Design of Weight Distribution Monitoring System

Biomedical Engineering Design 200/300

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Abstract

Ms. Carol Rohl is a hemiplegic woman who suffered a thalamic bleed in 2004. Our team has been approached to assist in her rehabilitation. Currently, she does not know when her stance is balanced due to a lack of sensory feedback on the left side of her body. She would like a portable weight distribution monitoring system that she can use to train herself to recognize an even weight distribution. The three concepts we developed to accomplish this are using a Wii Balance Board, a mechanical balance, and a Wheatstone bridge balance. The use of a decision matrix led to the selection of the Wheatstone bridge balance as the best design. There is still work to be done over the remainder of the semester, including fabricating the Wheatstone bridge and its casing as well as developing a calibration method for the FSRs. We'll then implement a microcontroller and a display as well as final calibrations. By the end of the semester, we intend to have fabricated a functioning prototype of the Wheatstone bridge balance device that our client can use to aid her in balance rehabilitation.

Problem Statement

Ms. Carol Rohl is a hemiplegic patient who cannot feel the left side of her body. Due to the lack of sensory feedback on the left side of her body, she often struggles to evenly distribute her body weight: rather than standing with her weight balanced, she tends to put most of her weight on the right side of her body. Ms. Rohl believes that with the assistance of a device to measure her weight distribution, she could practice standing evenly and eventually improve her stance through visual reinforcement.

In 2004, Ms. Rohl suffered from a thalamic bleed, a normally fatal type of stroke in which a blood vessel ruptures in or near the thalamus. As a result, she lost a significant amount of the motor and sensory functions related to the left side of her body. Since her stroke, she has been undergoing physical therapy in hopes of restoring her sensory and motor capabilities; however, she has found these means insufficient for the degree of recovery she wishes to achieve and has begun pursuing alternative means to aid her in her recovery, which ultimately lead to our design team.

The aspect of her physical therapy we were tasked to focus on was developing a system to aid in her balance recovery. The source of this problem stems from the numbness that Ms. Rohl says she experiences across her entire left side. This prevents her from properly ascertaining how much weight she is placing on her left foot, and the uneasiness this produces makes it difficult for Ms. Rohl to stand or walk as freely as she would like to. Our goal is to create a device that would monitor Ms. Rohl's weight distribution on a fixed surface and then relay this information back to her through quick visual feedback. This device will reinforce the sensation Ms. Rohl feels when evenly placing her weight over both feet by providing instant feedback.

Since Ms. Rohl cannot look down at her feet without becoming more imbalanced, the device's feedback must be presented near eye level. Ideally, this feedback would be presented with a simple user interface. Additionally, portability is a key component of the device: the client hopes to improve her balance through frequent practice, so the device must be functional in all environments, including outside and in smaller spaces. This desire for frequent practice also necessitates that the device can be used briefly many times throughout the day and while multi-tasking. To accomplish this, the balance system should be durable, not subject to deterioration over repeated use, compact enough that it could readily be carried in a purse or tote bag, and require only simple setup.

In addition to being as compact as possible, the device must also be no taller than 2.5 cm (1 in.). If the device was any taller, Ms. Rohl would have trouble stepping onto it. This was observed during our client meeting both when climbing onto both the Wii Balance Board and one of our team member's design notebooks proved difficult for her left foot. Ms. Rohl also identified that the device should weigh less than 1.4 kg (3 lb.) since anything heavier than that would be impractical for transportation and difficult to put away once she was done using it. Due to limited use of her left hand, Ms. Rohl also specified that she must be able to pick the device off the floor using only one hand: this could be accomplished through making the device lightweight or through the addition of a handle. She also requested that the size of the final balance system be about the size of a notebook; this would make it both portable and easy to store. The device must also both support a person's weight and accommodate a shoulder-width stance. The team also hopes to optimize safety through the inclusion of no-slip surfaces and waterproofing.

There is currently no set budget for the project; however, the team plans to minimize costs as much as possible.

In terms of preexisting devices, the team has found there are a number of similar devices currently in use clinically. However, none of these devices fulfill the client's needs: very few of the devices are portable since most are meant to stay in a clinical setting. Of the few devices that claim some portability, the size and weight of these balance systems make them impractical for Ms. Rohl's situation or require the use of a TV (Navarro et al., 2012) which Ms. Rohl does not possess.

