Design of Weight Distribution Monitoring System

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Abstract:

Stroke victims commonly suffer permanent physical disabilities, such as hemiplegia. Hemiplegic individuals face many challenges in their recovery, including inability to balance, loss of ambulation, and muscular atrophy. Physical therapy remains one of the most effective methods of treatment for these conditions. As such, our client liaison believes that a device allowing hemiplegic individuals to assess their standing weight distribution will be highly beneficial to their motor function. However, most weight distribution measurement devices are only available at the clinical research level and are not available for home use. Here we propose a design of a weight distribution sensor board that is portable and easy to use for those with limited motor function. This design will incorporate force sensors and visual biofeedback to assess and display weight distribution.

Introduction:

Stroke is a major issue in the U.S. with more than 800,000 yearly occurrences and 133,000 deaths every year. 88% of these stroke victims in the U.S. are greater than 64 years of age. As a result, stroke occurrences are set to increase in correlation with the increasing age of the baby boom generation [1]. This elicits a need for improvement of current treatment methods for those who suffer from stroke. Improving rehabilitation methods for stroke victims will reduce the impact of strokes, improve patient quality of life, and contribute overall societal and economic benefits.

The most common cause of stroke is the occlusion of an artery within the brain. This results in an inadequate supply of glucose and oxygen to the surrounding tissue, leading to a reduction in oxidative metabolism within the cells. Ultimately, cell death will occur within a few hours of the blood flow restriction [2]. Many stroke survivors experience brain damage that can leave their body permanently injured. Hemiplegia is one of the common conditions resulting from a stroke. Depending on the severity of the event, individuals can suffer a loss of sensation from on an entire half of the body. This can have substantial consequences on an individual's motor function, including impaired balance, complete loss of ambulation, spasms, muscular atrophy, and osteoporosis [3].

Physical therapy has consistently shown to be an effective means of treatment for hemiplegic individuals, exhibiting measured results showing improvement in overall health, fitness, and ambulation in patients. Types of treatment include effort training, gait training, and muscle training. Due to a large diversity among treatment methods, it is difficult to select an ideal therapy regimen. Still, common underlying themes are present in the different regimen. One such theme is consistency; like any exercise regimen, it is extremely important that patients keep up with their program and do not fall into a cycle of inactivity [3]. As such, it is important that an activity not be exceedingly difficult for an individual to perform, as they may get discouraged and not perform that task as often.

Our client liaison would like us to design a balance monitoring system for a hemiplegic individual who suffered a stroke nine years ago. She has lost all sensation from the left side of her body wishes to improve her standing posture and balance. She is ambulatory but standing and walking are mentally and physically exhausting. While standing, she unintentionally bears her weight to the right. We are working on a portable device that will allow her to practice proper weight distribution by providing her with valuable biofeedback. By training on our device, she will be able to familiarize herself with the sensations that correspond to proper balance and through muscle memory achieve balance without feedback. Better balance will provide mental and physical endurance and decrease fatigue during standing activities. We hope that by practicing with our device, our client will be able to improve her balance and overall quality of life.

Mechanism of Weight Distribution:

To properly construct a device for our client liaison, we first needed to understand how weight distribution is found. Weight distribution is determined by calculating the center of pressure effected by the vertical forces of the foot and the moment about the ankle (Figure 1). In a standard force plate, there are four sensors, one in each corner that take readings from the deflection in the plate's surface. Or rather the force load on the plate deforms each sensor differently, depending on position and direction. This placement is used to increase the accuracy of the device, recognizing movement in the anterior-posterior direction and the lateral-medial direction. The accuracy accommodates for the fact that when standing the body's center of mass is in constant motion. The body responds to this movement by adjusting the center of pressure beneath the individual's feet [4].

