the incomplete knowledge of the group members on the topic of orthopedics. To make sure that the product will be more effective and less expensive, thorough research was conducted to find the best alternatives and parts for the final idea generation.

4.1 Literature Review

Team S.M.I.L.E. studied four different brands of orthopedic products that addresses foot pain and or posture. This literature review gave the team a better overview of the current products on the shelf, the customer segments and the customer's relationship of each brand. This information will help form a clearer expectation of the market dynamics and will be used to design the team's product.

One overarching theme for the insole market was that 1) insoles even custom made ones did not work effectively 2) insoles were too expensive, 3) insoles move around in the shoe causing discomfort and 4) foot pain can be cured with stretching or other methods. A 2006 New York Time article reports that even many podiatrists were dubious of insole's effectiveness. **cite**. In short, many customers did not believe insoles were necessary for their foot pain. The other theme was that insoles such as diabetic, arch support, heel support, shock absorbent, and etc. were capable of solving many health related ailments. Supporters of this theme remarked that insoles help improve the running and walking experience. A New York Times report on foot pain listed buying insoles in five out of fifteen foot pain conditions. In short, the insole market is polarized wondering whether insoles are worth the investment or not.

Dr.Scholl's insoles tailor towards alleviating a wide range of ailments from the foot, body and skin. These insoles focused on different pressure points in the foot and has resulted in five different brands customized for sports, high heels, everyday use, lower body pain, and high end users. The wide variety of products and its quality allows Dr.Scholl to command much of the market. According to SymphonyIRI, Dr.Scholl's products dominate over 52% of the insole market or \$194 million out of the \$370 million market. In the reviews section, ratings range from 3.3 The reviewers state positive remarks such as "Very comfortable and they give a ton of extra cushion to go the extra mile" to "they are cheaper made, thinner and have no cushiony support like the old ones." Prices range from \$19.99 to north of \$500 depending on the product.

Custom tailored for each customer, ArchCrafters Custom Comfort Insoles target specifically sport minded people and professionals who are on their feet often. They claim that their insoles provide maximum comfort and as a result they have a 3% return rate for their insoles. One secret to ArchCrafters's success is that it measures every nuance of the undersurface - including foot curvature and size - of the individual. These custom insoles come at a modest price or roughly \$100. On Amazon, the average rating for this product was 3.8 out of 5 with 16 ratings total. Customer Reviews ranged from "Great Product and Service" to "disappointment..." However, many of the negative reviewers used the insole in a way that ArchCrafters did not endorse in its FAQs page. The issue is that ArchCrafters insoles should not be used across multiple shoes. Also they don't work well for people with flat feet.

Spenco Insoles provide feet comfort for five different customer profiles. They are Stability, Cushioning, Classic Comfort, Specialty and Ironman. The first three offers three unique shoe comfort experiences. Specialty is geared towards specific uses such as high heels and sports. Ironman is for kids. A unique feature about Spenco Insoles is that they offer insoles for only heels, only arches, orthotic arch support etc. Thus the customer has from a wide variety of options to choose. These insoles come relatively cheaply and for the typical full-length insole, the starting price is at \$30. For insoles made only for the heel, they go around \$8. On Amazon, the average customer review was 4.3 out of 5 with 389 total ratings. Sifting through the reviews, many expressed happiness for Spenco's product. However common complaints for these insoles were that it hurt the user's feet and that it squeaked frequently.

4.2 Patent Search

A thorough patent search was done to understand the existing market for insoles and posture correcting technologies. Team S.M.I.L.E. created an Art-Function Matrix in Table 4 to show the seven patents most relatable to our idea. This matrix allows the team to visualize the relationship between the idea's many functionalities and the idea's parts that perform these functions. The parts are the result of the patent search.