Balance Background

Stroke survivors commonly experience a loss of functional standing balance and asymmetric weight distribution while standing their hemiplegic lower limb typically supports less of the weight. A patient is considered to have functional standing balance if they can maintain a standing position in a static environment as well as when their balance is subjected to external disturbances[2]. Currently, physiotherapists will attempt to improve this functional standing balance in stroke survivors by prescribing exercises that will increase the weight that the hemiplegic limb supports. Recently, new kinds of treatment seek to assist rehabilitation through force platforms that provide the patient with visual and auditory feedback. To prove the validity of this treatment, a study conducted seven clinical trials to compare the progress of hemiplegic patients on the force platforms with that of patients completing traditional balance treatment[2]. The study concluded that the force platform, like the balance exercises, will result in more even balance distribution. Such reasoning is the driving force behind our design.

Wii Balance Board

We initially planned to implement the balance system using a Wii Balance Board. A Wii Balance Board can provide instant feedback regarding balance by using four transducers in each corner of the board[3]. The transducers measure the force in each corner of the board by calculating ground reaction forces at that point and, when combined, provide an accurate analysis of center of pressure movement and force distribution[4]. Wii Balance Boards have previously been used in research to examine balance discrepancies, so we hoped to manipulate the design to enable the board to fulfill Ms. Rohl's requests for portability and simple user interfaces[3].

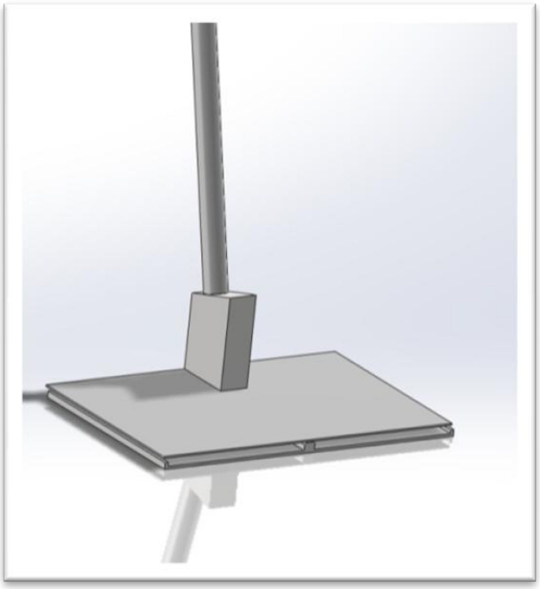
(fig a.) Picture shows a Wii balance Board. Transducers in each corner measure forces across the board and accurately calculate the weight distribution across the device. In our design it will communicate with a microprocessor via bluetooth to relay the distribution.

In this first design alternative, rather than connecting the Wii Balance Board to a television screen or computer as is traditionally done, we planned to connect the board’s force output to a microcontroller with Bluetooth capabilities. Using this wireless capacity, the data would be conveyed to the user through an LED strip programmed to display the degree of imbalance: while the user’s balance was concentrated on either side, the LED lights on this side would turn on, with more lit LEDs indicating a greater degree of imbalance. When the user is balanced, the device would indicate the force distribution by turning on the center LED light.

The Wii Balance Board is an extremely accurate method of measuring balance distribution; research has found it to be comparable to a laboratory-grade force platform[3]. Compared to these force platforms currently in use, the Wii Balance Board is much less expensive: the board costs about $100 dollars while other clinical balance systems can cost ten times that amount.[4] However, we believed that a more cost-effective solution was possible, especially since a microcontroller with Bluetooth capacity would also be expensive. Additionally, when we met with Ms. Rohl, she expressed concern that the Wii Balance Board, weighing 3.6 kg. (8 lbs.), was too heavy for her to realistically transport. This encouraged us to consider options that incorporate the Wii’s reliability with increased portability and cost effectiveness.

Mechanical Balance Design Process

The mechanical balance design consists of a teetering board atop a “W” shaped base (fig b.). Springs placed in the gaps between the two boards limit the degree of movement of the teetering platform. A telescoping pole, angling away from the board and user, attaches to a level at a height that’s comfortable for the user to read. The angle of the pole amplifies the sensitivity of the level to the movements of the platform, giving more accurate feedback. If the user leans too far to either side, the level reacts accordingly.



(fig b.) The mechanical balance operates by pivoting on the center column on a “W” shaped base. The outer walls limit the degree to which the platform can pivot. A pole attached to the platform magnifies the small angle the platform pivots, making the level easier to interpret.