The center of pressure is found due to the force platforms ability to access the forces along three perpendicular axes and find the moments about those axes. The purpose of the finding to center of pressure is to determine how far an individual's weight distribution strays from the norm. The normal weight distribution is located in the center of both feet and if it moves towards the foot's edge the individual will most likely lose balance. The center of pressure is determined by using the forces and moments along the line of action. This position is calculated using the equations [4]:

$X_{cp} = \frac{-M_y}{F_z}$ and $Y_{cp} = \frac{-M_x}{F_z}$

We will use these formulas and techniques to create a range for a normal weight distribution. If the client's distribution is outside of the desired range the biofeedback will direct her until the posture is corrected.

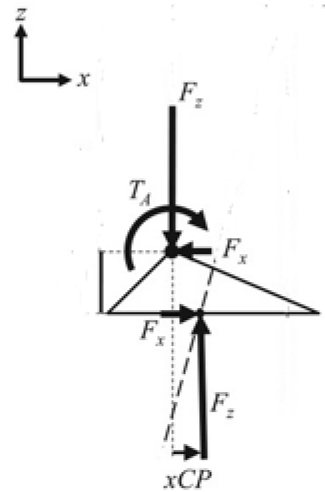

Figure 1: The diagram depicts the vertical forces and resulting moment present in the foot as a result of the center of pressure moving past the ankle [4].

Current Competing Designs:

Currently, there are multiple designs and products that use the weight distribution techniques. Two of the most noteworthy examples are the Wii Balance Board and a standard force plate (Figure 2 and Figure 3 respectively). Wii Balance Board is constructed to a similar shape and size of that of a common household scale. The device runs on four AA batteries and uses Bluetooth technology to emit the signals to a television screen. The interfaces of the Wii are programmed to work with modern electronic devices for feedback display. The overall design is similar to a force plate using four sensors to measure the center of pressure of the user. The balance board is primarily used for a gaming device so the sensors are not sensitive in comparison with a force plate. The Wii Balance Board is not applicable to the client because the board has a high platform, making the device difficult to step on to. In addition, the client stated that a television hookup was possible, but not desired. The standard force plate has one force sensor in each of the corners of the plate (Figure 3). The mechanics and specifics of a force plate design is explained in the previous section explaining weight distribution.

Figure 2: View of the bottom of the Wii Balance Board. Shown at each corner are the force sensors used to determine weight distribution [4].

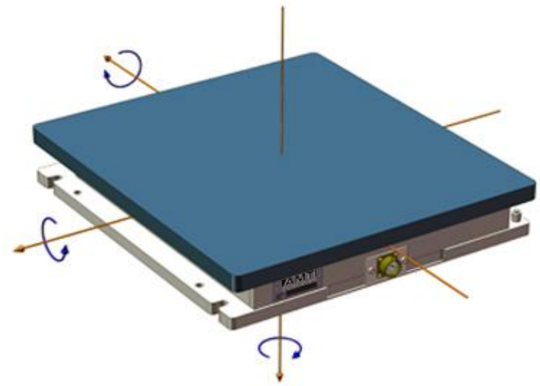

Figure 3: Force plate demonstrating the three perpendicular axes that moments can be calculated about [4].

Previous design:

The previous design was constructed of a clear and durable pieces of polymer that were connected by a series of hinges for folding and portability (Figure 4). The device had two Flexiforce sensors on the lateral sides of the feet. The device displayed its biofeedback through a handheld apparatus wired to the device and contained an array of LED that lit up according to the client's weight distribution. The device was functional, but broke after minimal use. In addition, the client had several complaints with this design. The handheld device made it difficult for the client to concentrate on their weight distribution. The design should have a hands-free approach to the biofeedback method and not require the client to look down at the floor or on her body. The client disliked the hinge-folding function as the hinges made the device harder to move and damaged her hardwood floor.

