BackBone

A Tool for Posture Tracking and Correction

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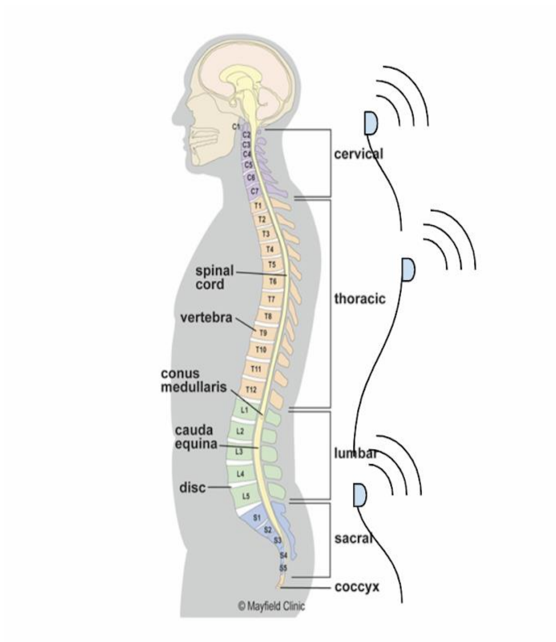
I. Introduction

Back pain is a common ailment in the developed world, affecting millions. While there are a wide range of causes and solutions, one very simple way of reducing, and in some cases eliminating back pain and its associated health effects is to maintain correct posture. Forming a habit--any habit; even one as mundane as maintaining correct posture, can be difficult. To assist in this, we envisioned and developed Backbone, a sensor and mobile application combination that detects posture and reports deviations to the user if and when they occur.

The human body has evolved several senses to provide useful and precise information, quickly, where and when it is necessary. The significant part of that statement as pertains to our project, and to human augmentics as a while, is the addition of the words “where and when it is necessary”. Necessarily the human body has evolved to adapt to whatever conditions may befall it. While this is mandatory for a Cro-Magnon man that has suffered an infection in a toe, in our modern age this oftentimes inadvertently coerces the human body to adapt to a sedentary lifestyle its owner doesn’t want it to adapt to! If a person maintains poor posture long enough, their body will begin to adapt to that posture, changing musculoskeletal to adapt to such a position, and causing chronic pain as an unintended result. It is easy for a person to distract themselves and forget to consciously maintain good posture as they sit for eight hours, or contort themselves to operate heavy machinery, or type constantly on a laptop keyboard. To aid in this, backbone does the work of this person, detecting posture deviations and reporting to the user when they fall into incorrect posture, and reporting the information they need to correct their posture in the way that suits them, providing different cues to individuals with lordosis over kyphosis, for instance. The use of this device is an augmentic device, as it is aiding the person by providing sensory information *their brain has deemed unimportant*, both alleviating them of the conscious mental burden of maintaining correct posture, as their brain is happy to do, and also providing that necessary information to either correct or prevent bad posture, and the chronic maladies that can result.

From its outset, our product was always meant to detect the position of some part of the users body. However, what body part, to what end, and how we used and reported this information has gone through several iterations. From its inception the ideation process went through four major phases. Very roughly, these can be broken down into: one, what body part are we sensing; two, to what end; three, how do we detect and report this information; and four, how can we adapt the design to complete the project on-schedule? A brief explanation and breakdown of each of these phases follows.

The first phase of the ideation process answered the question: “what are we sensing?”. Originally, this was between two body parts, the hand, and the spine. Our team very quickly decided upon the spine, as this was meant to have multiple sensors, even for one appendage, a full description of the position of the fingers would at minimum have three times the sensors required for the spine to achieve the desired fidelity, in addition to increased accuracy and update frequency to account for the differing physical characteristics of the spine and fingers. For this reason, mainly, the spine was chosen as the desired body part.



The second phase answered the question: “Why are we measuring the spine”. At this point, a clear vision for the project hadn’t yet been decided upon, and so at the choice was between the use of this device as a sleep aid to detect spine curvature, and to use it as a posture-checking assistant; also measuring the spine but with more attention being put on detecting deviation. Eventually we decided upon the posture-checker, as we found this more directly translated into a standalone project.