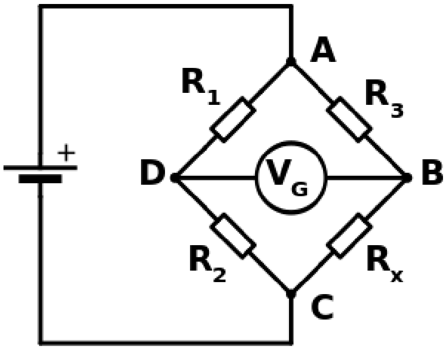
It is apparent that this design is not very portable, so in an effort to remedy this, we would make the balance easy to disassemble and be interlocked with its various components. The telescoping pole would be collapsible and could be locked onto the casing of the design. Also, the level would be removable and could be stored alongside the pole.

This design would be easy to fabricate because assembly requires a minimal amount of fabrication skill and time. In addition, the necessary materials are low cost and easily obtainable. Both the platform and the base would be made of wood. Springs and a level can be purchased at any hardware store, and the telescoping pole could be easily obtained through any third party internet supplier.

Although this alternative would be cheap and easy to fabricate, the mechanical balance system would not satisfy our most important design specifications. Since a level is not as easy to read as a digital display, the mechanical balance would be difficult for Ms. Rohl to interpret clearly. Also, the setup necessary to use the balance contributed to the low score for ease of use in the design matrix. This design requires the board to tip left and right slightly, which is a safety concern to Ms. Rohl who already struggles to keep her balance. Stepping onto the platform could be dangerous since, as Ms. Rohl informed us, her left foot is difficult to lift more than one inch off the ground. Lastly, despite our efforts, the balance would not be convenient for storage and would be difficult for our hemiplegic client to carry.

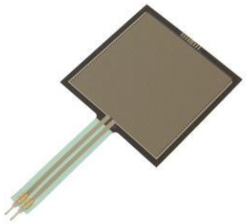
Wheatstone Bridge Balance

Our third option is a Wheatstone bridge balance. From the user's perspective, it functions the same as the Wii Balance Board. A mat unit is placed on the ground and the user stands on it, a display will then indicate the user's relative weight distribution across either side of the mat. It would be small, light, and battery operated.



(fig c.) This is a wheatstone bridge, comprised of three parts; a power source, voltmeter (V_G) and resistors ($R_{1\text{-}3,\ x}$) in parallel. They are typically used to measure unknown resistance in devices (R_x). We will use the same concept to measure voltage differences on either side of the circuit.

Our design is entitled the Wheatstone bridge option because at its core it is a simple Wheatstone bridge. Which is an electrical circuit used to measure unknown electrical resistance. The circuit is comprised of three parts: a voltmeter, a power source (i.e. a battery), and a set of resistors in parallel (fig. c). The voltmeter (or any device used to measure differences in potential) will register differences in voltage across either side of the parallel circuit. This functionality provides us with the fundamental concept behind our design. If we can translate force from her foot into resistance, we will be able to use the output from the voltmeter to determine the distribution of weight.

