Tech to the future: Problems with balance, troubles with therapy

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The ability to balance is a prerequisite to sitting, standing, and walking and requires complicated physiological coordination. The disruption of any components of the equilibrioceptive, proprioceptive, or visual systems can significantly handicap balance, such as in some cases of cerebral palsy, spina bifida, arthrogryposis, cystic fibrosis, and many other diseases and injuries. Unfortunately, in patients with damaged brain function the disorder at the root of the problem cannot typically be treated but, with physical therapy and braces or other aids, the balance handicap may be overcome. The goal of therapy is simply to improve performance, regardless of what specific benchmarks a particular patient can surpass. A heavily braced patient may strive to stand alone or a walking patient may endeavor to pivot and turn around. Successful balance may require an atypical stance or gait and not look normal, but as long as it is an improvement, it is encouraged.

Balance disorders in children can be improved by therapeutic exercises that challenge the patient to maintain appropriate balance. However, existing therapy devices are expensive, ineffective at engaging the patient, and do not account for the patient's reliance on balance aids. We aim to create an inexpensive device that could challenge, entertain, and reward a patient while improving autonomous balance. Following this introduction are more detailed explanations of the problem we are addressing, our

Digital Object Identifier 10.1109/MPOT.2011.942971
Date of publication: 12 January 2012

engineering solutions, the functions of our final product, and our design process.

The more technologically sophisticated approaches to balance therapy that are currently being used involve force plates, gyroscopes, and infrared cameras. The major benefit of these high-tech approaches is that they are able to provide very accurate feedback to the physician—often in real time—in a numerical format that can be stored and tracked over the patient's treatment.

However, these state-of-the-art systems are time consuming to execute and impossible to translate to the home, so they are impracticable as a practice tool for patients in therapy. In addition, these methods are not easily able to determine the reliance on balance aids by the user. If the user were able to more frequently make use of the balance-measuring device, they would derive greater benefit from the practice. If that practice included a direct disincentive to rely on aids for balance, the therapy would be even more beneficial. One way to both apply an incentive to use the system and build in the framework to discourage the use of aids is to make the system center around a video game.

There are commercial video games available that use balance measurement as game input, such as games using the Nintendo Wii Balance Board or instructional games for golfers. Changes in balance, or changes in location of center of balance, are translated into commands in the game. Game-based treatments have been devised for many other disorders and disabilities, many of them relying on the Wii Balance Board hardware for use. Among these disabilities are mental disorders such as attention deficit disorder, neurological or muscular disorders such as stroke, Parkinson's, or cerebral palsy. For most of these treatments, the purpose of the video game component is to encourage the patient to perform assigned therapy exercises by making them fun, providing reward, and tracking improvement through the video game score. The interface of the video game is designed creatively to correlate with the specific movements or exercises prescribed. In the special case of balance games, the goal is to make games that strengthen the user's independent balance.

Designing the solution: Criteria and approach

Physical component

In selecting our design strategy, we knew that our final device must meet all of the following design criteria, as well as the specific parameters of Table 1:

Table 1. General design criteria for entire device.

Design Parameter	Criteria	
Size (L × W × H)	175 × 70 × 90 cm	Large enough to walk two to three steps and turn around
Cost	<US$2,000	Must be available to public for in-home use
Weight/portability	<125 lbs	Capable of being lifted by two people, or rolled by one
Sampling rate	30 Hz	For sufficient and accurate date collection
Measurement range	0–300 lbs	Weight of patients varies
Measurement accuracy	95%	High accuracy for appropriate judgment of improvement
Breadth of users	6–18 years of age	Adjustable for users of different heights and mental capacities

One way to both apply an incentive to use the system and build in the framework to discourage the use of aids is to make the system center around a video game.

- to measure patient's reliance on rails for balance
- to measure patient's center of balance
- have a gaming space large enough in which to walk and turn around
- provide an interactive gaming experience
- ensure patient safety.

As a result, the system should meet the overall project goals:

- encourage patient use of therapy
- discourage reliance on balance aids
- quantify patient performance.