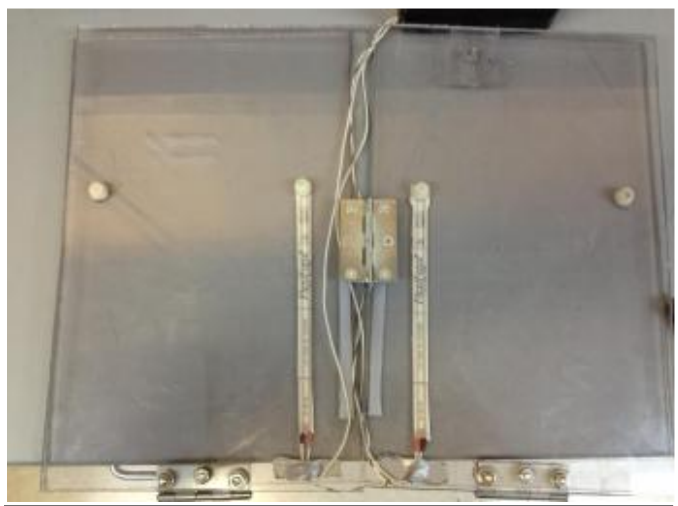

Figure 4: Top view of the pervious semesters design. The housing unit for the LED array is partially visible along the top of the image.

Some of the design ideas we plan on keeping include the use of Flexiforce sensors, a slender and durable build, a similar array of lights for the biofeedback method, and the Arduino microcontroller. We plan on using the two Flexiforce sensors from the previous design, in addition with two more, as to equip the four corners of the scale with sensors. Reusing the old

Flexiforce sensors will save on cost and still provide accurate, consistent feedback. The design must continue be slender so that the client can mount onto the device with ease. Our first thought was to remodel a bathroom scale since they are already designed to support the weight of the human body. One problem associated with this is that most scales have a higher platform that the client would have to step onto to use. In addition many of the load cells of each bathroom scale have been pre-wired to only compute net weight and would be difficult to break up into four separable force vectors. For this problem we will continue to look into different models of scales or even explore other opportunities. Currently, the Arduino microcontroller of last year is going to be implemented into our project. If the battery life proves to be too short, other options have been explored including Raspberry Pi and PICAXE microcontrollers. To convey biofeedback we would like use a light scale similar to the previous design. This will be discussed further in the design matrix.

Design Process:

The project will contain a similar weight distribution system as the previous design. Four force sensitive resistors will be placed at each corner of the force plate. This design allows for more accurate readings even when the client is standing towards the edge of the force plate. In addition to the increased accuracy, it allows for a larger market possibility if this product is going to be commercialized by taking measurements in two planes. The main variable altered within our design matrix is the biofeedback mechanism. The three biofeedback systems that were considered included visual, vibrational, and audio.

The visual system involves projecting a light gradient onto a wall that shifts based on the clients weight distribution (Figure 5). One possible idea was to have lasers that have been modified to shape into arrows on the wall. This could be done with one straight array of light for our client or arrays in two dimensions to represent both left and right orientation as well as front and back orientation.

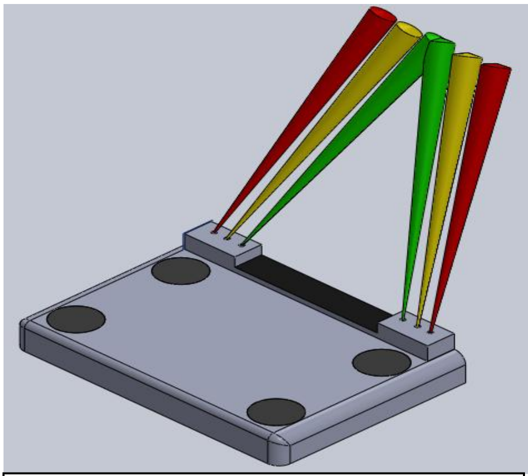

Figure 5: SolidWorks model depicting a visual feedback system. All lights are active for modeling purposes only.

The vibrational system would include vibrating motors on both sides of the right foot, since our client doesn't have sensitivity in their left foot (Figure 6). A more commercial product would include motors on all four corners to allow the user to adjust based on where sensation is felt. This system is based on increasing vibrational intensity on the heavier side until the client corrects her balance.