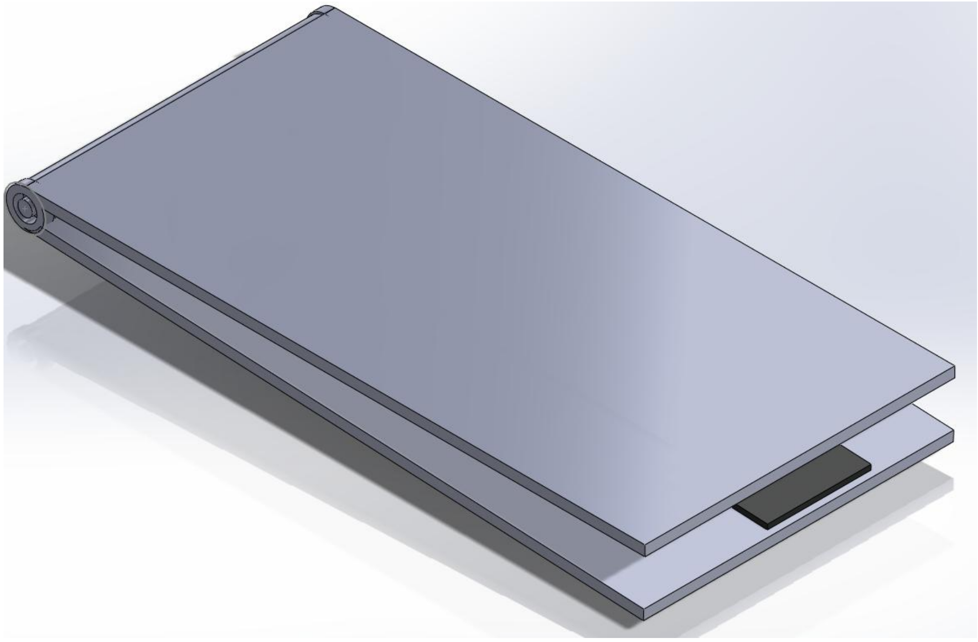


(fig d.) A FSR or Force Sensitive Resistor comprised of two conductive surfaces separated by a semi-conductive matrix, as pressure is applied to the outer surface resistance across the device decreases. We will use them to gauge the force of her feet on either side of the board.

FSRs, or force sensitive resistors (fig d.), are resistors that have varying resistance based on the forces they are subjected to. Although there are many designs available, they operate on the same concept. Some material, consisting of conductive and nonconductive particles, separates two conductive surfaces. As pressure is applied to the surfaces, the conductive particles get closer, allowing for easier transfer of charge and reduction of resistance between the outer surfaces. This functionality, when combined with a Wheatstone bridge, forms the technical backbone of our design. FSRs come in many models, so a wide variety of physical dimensions and specifications are available to us. They can be as thin as .5 mm, and can accommodate forces beyond 4000 N (1000 lbs). These possible ranges make FSRs extremely versatile, and their inclusion in the device will allow it to be very portable.

The heart of our design is a Wheatstone bridge and two FSR units, one unit on each side of the parallel circuit. Each FSR unit will receive the pressure from one of the user's feet, and its resistance will vary proportionally to that force. The FSRs will change the voltage on either side, and the voltmeter will monitor that difference in real time and display it to provide feedback to the user.

We have many options open to us for the physical device due to the inherent thinness of our circuit. The only restriction is the FSRs: we must ensure that the FSRs receive the full force from her feet. Due to the small size of the FSRs, if a user were to step directly onto the sensor with nothing focusing the force, it is likely that they would miss the sensor and their weight would not be measured accurately. We solved this problem by focusing her weight directly onto the FSR using two independent lever plates (fig e.). These two plates form the majority of the body of the device. The rest of the body will simply be housing for the two plates and circuit wiring.



(fig e.) Our design uses two of these lever plates to direct the force from her feet directly onto the FSRs. These form the majority of the physical body of the device. An FSR is sandwiched between two Plates. Ensuring the FSR receives the full force from the users foot.

Our primary objective in our design is ease of use, portability, and reliability. In order to achieve maximum portability, we wanted our device to fold or roll up into a more compact size.

Because the lever units are stiff, we decided folding was our best option.. We also wanted to make our device non-slip with a minimal height. To this end, we decided to house the device within a rubber mat or a latex pad. This will make the device both waterproof and non-slip while maintaining a low profile and allowing the device to be folded through the middle. When we met with Ms. Rohl, she had difficulty getting her left foot onto a notebook. The toe of her left shoe caught the edge of the notebook and caused her difficulty. Our design's low profile and beveled edges will allow our client to easily get her left foot onto the device without catching any edges.

While we have not settled on the materials the Wheatstone bridge will be constructed from, the lever plates should not break or bend at all. To that end we will probably use a metal of some kind. We are actively researching FSR models that will accommodate the forces we need, approximately 500 N (112 lbs.). The FSR we ultimately choose will have to be able to deal with repeated loading for extended periods.

The Wheatstone bridge design has many benefits. Because our circuitry (you only get one backbone) is so compact, we will have many options available to us as we fabricate the device. The Wheatstone bridge is a simple circuit that can fit inside almost any space, and FSRs are typically .5 – 1 mm in thickness. Because of this, each lever plate can be less than a centimeter thick. Therefore, this design should be extremely lightweight. Each plate should not be much larger than one of the user's feet. This allows the device, when folded up, to be about the size of a tablet computer. This will make the design extremely portable when traveling.