The purpose of a patent search has two folds. First, the team needed to know what technologies had patents and therefore would require collaboration with the patent holders. Second, the team needed to identify a niche in the market to differentiate itself from the orthopedic market. Through this, team S.M.I.L.E. will be able to create a sound and marketable product. As shown in Figure 7, there are not many patents on arch correction and insoles in general, which, as a result, means that it will be rather difficult to infringe upon any existing patent(s).

Figure 7. Art-Function Matrix for S.M.I.L.E Insole

| | Art | | |
|---|-------------------------|------------------|-----------------|
| Function | Cushioned Insert | Orthotics | GaitScan |
| Foot/Knee Comfort | US4020570 | | |
| Correct Flat/High Arch | | US4250886 | |
| Provide Info. Regarding Weight Distribution | | | US8028576 |

4.3 Benchmarking

As a group, Team SMILE compared our smart insole to other familiar insoles and arch-correction products. Figure 8 shows how different features of the smart insole rank among the different types. The features in the table range from most important (1) to least (7).

Figure 8. Benchmarking of Four Products

| Feature | Cushioned Insole | Dr. Scholl's Custom Fit Orthotics | Custom-Made Orthotic | Smart Insole |
|-----------------|-------------------------|--|-----------------------------|---------------------|
| Appearance | 7 | 7 | 7 | 7 |
| Weight | 1 | 5 | 5 | 5 |
| Price | 3 | 3 | 4 | 3 |
| Comfort | 2 | 2 | 2 | 2 |
| Durability | 5 | 4 | 3 | 4 |
| Effectiveness | 4 | 1 | 1 | 1 |
| Odor Protection | 6 | 6 | 6 | 6 |

4.4 Design Target







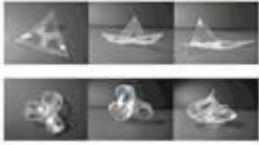
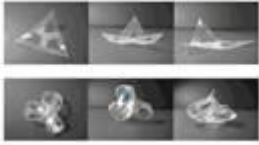

After conducting its external search -- which included reviewing current resources and articles about orthopedics, searching for patents, and benchmarking the different insoles that are currently on the market -- Team SMILE has gained invaluable knowledge of the world of insoles and how to differentiate its product from others. Through the

patent search, the team was able to determine which ideas had already been developed by other companies, such as correctors for flat or high arches and insoles that deliberately target reducing foot, ankle, and knee pain. The team also analyzed three insoles that were currently on the market, using the criteria the team developed from the customer feedback survey. By doing this, the team was able to better understand what current products had to offer, and how the team’s own product would be able to improve upon pre-existing models. By analyzing the current literature, Team SMILE understood the intricacies of different insoles, and how different designs could target different areas of pain. For example, some insoles aim to reduce pain from osteoarthritis, while others attempt to correct deformities in the arch. Still others attempt to improve posture by subtly correcting spine shape and weight distribution, and there are some that purport to provide the user with an athletic edge. To design an improved, “smart” insole, the team needed to be able to fully comprehend the different possibilities insoles offered, and the team did this by going through its external search.

5.0 Concept Generation

Once Team SMILE had completed its external search and fully understood the intricate ins and outs of the orthopedics world, the team began the concept generation and selection phase of the design process. The team first began by generating various concepts through brainstorming different ideas for the energy, material, and signal of the final product. Once the team had generated enough ideas, Team SMILE systematically organized the different ideas into a morphological chart, which is an easy to use visual organization of the various potential concepts for a given product. Below is the morphological chart that Team SMILE generated after many painstaking hours of creative concept generation, better known as brainstorming.