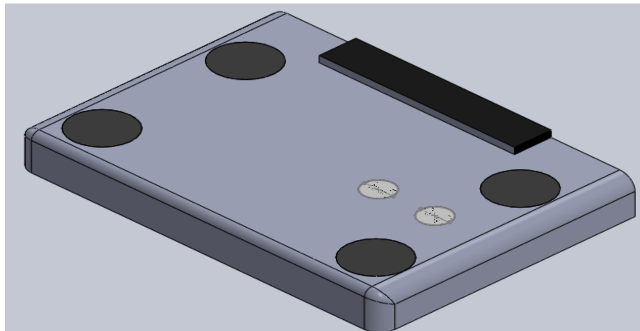

Figure 6: SolidWorks model depicting vibration feedback system. The vibrational motors can be seen, securely integrated within the framework of the board.

The audio feedback system allows the client to be able to hear the direction of leaning by a beeping noise varying in intensity based on how far off the weight distribution is (Figure 7). This model would not be as effective if applied to a two-plane model like the other feedback options.

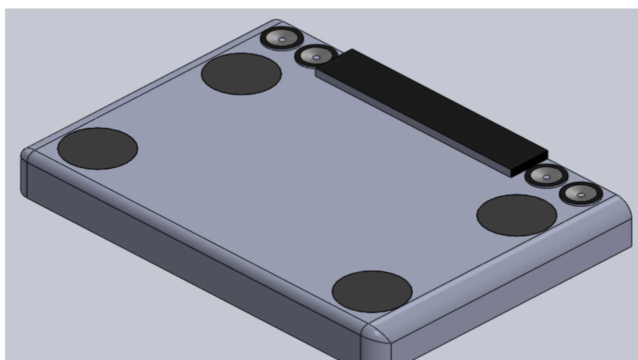

Figure 7: SolidWorks model depicting audio feedback system. Speakers allowing for audio feedback can be seen integrated within the framework of the board.

The three feedback systems were analyzed on the design matrix (Table 1). Although the vibrational option would be the cheapest, client comfort and effectiveness may be a concern. Vibration can be an annoyance with continuous use and would not be suitable for the client. In addition to the discomfort, it might not be effective either. Continued vibration often leads to numbing, in result hindering the foot's ability to locate the source of vibration as well as the intensity. This could lead to missed corrections or even possibly false corrections.

Table 1: Design matrix for our various visual biofeedback designs. The yellow represents the winner of each category.

Design Criteria (weight)	Visual Feedback	Vibrational Feedback	Audio Feedback
Ease of Use (30)	5 | 30	4 | 24	4 | 24
Effectiveness (25)	4 | 20	2 | 10	4 | 20
Comfort (20)	4 | 16	2 | 8	3 | 12
Safety (15)	4 | 12	3 | 9	3 | 9
Cost (10)	3 | 6	4 | 8	3 | 6
Total (100)	84	58	71

Another, more effective, option would be audio feedback. The design shows promise in the fact that it only relies on the user to listen to beeps and correct based on what they hear. Many speaker systems have been integrated with microcontrollers before so programming would not be too difficult with the right speakers. It may be nice to not be required focus on anything besides a noise but the consistent beeping could also be an annoyance. Also it may be difficult for the client to determine the magnitude of how much to correct her balance because it is based on her acuity to depict varying audio intensities.

The visual option may vary in price based on the projection method used but it appears to be the best suited for our client. Based solely on the ease of use, effectiveness, and comfort this design stands out. If the laser route is taken, the cost is very low and it still maintains a user-friendly design. The client simply has to view the visual in front of them and adjust accordingly considering they have a space to project the lights.

After deciding on visual biofeedback, our team then explored several options to display the feedback visually. Each design will still incorporate the four force sensitive resistors as well as Arduino microprocessor as shown in the previous three designs. Each of the following designs will focus on relaying the weight distribution measurements back to the client in a visual format.