We brainstormed many methods of achieving our objectives and put forth many options before choosing one that fit within the scope of our available knowledge, abilities, time frame, and budget (Fig. 1). Ideally we would have performed tests with components of our alternatives, however neither our budget nor our time frame allowed for this luxury; therefore we had to resort to more calculated manners of elimination. To compare

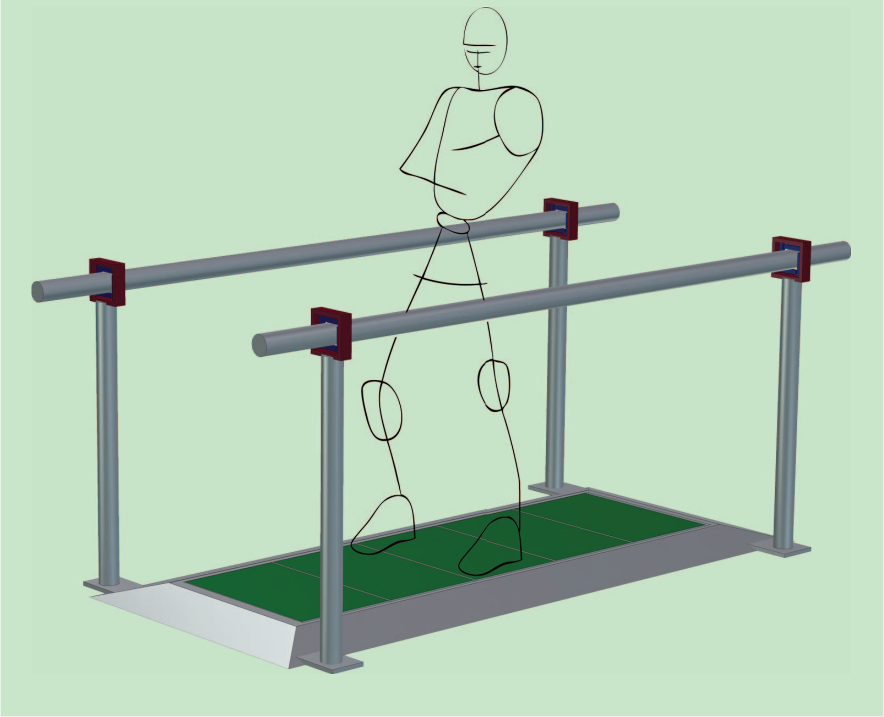

Fig. 1 Final design for the Equiliberator.

all of the alternatives, we created decision matrices comparing the necessary components of the system: force measurements from feet, force measurements from hands, and the video game element.

Wii Balance Boards won out against the other options, giving us a direction to start in our development of a physical product. The Wii Balance Board is a product that serves as a video game controller for the popular Wii Fit series. These boards are built to measure the patient's weight and center of balance as they stand on the board. The board uses strain gauges mounted in the feet on each corner of the board, similar to a bathroom scale, and communicates measurements via Bluetooth to a connected operating system.

For measuring reliance on balance aids, we developed and selected a handrail design with sensors mounted at the connection of the rail to the supporting upright. Having sensors on the floor would result in a greater window for error in calculation due to the mechanical forces applied to the handrail at different heights. It also increases the total floor coverage of the device, and space should be minimized for the product's ease of use. Having the sensors mounted on the handrails will give us more accurate readings of the forces applied by the user. A drawing of our handrail sensor can be seen in Fig. 2.

Our choice of materials for the design was largely based on the factor of cost, particularly for the first prototype. The materials—specifically aluminum, Eucaboard, steel, and plexiglass—were chosen for ease of machining and ready availability. The aluminum, used for the sensor boxes, needed to be strong enough that it would not bend under the weight specifications of the handrails or beyond the limits of the strain gauges and dimensions of the housing, causing contact between the deflection bar and the housing wall. Eucaboard served as an easily cut and very lightweight housing for the Wii boards. Steel was used in the rails and rail supports for its strength and rigidness.

Video game component

Designing the video game presented its own challenges. Since many, but not all, of the target patient audience suffer impaired cognitive ability as well as disordered balance, the game needed to be simple enough not to frustrate some patients but able to provide the entertainment of a challenge to all players.