Figure 8. Morphological chart

| | Power Generation | Material | Signal |
|----------|---|---|--|
| 1 | <p>Lithium Batteries</p>  | <p>Flexible Plastic Polymer</p>  | <p>Pressure Sensitive Switch in Heel</p>  |
| 2 | <p>Piezoelectric Generator</p>  | <p>Isofoam</p>  | <p>Piezoelectric material to sense pressure</p>  |
| 3 | <p>Powered by Body Heat</p>  | <p>Electroactive Polymer</p>  | <p>Bluetooth connected to Phone</p>  |

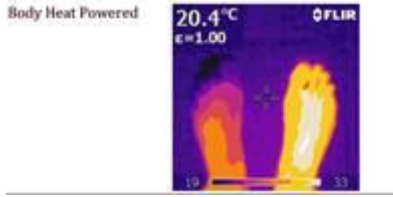
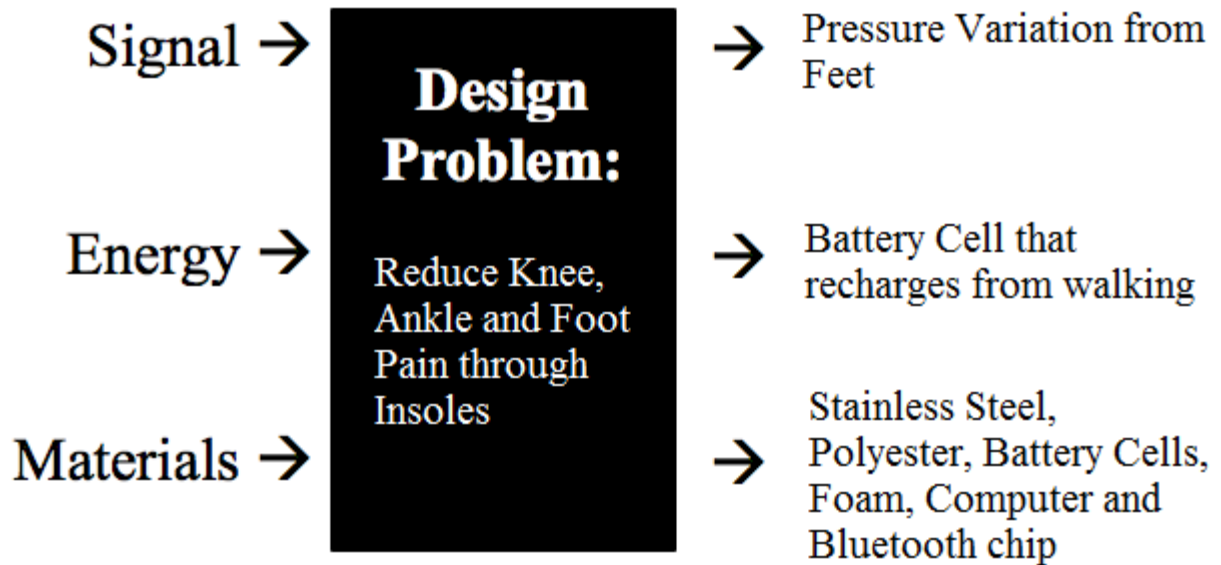
| | | | |
|---|--|--|---|
| |  | | |
| 4 | <p>Battery pack in pocket that is wired down the user's leg to insole</p>  | <p>Memory Foam (Polyurethane Foam)</p>  | <p>On/Off switch on Battery Pack</p>  |

Figure 9. Black Box Model


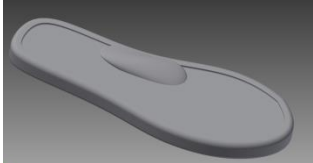




6.0 Concept Selection

Once the team had generated enough concepts, the team entered the concept selection phase of the design process. This is where the team quantitatively analyzes the various potential concepts that may be finalized in the end result of the design process. To do this, the team developed a Pugh chart (Figure 10), which allows the team to objectively view every individual concept it had generated and the relative merits of each one. The Pugh chart uses the consumer-aided criteria that were found through the AHP and the consumer survey data. This is to say that every concept is analyzed based on how effectively it meets the criteria that customers specified that they want in a given product, which in this case would be a smart insole that morphs according to the user's feet and motion. From this data we gathered that MotionSoles, the smart shoe insert, would be the most viable option and solution for our

defined problem statement of creating a wearable device that reduces knee, ankle, and foot pain of everyday and athletic wear and tear.