Unfortunately, this design is not without pitfalls; FSR units require constant recalibration. After a load is applied to FSRs, it is common for the unit not to return to its original resistance. This will skew the voltmeter's measurements and lead to an inaccurate display for the user. This problem can be solved with calibration and recalibration before each use. This will require a microprocessor in addition to the voltmeter in the Wheatstone bridge, which will add to cost and make it more difficult to implement. However, it does allow us to use a variety of different outputs. If we just used a voltmeter, we would be limited regarding output options of the voltmeter itself; however, with a microprocessor we can choose from many more possible feedback options including LEDs and either auditory or numerical representation.

Decision Matrix Analysis

Criteria	Wii Balance Board	Wheatstone Bridge	Mechanical Balance
Accuracy (10)	10	6	6
Aesthetics (5)	5	4	2
Cost (5)	1	4	5
Ease of Use (20)	13	17	5
Feasibility (10)	4	6	9
Portability (15)	5	14	8
Reliability (15)	13	12	10
Safety (10)	5	9	4
Size (10)	5	9	2
Total (100)	61	81	51

(fig f.) Our Design Decision Matrix was used to compare our three potential designs and decide which we will implement during the remainder of the semester. Values are assigned to each quality and each design is scored out of that value. Higher scores mean it is a better design. Ease of use, portability, and reliability were the most important attributes, and received the highest values. Ultimately the Wheatstone bridge was chosen as the best design option.

Ease of use was stressed as the most necessary functionality by our client of any conceived design. The mechanical option scored the lowest since the amount of time required for setup and disassembly was excessive and the overall perceived awkwardness of the design deemed it unfavorable. The Wii Balance Board was relatively easy to use in terms of practicality. However, unmodified it requires a TV--which our client does not have. Also, Ms. Rohl showed difficulty stepping onto the Wii balance board, and both of these drawbacks hurt the design in this scoring of the matrix. Ultimately, the utility and adaptability of the Wheatstone bridge approach gave it the highest score in the ease of use, because it can be tailored to Ms. Rohl’s needs.

Another vital aspect of the design was portability: Ms. Rohl travels frequently, and she wants the option of bringing this device along with her to stay consistent with her balance practice. The Wii Balance Board scored the lowest on this criterion as, when we presented one to our client in our meeting; it was difficult for her to carry. The notion of her needing to pick it up with one hand and carry it around with an accompanying notebook or feedback source was impractical. The mechanical option scored slightly higher as, in theory, it could be compacted, bundled together, and carried around to some degree. The inevitable bulk, however, still far exceeded the portability which we were striving for. The Wheatstone bridge option scored the highest as the portability for the potential implementation resulted in no real limitation to portability.

Reliability was the last of the key defining characteristics to our project; this category is important because our device needs to provide consistently reliable feedback to the user in order to effectively assist in balance recovery. In terms of reliability, the Wii Balance Board scored the highest as a number of reliable online projects already exist. The Wheatstone Bridge/FSR approach scored only slightly less than the Wii Balance Board after assuming that the problems of calibration and deterioration could be overcome. The mechanical balance was deemed too difficult in terms of user feedback as the level could not be calibrated to a specific baseline, and any distortion in the surface on which the device is placed would significantly skew the readings.

Aesthetics and cost received the lowest scores in the decision matrix as the functionality of the device was prioritized over appearance and “money is no object” (Tompkins 2012). The Wii Balance Board is a consumer product, so the aesthetic quality is already ensured; however, as a consumer product, it is also priced with a certain profit margin in mind so the price exceeds what we would deem appropriate. The Wheatstone bridge was both cost effective and circuitry could easily be concealed to improve appearance, so the aesthetic potential was favorable. The mechanical balance option would be an eyesore, although cost effective, which is represented on our design matrix.

In terms of safety, the Wii Balance Board and the Mechanical Balance received lesser scores as their thickness would be dangerous for our client. Also, the mechanical balance would involve movement of the platform, leaving our client’s balance at risk. The Wheatstone Bridge scored highly in the safety category since it can be extremely thin (less than two cm), and no movement takes place.

Although accuracy is important, it was not rated as highly as some of the other categories. Since Ms. Rohl is only concerned with weight distribution, not specific weights, accuracy becomes less of a vital issue. As indicated previously, Wii Balance Boards are extremely accurate, and are commonly used in a rehabilitative setting to aid in balance monitoring. For this reason, the Wii Balance Board received a perfect score in our design matrix in this category. A Wheatstone bridge would give accurate feedback on distribution on either side of the circuit, but deterioration of the FSRs may cause less accurate results. The Mechanical Balance received a similar score because, although the level itself is an accurate test of distribution, an uneven surface would skew results.