The creative potential for the video game component is staggering. When the perspective is taken that the device we designed is essentially a giant video game controller, uses for this controller begin to flower and evolve. The five boards measure the player's center of balance and location on the walkway. Turret defense games become far more interesting when each board controls a different turret, the direction of lean controls aim, and the magnitude of lean controls the power of the shot. Of course, not every aspect of the input need be incorporated; simple rhythm games can rise out of detecting nothing more than on what board the player stands.

The only common threads between acceptable game concepts are age and

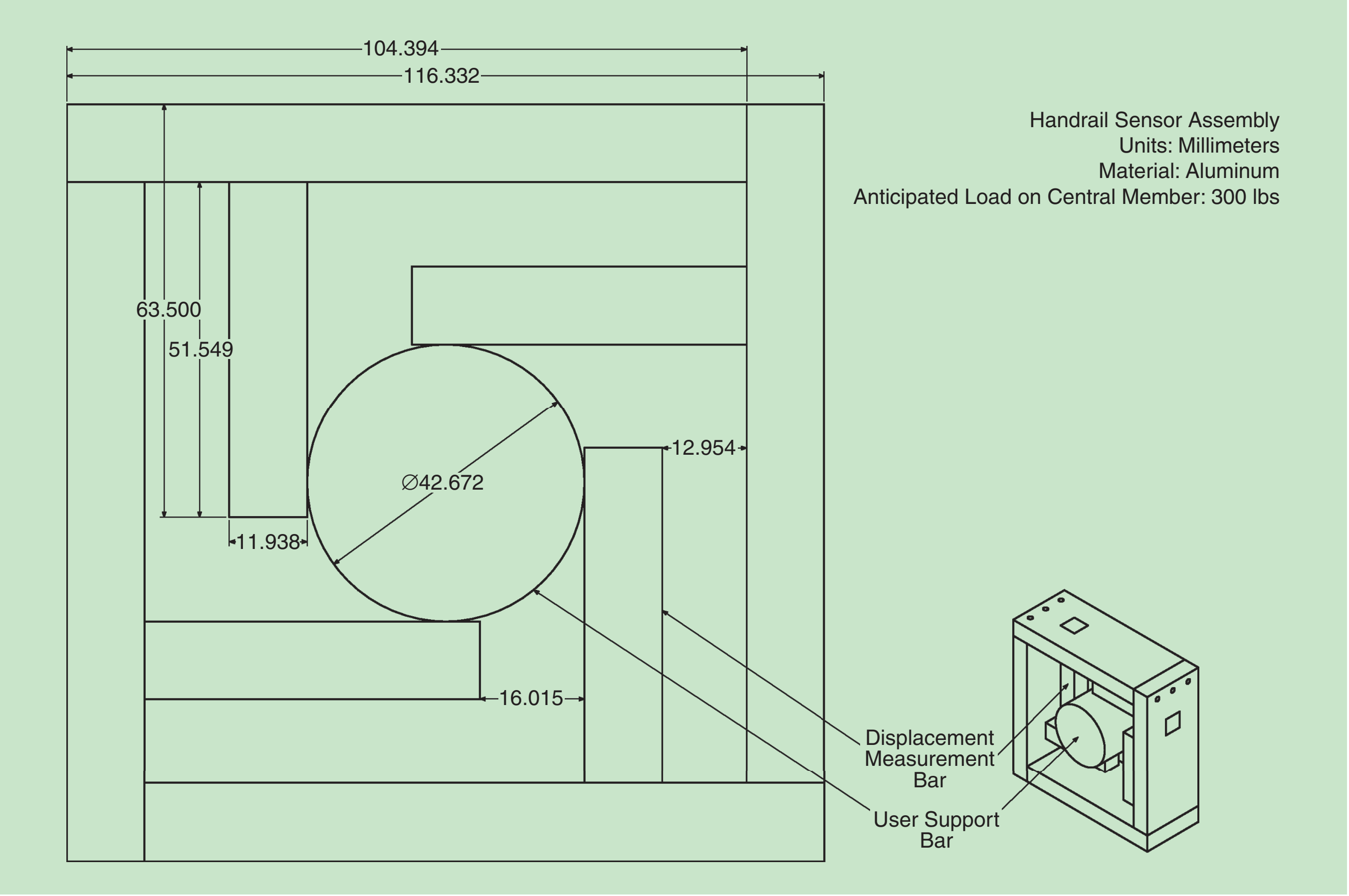

Fig. 2 The handrail force sensor box. By placing load cells on the displacement measurement bars, force data from the handrails can be collected in real time.

ability appropriateness and the convention of punishing the player's performance when the handrails were relied on for balance. The handrails can also be incorporated as positive input devices for menu selections or game controls as long as sufficient portions of the game ban reliance upon them.