Figure 10. Pugh chart

| Description | | Dr.Scholls Insoles | MotionSoles | Motion Shoes | SmartSocks |
|---------------|--------|---|---|---|---|
| Sketch | |  |  |  |  |
| Criteria | Weight | Datum | Design 1 | Design 2 | Design 3 |
| Weight | 1 | 0 | 0 | - | 0 |
| Price | 1 | 0 | - | - | 0 |
| Comfort | 2 | 0 | + | + | 0 |
| Durability | 2 | 0 | 0 | 0 | - |
| Effectiveness | 3 | 0 | ++ | ++ | + |
| + | | 0 | 2 | 2 | 1 |
| 0 | | 5 | 2 | 1 | 3 |
| - | | 0 | 1 | 2 | 1 |
| Net score | | 0 | 7 | 6 | 1 |

7.0 Final Design

After countless hours of painstakingly hard work, Team SMILE finally did it. The team settled on the “MotionSoles” as its final design. There is, admittedly, a need among engineers to be modest, to deliberately diminish their accomplishments and say that they are just “doing their jobs.” But if the false modesty is stripped away, the hard-working engineers at Team SMILE can confidently proclaim that MotionSoles is a revolution in orthopedics, in the way people approach shoes, and in the way people walk. It is not an understatement to say that MotionSoles will change the very course of human evolution. Walking is the most basic way in which people interface with the environment--even with modern, motorized transportation, human beings still need to use their legs to propel them from point A to point B. What the MotionSoles does is change the very nature of walking by dynamically adapting to the user’s individualized walking style. After conducting a rigorous analysis of consumer needs through the highly useful Pugh Chart, the Team concluded that the MotionSoles was the best step forward--for this project, and for mankind

Present Value Calculations:

Cost = \$110

Maintenance = \$5 / year

Salvage = \$20

Lifespan = 6 years

$$PV = -110 - 5/1.1 - 5/1.1^2 - 5/1.1^3 - 5/1.1^4 - 5/1.1^5 + 15/1.1^6 = -\$120.49$$

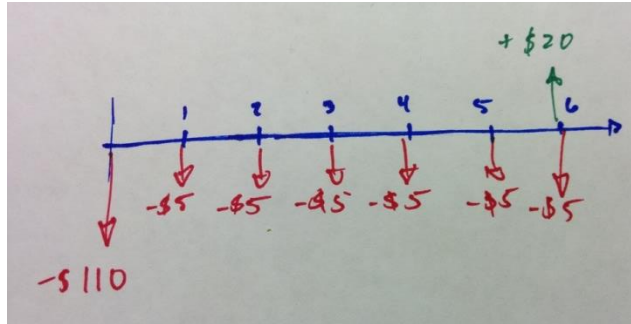


Figure 11. Present Value Calculations

Figure 12. Bill of Materials for Final Design

| # | Part Name | QTY | SOP Effect | Function | Mass (g) | Material | Manuf. Process | Dimensions | Cost |
|---|--------------------------|-----|------------|--|--------------------|-------------|---------------------------|------------------------------------|-----------------------------|
| 1 | Pin and Sensor | 30 | No | Measure data, and adjusted to change height | 0.25 g per 7.5g | Aluminum | Injected Molded Aluminum | Max Dim: 0.689 in x 0.689 in | \$2.5 per ---- \$75 |
| 2 | DC Motor and Axle System | 3 | No | Provides torque to change height of the pins | 1 g 3 g | Aluminum | Injection Molded Aluminum | Max Dim: 1.0 in x 0.75 in | \$2.5 per ----- \$7.5 |
| 3 | Upper Layer | 1 | Yes | Top layer of the insole "sandwich" | 1 g | Plastic gel | Injected Molded Plastic | 12 in * 3 in | \$5 |
| 4 | Lower Layer | 1 | Yes | Bottom layer of the insole "sandwich" | 0.010 | Plastic gel | Injected Molded Plastic | 12 in * 3 in | \$5 |
| 5 | Micro-chip (CPU) | 1 | No | Processing center | 0.012 | Silicon | Silicon crystallization | .5 in x .5 in x .125 in | \$5 |