Feedback Displays

Feedback is crucial to our project, because MS. Rohl wants to use our device to train herself to recognize her weight distribution. In order to so, our design must be capable of conveying her current distribution and how to correct it in a clear and efficient manner. The display will be the only method of communicating that information. The display must be clear, easy to understand and accurate. We considered several feedback options during our design brainstorming that would satisfy our client's criteria: the voltmeter dial, an LED strip, a digital display, and audio feedback.

The output of the Wheatstone bridge is a voltmeter. Because of this, the first natural option would be to use a voltmeters display as an output. Many common voltmeters use a dial to display positive and negative voltages. The main advantage of this display is that it is simple to implement and very accurate. However, because the dial is an analog option, it would be difficult to incorporate a microprocessor, which is necessary for the calibration of the device. Another potential problem with this display is that it may be difficult to interpret. The dial would display the exact measurement from the voltmeter: if the relative weights fluctuate quickly, the dial could easily become confusing.

The second possibility we considered was an LED strip. The LEDs would light up in either direction away from the center depending on the magnitude of the voltage difference between the two sides of the circuit. This would be very intuitive and easy to read: because there are a set number of LEDs, there would be a natural histogram effect. Small fluctuations would not be displayed to the user, which means the information presented will be simple and easy to understand. However, this means the LED display would not be as accurate as the dial or numerical options.

The final display option we considered was a digital display. This display would give the user a numerical value detailing the exact weight distribution as a percentage. The benefit of this design is that the information is more precise than the other designs we considered. It is also very easy to interpret. However, we believe that this design will be difficult to read at a glance. This readout requires two separate numbers since it will display a percentage for each side of the device. This will confuse the user and make interpretation difficult, especially if the user just glances at the display.

We also considered auditory feedback. Ms. Rohl is a lifelong musician and we believe that music and sound will help reinforce the benefits from training with this device. However, she thinks audio might be an “annoyance.” We believe that it may be a useful feature, for scenarios where the visual display may be cumbersome. It is simple enough to implement that we may opt to include it as an optional feature that the user can turn on or off as they choose.

Criteria	Weight	Dial	LED Strip	Digital Display
Accuracy	15	13	10	14
Ease of Use	20	11	17	9
Cost	5	4	3	2
Feasibility	15	8	11	11
Reliability	10	7	9	9
Aesthetics	5	3	4	3
Total	70	46	54	48

(fig g.) This display decision matrix compares the three different outputs we considered. Like the design decision matrix we valued Ease of Use as the most important quality.

Budget

Our team was not given a specific budget by our client, but we expect to minimize cost as much as possible. We intend to spend less than $50 on FSRs, which are some of the more costly components of our design. The device also requires a microprocessor for feedback, which we will try to purchase for under $50 as well. Any other elements of the design (circuitry, power sources, and housing material) will be much less expensive and we expect all other purchases to total less than $50. Overall, our team intends to have the prototype cost less than $150.

Future Plans

In the second half of the semester, we must decide on an FSR model and buy materials. We will then fabricate the Wheatstone bridge mat and display unit. Following fabrication, we will test the device and calibrate the microprocessor and display. We also must determine accuracy, establish upper limits for loading, and ensure the device interface is user friendly.

Testing Procedures

Testing of the device will be incredibly important. The biggest flaw in our design is a potential calibration issue with the FSRs, therefore it is imperative that we implement an effective calibration and recalibration mechanism to go into effect each time the device is used.