The first visual feedback design is the projection feedback (Figure 8). A projector will be mounted on the force plate that will connect to the Arduino microprocessor to output a live image. The tentative idea is to display an animated person that leans left or right in correspondence with the weight distribution. If our client is focusing more weight on our right leg, the animated person will lean to the right with further lean indicating more distribution. This will allow the device to integrate visual feedback with the force plate, allowing our client to only carry one device for portability. The display will also be intuitive and will allow our client to easily determine where her weight distribution lies.

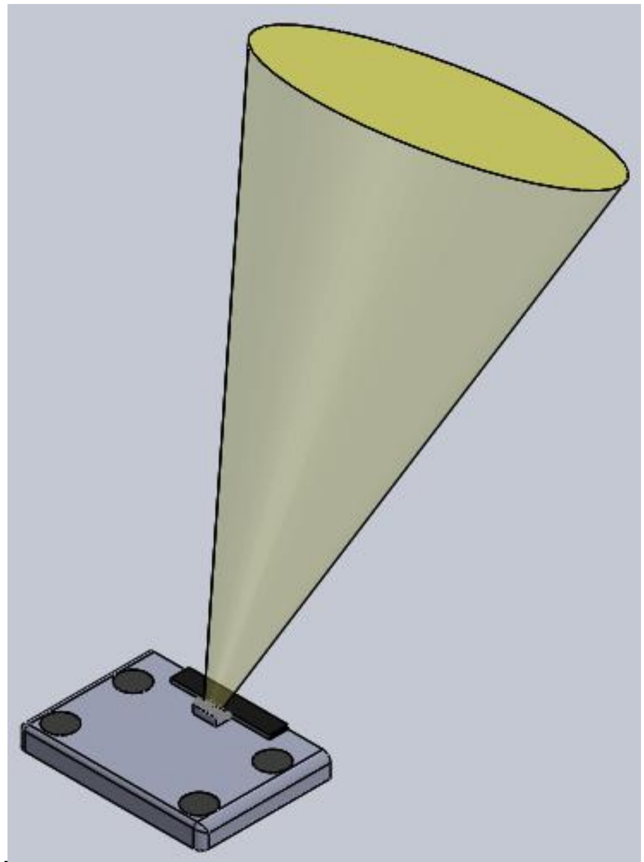

Figure 8: SolidWorks model portraying the projection system. The projector will display an image on the wall approximately at eye level.

The second visual feedback is the laser feedback (Figure 5) as described above. Instead of a projector, six lasers will be aimed from the force plate to a point on the wall at eye-level. The laser will include lights that are either red, yellow, or green. If the client shifts her weight distribution too far to the right, then the right red laser will turn on. The client will then aim to keep the middle green lasers lit.

The third visual feedback is the wireless and mounted feedback **(**Figure 9**)**. This design will incorporate an external display that connects to the device via Bluetooth that can be mounted on the wall or held up by a rod apparatus. This design can allow for many displays but our tentative plan is to incorporate the same display system as the laser design. Instead of having lasers hitting the wall, the wireless display move from left to right depending on the weight distribution.

We then used our three designs in another design matrix to determine which design would be most suitable for our client and her needs **(**Table 2**)**. We decided on the laser feedback design as our final design due to several factors. Because of our client's limited mobility, we wanted to focus on the ease of use of the device so that she does not need to exert much force to use the device. The laser design incorporates the visual display on the force plate and allows our client to only carry one device. It is lighter than the projector design, allowing for further portability. The wireless design would allow for a higher variety of visual display but the addition of the secondary device would inconvenience our client. Although the laser design is not as accurate as the projection design due to the gradients allowed for weight distribution sensitivity, with our overall focus on ease of use and convenience for our client, we believe that our laser design is the most suitable design for our client and her specific needs.