7.1 How does it work?

An innovative system of shifting pins provides the output of the MotionSoles. Every individual pin can be raised or lowered dynamically, with streams of data on the user's weight, position, and stride customizing the pins to each unique individual. The data collected by array of pressure sensors on the different pins is processed by the central CPU and uses the information to adjust the heights of each of the pins. Once the pins are repositioned, the microchip collected more data, thus initiating a constant cycle of data, feedback, and recalibration. The top and bottom layers are made of a comfortable plastic gel that provides enough support for active users who are on the go day in and day out. The gel is also flexible and strong enough that the pins can extend upwards without puncturing the gel layer, so that it appears to the user that the layer is moving itself.

8.0 Conclusions

How do one improve upon something as fundamental as walking?

Ever since the first primates learned to walk on their hind legs, developing bipedal motion and thus forever changing the course of natural history, human beings have walked naturally, relying on pure instinct and nothing else. After taking a few tentative steps babies are able to walk within a matter of months, and improve their walking skills as they grow older. Inventions such as the Segway have attempted to change personal transportation, though their success is limited, at best.

At Team SMILE, limited success was not an option. The team would only be satisfied with a product that revitalized the orthopedics industry, revolutionize transportation, and fundamentally reshape the world as a whole. With these criteria in mind, the team can humbly proclaim that the MotionSoles are quite literally the greatest thing since sliced bread. After performing an arduous design process by surveying customer needs, analyzing the most important criteria, generating concepts, empirically selecting the greatest concept, finalizing the design, and developing a physical prototype along with a fully realized 3D CAD model (Appendix B), Team SMILE can finally bask in the inevitable glory that will follow the momentous release of the MotionSoles. While the presented models are great for detailing the concept, a final design overhaul will potentially be needed to reduce the weight and thickness of the product, but the resulting product does a very good job at achieving a solution to the problem presented before us, and is making headway in creating an affordable knee, ankle, and foot pain solution.

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Appendices

Appendix A: Customer Needs Assessment Questions

- 1) Do you currently use an insole or orthotic? Y/N
- 2) How much are you willing to pay for a custom-tailored insole that dramatically reduces foot and knee pain?
(Select all that apply)
 - \$0-10
 - \$10-30
 - \$30-50
 - \$50-100
 - \$100+

- 3) Would you be willing to pay more for the product if it improved your performance during athletic activity?
Y/N
- 4) How important is the appearance of the insole? (1-5)
- 5) How important is the weight of the insole? (1-5)
- 6) Out of the following, which are the most important to you in an insole? (Select all that apply)
- Price
 - Comfort
 - Durability
 - Appearance
 - Effectiveness
 - Other _____
- 7) How often would you be willing to replace the insole?
- Once every 3 months
 - Once every 6 months
 - Once every year
 - Once every 5 years
- 8) Optional: Is there anything specific that you would like to see exist in an insole?