The third phase was the longest and most difficult, answering the question: “how do we detect and report this information”. The question of how to detect the information mainly relied on the selection of a specific sensor technology and the design of a device that could accurately use these sensors to reliably obtain the signal we required. For this first question, we originally looked at several different technologies: piezoelectric devices, strain gauges, IMUs, and bend sensors. Initially, piezo-electricity was pursued, however after identifying the complications associated with the full design of a sensor, technologies that were less elementary were pursued. After this, the first design focused on strain-gauges, as these were the least expensive and simplest conceptually. However, after experimentation the strain gauges proved to be too delicate and sensitive for our manufacturing capabilities, and so we moved on to bend sensors and accelerometers. The second design relied on a combination of a bend-sensor and an IMU. The bend sensor was meant to provide a baseline that would correct for drift in the IMU, and the IMU provided detailed multi-axis position and orientation data. After experimentation, it was found that the bend sensor wasn’t aiding in the device’s fidelity, and so this more complicated design was scrapped. The current and final design relies solely on IMUs.

The fourth and final phase answered the question: “how can we adapt the design to complete the project on-schedule?” While this answer has been alluded to in previous sections, it will be addressed more formally in this section. In short: the main process is ongoing and has mainly relied upon quick iteration and throwing away things that don’t work quickly. As we stated in earlier sections, there have been many iterations of the design, and oftentimes the design or underlying technologies have been scrapped in favor of simpler and quicker-to-prototype solutions. The main virtue of the IMU over any other design selected was the ease and immediacy with which we obtained not only sensor data, but a visualization as well. “Hints” like these have guided the project from its inception and continue to do so.

The four group members are: Alfonso Arias, Bria Bolor, Ruy Calderon, and Sasan Schafikhani. The sub-tasks involved with the project were: enclosure design, mobile app design, sensor design and software, and hardware. Very broadly, the breakdown of work by group member follows.

1. Alfonso Arias: Hardware, Soldering, Circuit Design
2. Binderiya Bolor: Sensor Design and Signal Processing
3. Ruy Calderon: Enclosure Design and Embedded Software
4. Sasan Schafikhani: Mobile App and Bluetooth Pairing

II. Literature Review

Given that poor posture is almost ubiquitous in the developed world, it should come as no surprise that there is no lack of academic research and commercial products that address the problem. Of these products, we mainly investigated general wearable sensor technologies and commercial products that represent are direct competitors. We were also lucky enough to find a research paper that provided an excellent overview of the state of wearable sensor technology, specifically for the spine. We drew a great deal of inspiration from all these sources when designing Backbone.

To begin, with, this paper will first explore the lessons learned from the overview paper mentioned in the previous paragraph. This survey paper, entitled: “Wearable technology for spine movement assessment: A systematic review “provided a detailed look into the world of wearable spinal sensor technology by looking at all research papers on the topic and categorizing them based upon information provided, reception, and technologies used, among many other categories. While we learned a great deal from this paper, and it provided excellent general background information, the chief takeaway that influenced the design of backbone was in the decision to use an IMU as the primary wearable sensor. The survey paper showed that one or more components of a standard IMU was present in fifteen out of twenty-two devices surveyed.

> "The type of sensors used to assess spine movement varied from electro goniometers (3/22), strain gauges based sensors (3/22), textile piezoresistive sensor (1/22) and uniaxial to triaxial accelerometers, the latter often used in conjunction with gyroscopes and magnetometers (15/22)." (Papi, Koh, McGregor 2017)

This paper gave our team great confidence in the selection of an IMU as the sensor, as it strongly suggests the efficacy of this sensor type and ensures that there is a great deal of prior work to look at and build off of.