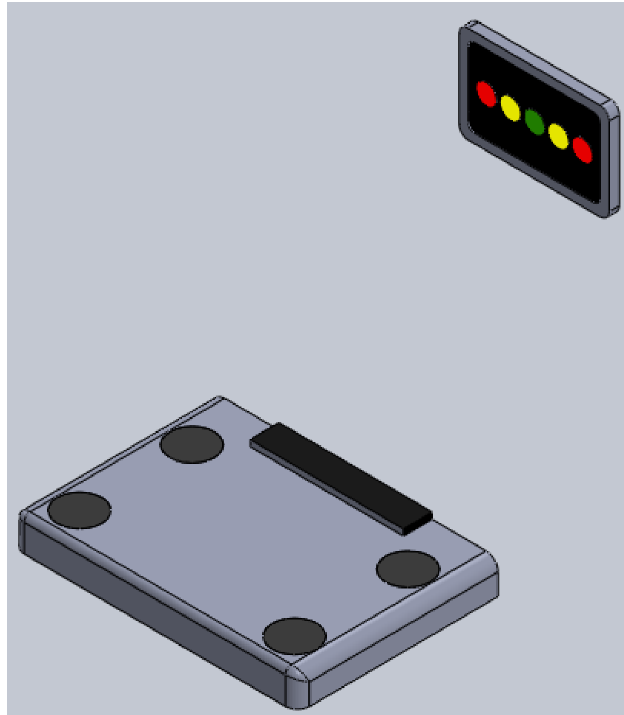

Figure 9: A SolidWorks model of our wireless/mounted visual feedback design. The external display will be attached to the wall or held up by a rod or some other apparatus. It will use the same display as the laser feedback.

Table 2: Design matrix for our various visual biofeedback designs. The yellow represents the winner of each category.

Design Criteria (weight)	Projection	Lasers	Wireless / Mounted
Ease of Use (30)	3 | 18	5 | 30	3 | 18
Effectiveness (25)	5 | 25	4 | 20	4 | 20
Comfort (20)	4 | 16	4 | 16	3 | 12
Safety (15)	5 | 15	4 | 12	5 | 15
Cost (10)	3 | 6	5 | 10	2 | 4
Total (100)	80	93	64

Experimental Testing:

Numerous steps will be taken to ensure accuracy of the weight monitoring system prior to completion of the design. Since FSRs are not manufactured with perfect consistency, it will be necessary to calibrate their voltage outputs. Calibration curves will be generated for each individual FSR. We will then include normalization coefficients in the code for the microcontroller. We will also have to test the laser output. For example, the lasers will need to be properly positioned into the correct array. The lasers can be varied in intensity and size to maximize the visibility of the feedback.

Timeline:

Through October we will order materials and begin manufacture (Figure 10). We will then continue manufacture and testing in November, preparing our product. We expect the interface between the laser and the scale as well as mechanical manufacture of the device in a thin form to present time-consuming challenges. Resources such as the student shop and the Arduino community will aid in overcoming these difficulties.

Task	September				October				November					December
	6	13	20	27	4	11	18	25	1	8	15	22	29	7
Project R&D														
Lit. Research	X	X	X	X	X									
Manufacturing														
Cost Estimation				X	X									
Prototyping														
Deliverables														
Progress Reports	X	X	X	X	X									
Midsemester					X									
Final Poster														
Meeting														
Client	X			X										
Team	X	X	X	X	X									

Figure 10: Expected timeline for the duration of the semester. The color represents where we expect our group to be during each week.

Conclusion:

Laser light biofeedback maximizes portability and ease of use of the design for our client. Observing the gradient of light lasers will allow the client to know when she is centered and not. Providing our client with a balance biofeedback board will hopefully improve the client's ability to balance increasing her mental and physical endurance to perform standing activities. Eventually a device like this could be broadened to a larger clientele, helping stroke victims practice weight distribution with a portable, user-friendly device.