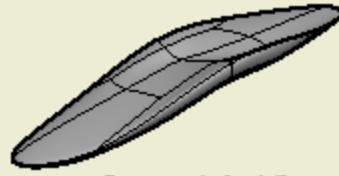
Appendix B: Final Design Drawings

B.1 Isometric Drawings

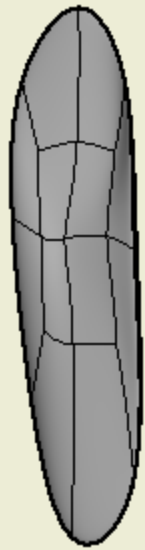
Figure 13. Orthographic Views of Insole



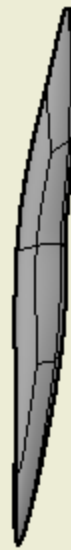
Top View



Isometric View

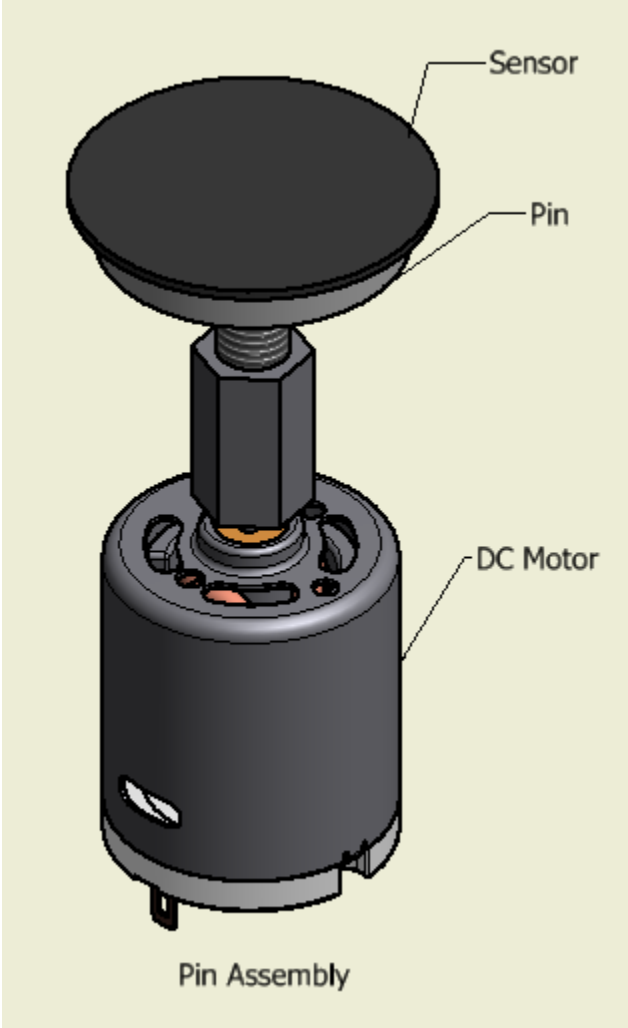