In addition to this paper, there were also a few commercial products the team looked to for inspiration and guidance throughout the design process. The chief among these are the MIT sensor tape, and the Bainisha Sensors for their fidelity as a general-purpose wearable sensor and identical use-case, respectively ("Unprecedented HD 3D Spine Movement Mapping" 2).

The MIT sensor tape developed by the MIT media lab purports to offer a "computer by the foot" product. In addition to offering positional sensors, an additional benefit of this device is that a contiguous strip of computers has its own built-in sense of "proprioception". To detect its position in 3D space, MIT's product uses "Accelerometers and gyroscopes track the positions of the sensors in real time." (Bennet 2016) After seeing the accuracy and fidelity of MIT's product using these sensors, we became confident that the IMU was a suitable choice for Backbone. One key difference between this product and Backbone, and how we'd like our product to be set apart, is price. The Computer-By-The-Foot product comes in at between $100.00 and $200.00 per meter and is not yet available for mass production.

The Bainisha product is specifically a sensor to track spinal positioning in 3D spaces, and is offered right out of the box as a wearable sensor ("Unprecedented HD 3D Spine Movement Mapping" 3). In addition, it offers dynamic 3D positional information, and can dynamically map arbitrary sensor positions to an approximation of the spinal position in real time. The sensor itself features an embedded microcontroller and is different from many other products in this field in that it exclusively makes use of bend sensors, and does not feature any

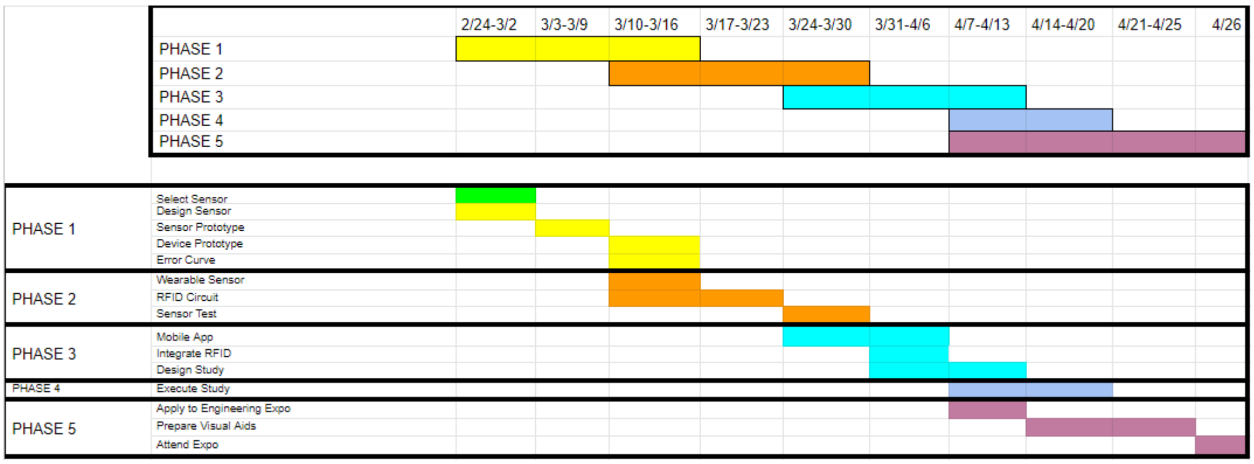
IMUs. At the time that we were looking at these products, the existence of this device persuaded us to use a bend sensor in conjunction with the IMU. The hope was that the bend sensor could be used to correct any deviations in the IMU data. The main benefit of this device is the robustness and simplicity of the directly-measurements. It is very easy to debug and the underlying technology is quite cheap. The downside of this product is that it is single-use. This makes it unsuitable for this task as it is meant to be as low-maintenance as possible and expecting the user to continually buy new sensors is not realistic for the average consumer.

While there were other devices and research papers that we read, these three informed the design of our device more than any other. From these three, we were able to neatly define a niche for Backbone using the pluses and minuses of these various products, and the context provided by the research paper selected.