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Design of weight distribution monitoring system

10/9/2013

Group Members: Kiersten Haffey, Dalton Hess, Jacob Hindt, Andrew Vamos, and Xiyu (Steve) Wang
Advisor: Dr. Thomas Yen

Client: Dr. Willis Tompkins representing Carol Rohl

Function: Stroke is a major issue in the United States with more than 800,000 yearly occurrences and 133,000 deaths every year. Many stroke survivors experience brain damage that can leave their body permanently injured. A hemiplegic individual who suffered a stroke five years ago lost all sensation on her left side of the body. She is ambulatory but suffers from improper gait and standing positions due to her left side. We are working on a portable device that will allow her to practice how it feels to stand with proper weight distributions. We hope that by practicing with our device, our client will be able to improve her walking and improve her overall quality of life.

Client Requirements:

- The client must be able to carry the device in one hand for convenience and portability
- The device must be thin, so that the client can easily step onto the device. Thickness of a scale is the maximum thickness desired.
- The device must not require the client to look downwards or hold a light display, which causes error in weight distribution balance.
- The device must not have a hand-held device.
- The device must not contain any hinges or metal parts that may damage flooring

Design requirements:
1. Physical and Operational Characteristics

a. *Performance requirements*: The device must be able to perform numerous tests with up to 800 N of force.

b. *Safety*: The device should be constructed so that the client will be able to stand and balance easily without any risk of falling or other harm.

c. *Accuracy and Reliability*: The device should be accurate enough to discern changes in weight distribution but not too precise as the body is never in rest, even when standing. A threshold of 10% will be adapted to allow the client to practice weight distribution.

d. *Life in Service*: The device will be operated on the timescale of half-hours and at a maximum an hour. It should not consume an excessive amount of power, as batteries can be costly to the client. The batteries will be replaceable when exhausted.

e. *Shelf Life*: The device must be able to be stored and easily retrieved for further use over a period of at least a year.

f. *Operating Environment*: The client intends to use the device in standard living environments with chances of humidity or other weather effects. The device will be used on a flat surface and at room temperature.

g. *Ergonomics*: There should be minimal interaction required by the client while attempting to measure her weight distribution. It should be simple to use and easily understood.

h. *Size*: The device must be portable - small enough so that the client can take it with her and use it in places other than her residence. Additionally, it must be thinner than 5 centimeters, as the client struggles to lift her impaired leg off of the ground.

i. *Weight*: The device must be light enough to maintain portability.

j. *Materials*: The materials must be lightweight yet durable enough to withstand the clients weight. Possibility of integrating commercial bathroom scale.

k. *Aesthetics, Appearance, and Finish*: The device should provide clear and easily interpreted feedback for the client. The body of the device will be compact and have no external parts that could cause safety issues.

2. Production Characteristics

a. *Quantity*: There must be at least one device fabricated

b. *Target Product Cost*: Price is not an issue for this device.

3. Miscellaneous

a. *Standards and Specifications*: The device will be less than 5 centimeters thick and weigh less than 5 pounds. The device must be IRB approved for human testing (if at all).

b. *Customer*: The device is being created for one specific client, however, there could be a potential market for this device.

c. *Patient-related concerns*: The client is unable to lift her left leg up very high so extra precautions will be taken to make sure that our device is low enough for her to conveniently get on and off. Additionally, looking downwards towards her feet causes the client to lose her balance.

d. *Competition*: Similar products have been designed to measure a person's weight distribution. The Wii Balance Board has been proven to be extremely effective in assessing weight distribution. It utilizes four force sensors to calculate the center of a given weight distribution. However, the client considers this device to be bulky as well as too tall.

Clinically, a few devices are used. One common clinical device the SMART Balance Master® provides balance retraining in a box-like device on an 18" by 18" forceplate through visual feedback on either a stable or unstable support surface and in a stable or dynamic visual environment. However the device costs $90,000.

Other clinical devices such as AMTI OR6-6 force plate uses auditory biofeedback. However this system interfaces with a laptop computer to acquire signals from the sensor and generate a stereo sound providing body-sway information.

Works Cited

http://www.sciencedirect.com/science/article/pii/S000399930500211X
http://resourcesonbalance.com/neurocom/products/SMARTBalanceMaster.aspx