Front View



Side View

Figure 14. Isometric View of Single Pin and Motor Assembly



B.2. Major Parts

Figure 15. Orthographic Views of Pin and Sensor

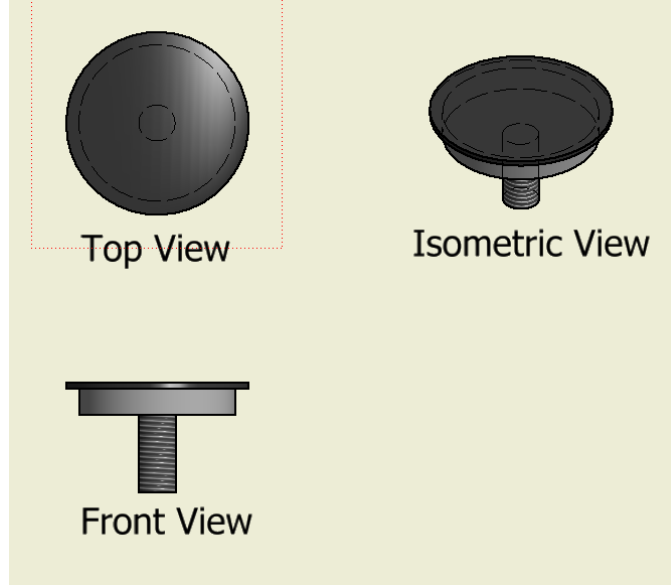


Figure 16. Full Breakdown Piece-by-Piece

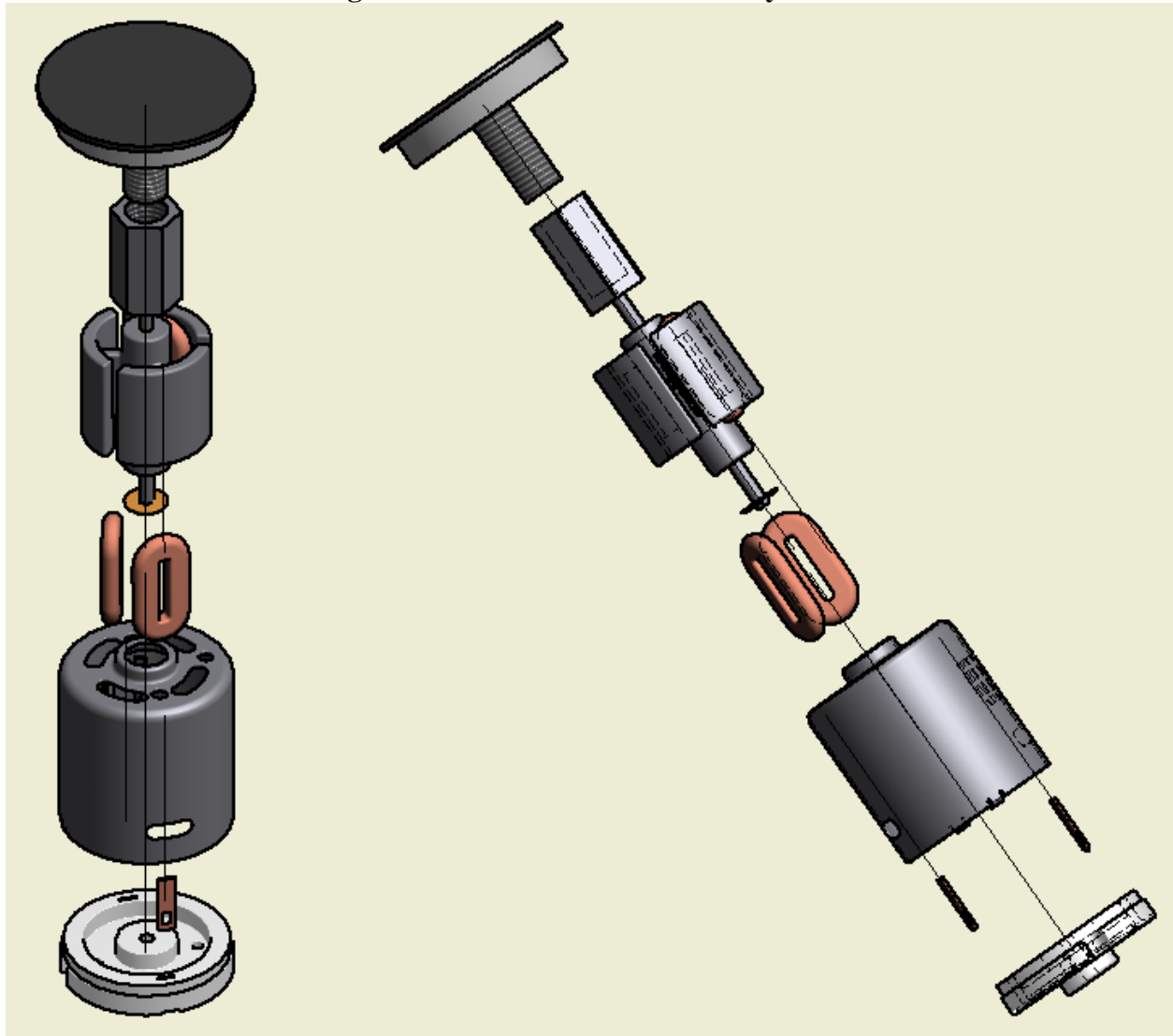


Figure 17. App Design