III. Project Development

Our original plan had the project broken down into five key phases. Phase 1 was sensor selection and testing; Phase 2 was device design and prototyping; Phase 3 was mobile app development and study design; Phase 4 was study execution; and Phase 5 was Engineering Expo prep. It is important to note from these phases that some chief goals our team had was to both prepare a product for Engineering Expo and see a mobile version of the device. We were not able to achieve these two goals, although we were able to prove the efficacy of the concept.

Proposed Timeline for Development



From the outset of Phase 1 we encountered significant difficulties in selecting a sensor that would give us the sensor data we need. In the project planning stage, there was time allocated for some degree of trial and error with respect to sensor selection, but we simply didn't allocate enough time to the task. Our first sensor type selected was the strain gauge. While this served as a good starting point, it was simply too sensitive for our purposes. From there, we tried to use a bend sensor, which was less sensitive and, for the most part, calibrated straight out of the box. However, we finally settled upon the use of an accelerometer as it was the easiest to use, doesn't require any additional input, is accurate, and immune to drift (at least in the planet's gravitational field). For each sensor type the barrier was the same: how can we get accurate and stable values? It took time, but eventually trial and error allowed us to converge upon what we believe was an optimal solution for the time we had.

The second phase actually went relatively smoothly. The device itself had an enclosure designed for it that needed to bend with the spine but also remain in the same position normal to the spine throughout the curve. The enclosure design itself had essentially the same concept throughout the design process, however the design itself required a few iterations before its form converged to one suitable to its designated function. The discovery of the correct use of the enclosure design was an accident, and simply the result of one group member absently putting pieces together, and another observing that this individual had accidentally put them together into a useful assembly. This was the final assembly used for the project.

Phase three had a number of difficulties. Unfortunately, these proved to be insurmountable. From the outset, we had very little experience with mobile development, and as such there was very little prior experience to draw from. Compound this with the lengthy time associated with finding the correct sensor for our purposes meant that there wasn't time to create an app with sufficient polish to be presentable by the time the project was due. It was a hard decision, but the team had to concentrate on the development of a minimum viable project, so it was cut.

Phase four went surprisingly smoothly. The study was executed quickly, and very surprisingly had quite positive results. If there was one aspect that was difficult it was the short time span, we had to complete the study. However, we were able to overcome this by putting extra work in and making some changes to the device design to make the process of data collection faster.

Phase five had no barriers, because we didn't even begin it. It became clear when we were still working on finding sensor prototypes that the extra two weeks allocated to prepare for Expo would be required to finish the project. It was very useful to have an extra two weeks of time to borrow from to finish the project, though, so planning for a Phase five, and more importantly, allocating time for it, was actually a very useful tool. It is arguably the reason we were able to finish the project on time.

After all five phases, the final design used two modules each consisting of an Arduino and an IMU with a 3-Axis Accelerometer to collect the data and used Processing3 to collate and display the data. Of particular note to the reader should be the fact that only two modules were used, and that only the 3-Axis Accelerometer was used to collect data. This was done for one very simple reason: for our purposes, we found that these alone were *sufficient* for our needs.

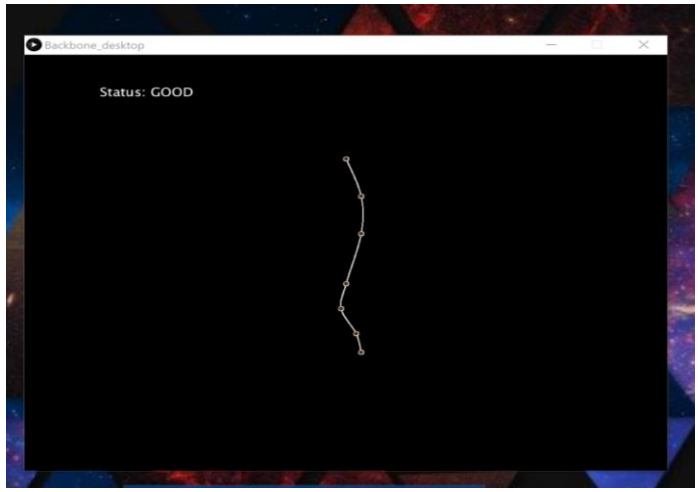
Starting with the partial utilization of the IMU, of course, were we to have more time, we would have made full use of the data provided by the IMU, however, the fidelity of the signal we received from the accelerometer alone was sufficient, so we decided not to complicate the software further by making use of it. Moving on to the use of two modules instead of three; we only needed two to get a sufficient idea of the patient’s orientation--using two modules had an additional benefit though. As alluded to above when discussing the barriers confronted with phase 4, if we reduced the device to this number, it meant that we could construct two prototype devices, meaning that the amount of time taken to conduct our study was halved. As we were already behind schedule, being able to essentially halve the study time was essential.