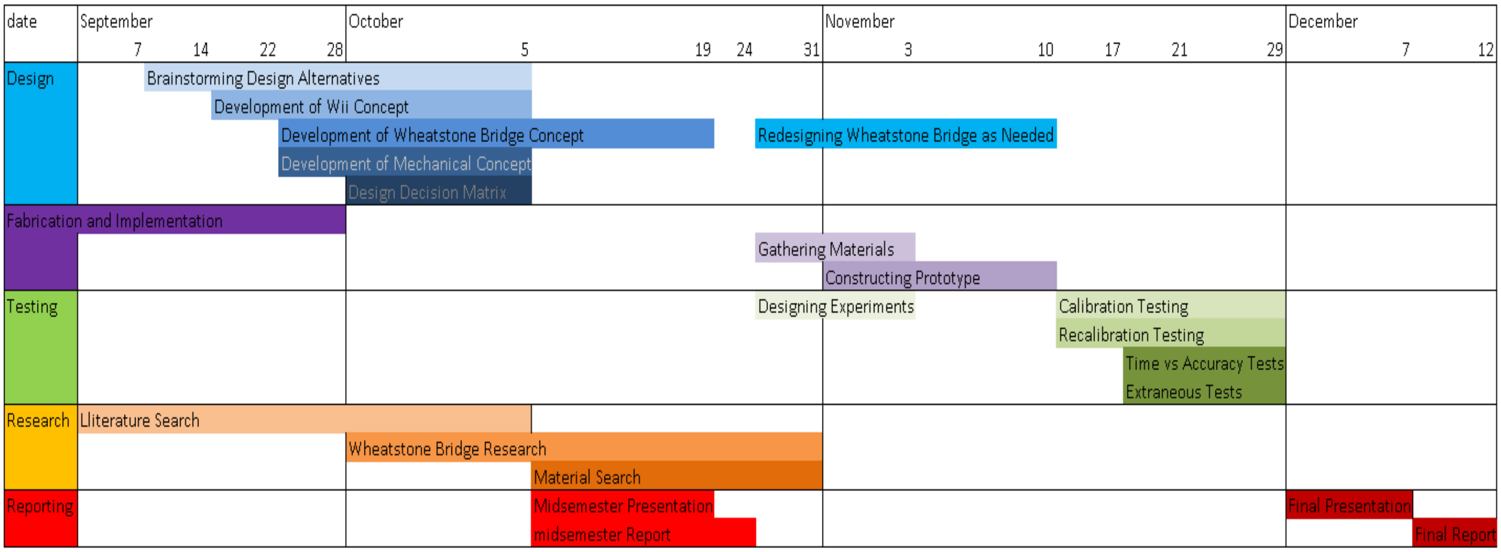
In order to set up baseline calibration we will use weights to quantify a known weight distribution. We will then write a program that interprets the readings from the Wheatstone bridge and adjusts for expected variances. These expected variances will be found during calibration testing.

We also want to find if extended periods of use will negatively affect readings from the Wheatstone bridge. In order to do this, we intend to use the device for a period of several hours while recording the readings to determine if time in use is a factor in the readings.

Before we present the device to our client, we will have completed calibration testing, re-calibration testing, and tests to establish the effect of time on accuracy. We will also have conducted simple tests to determine if our design is waterproof, non-slip, and easy to use. Naturally, all of our experiments will be repeated a number of times to minimize the probability of error.

Timeline:

Already this semester, our group has taken many steps towards our final design completion. We considered and researched a variety of design options and have settled on our design to fabricate. In the next few weeks, we will begin gathering materials and building our prototype. Once the materials are at our disposal, we intend to take one to two weeks constructing the circuitry and platform system, then another two weeks implementing the software for interpreting the information and displaying the output. After the device is functional, we will spend a total of three weeks testing it, with most of our tests focused on proper calibration. Any time remaining in the semester will be spent on our final report.



(fig g.) This Gantt chart depicts our timeline. Up until Oct 23 it is accurate, beyond that it is our predicted schedule. We plan to acquire materials and construct the prototype in the next few weeks. Following that we will develop a calibration method, and begin testing the prototype before delivery to Ms. Rohl.

Conclusion

We have been tasked with designing a device to assist our client in improving her weight distribution and balance through visual feedback. We considered three design alternatives: a repurposed Wii balance board, a mechanical balance, and a Wheatstone bridge balance. After analyzing our options, we decided to implement the Wheatstone bridge balance. Our client wants a small, lightweight, portable, and robust device that she can bring on trips and use on a daily basis. The Wheatstone bridge design fulfills all of these criteria.

As we prepare for the second half of the semester, we face several challenges. We must still find an FSR unit that is a good fit for our purposes, determine a reliable and effective method to re-calibrate the device before each use, and, of course, fabricate the balance itself. We are confident that we are up to the challenge and have resources aplenty to ensure we are successful.

The next step in our design process is to fabricate the Wheatstone bridge. Next, we will calibrate the microprocessor and program the display. Finally, we will test the device to make sure it is functional and accurate before presenting the prototype to our client. We are excited to have the opportunity to help Ms. Rohl, and we are confident that our prototype will be able to help her train and improve her stance, balance, and confidence. Our future work for the remainder of the semester is to fabricate the Wheatstone bridge and the balance to house it as well as the calibration and fine tuning of the FSRs.

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