Throughout this entire project there was a constant process of trial and error occurring at every stage. We were very quick to try new things and throw them away if it seemed like they were taking too much time. While, in retrospect, this may have resulted in preventing us from taking what would have been in hindsight an optimal path (effectively traversing local minima) it did allow us to quickly find and iterate through local maxima.

To collect data on the efficacy of our product, we went through two separate processes. The first was one we conducted ourselves and was simply to activate the device and contort the sensors with our hands. If the data output--at this point a line indicating raw delta--seemed to match we moved to actually display a visual output which was a rendered cube that served as a digital representation of the sensor. If this visual output did match the position of the sensor then we moved on to use the device in the study. The first device to give us the data we needed was the accelerometer, so this is what we used.

The study itself consisted of two separate trials for each subject. In both we had the user wear the device. For the first, we asked them to maintain a good posture, and collected data but did not display the visual representation of their spine’s orientation. In the second we did the exact same, but this time we did display the spines position, with an overall message being “Good” or “Improper Posture”. Across the entire study cohort, we saw an overall doubling of the time spent in a state of good posture, on average. While we may have settled upon a local maximum for our device, as the data shows, the local maximum we found was more than sufficient for our minimum viable product.

IV. Conclusion



There were many takeaways from this project. From the very start of the semester, seemingly until the very day of the presentation there were lessons to be learned, and aspects of the process we had taken that could have been improved upon. Overall, the result was a success. To have an idea that something should work is one thing, to actually see it realized in physical form, and confirmed by impartial users is something else entirely. We had never planned to have a polished product at the end of the course, and while we didn't achieve everything we had set out to, we proved that our concept was sound, and to an extent we couldn't have hoped for.

At the outset of the project, from the lecture material we had known that the project takes more time than expected, and so we tried our best to prepare for that. We set a somewhat aggressive schedule and set our meeting times early on in the semester, we held our first meeting was the first Friday after the groups were chosen. We had a clear idea of "what" from the outset, "why" from the first few days. We ran into trouble with "How". If there was one takeaway with this aspect of the planning phase, it was that our conscientious scheduling almost lulled the group into a false sense of security. We prepared. We did everything right. If we experienced barriers and setbacks, we thought they weren't as significant as they were, because we did everything right, so it had to still be going according to plan. The false sense of security one gets being slightly ahead is insidious; there should always be some fear. Too much is obviously bad, but after this project, we have found that it is a very vital driver of creativity. That is a lesson we will never forget.

The question of how one would do a project over again from day one is an interesting one. With the benefit of hindsight every correct decision seems inevitable, and incorrect decision seems easily avoidable. The fact that our project seems no different is a very good thing, as it implies, we learned the lessons we needed to confront similar situations with the wisdom of our past mistakes. If we were to start from the beginning again, we wouldn't have planned differently. We would have executed differently, and we would have approached our every day with a different mindset. As stated earlier, we didn't have enough fear at the end. We weren't so much driven by necessity as by a little curiosity and a little routine. To be driven by curiosity is a gift, but it can also be a curse, because it's too easy to be led away from the end goal. It is the difference between pure research and product development. Being in academia for the last 4 years, we are used to letting our curiosity drive us. We have been tempered by this experience and were we to see the same task through to its conclusion again, it would show.

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