Finally, a balance therapy entertainment system

Design

The Equiliberator is designed to be cost efficient, lightweight, portable, and user friendly. The system is comprised of three main subsystems: the base, handrails, and video interface. The base is made up of the frame, ramp edges, and Wii board array. The handrail subsystem consists of the vertical supports, sensor boxes, and horizontal handrail. The video interface consists of the the computer and display screen.

Base

Frame

The frame is a rectangular box made of 3/16-in-thick Eucaboard housing an array of five Wii Balance Boards. The frame is surrounded by ramps constructed of foam insulation extending 20 cm outward from the base that terminate on the ground at approximately a 30° angle (see Fig. 3). The purpose of the ramps is to address concerns for the patient's safety and risk of falling or tripping on the edges of the device when stepping onto or off of the unit.

Wii boards

The Wii boards fit tightly inside the frame but are not anchored to the frame. Rather, the boards sit freely on the bottom surface and are held in place by the friction of the Wii board grips. This way the operator can easily access the Wii boards for setup, troubleshooting, and repair. The boards are each covered with a 3/16-in-thick piece of plexiglass (indicated by the dark green color in Fig. 3 and shown in Fig. 4), measuring 51.5 cm wide by 31.75 cm long, that serve to create continuity between the boards. This also addresses concerns of the patient falling or tripping by slipping their foot between the boards and, as an added bonus, makes the iconic Wii Balance Board highly visible, reinforcing the idea that the patient is playing a video game and therefore having a good time.

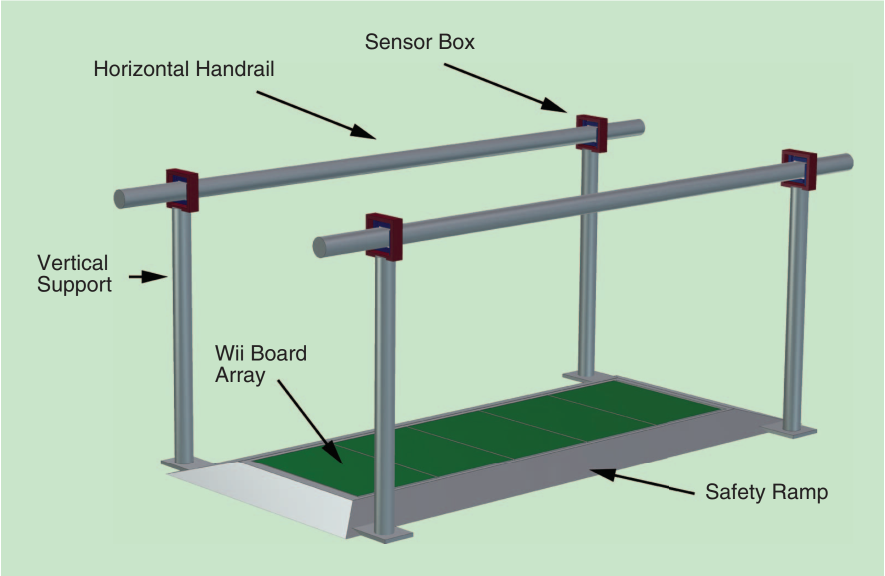

Fig. 3 Labeled components of the Equiliberator.

Handrails

Vertical supports and horizontal handrails

The vertical supports (Fig. 5) hold the horizontal handrail at 80 cm, measured from the top of the platform to the middle of the handrail, and connect to the base on assembly. The vertical height of the handrails are capable of rough adjustments through the addition of a nipple and fine adjustments through the turning of the couple on the sensor box on the upright. The vertical supports are mounted with the force sensor box as seen in Fig. 6. The aluminum horizontal component of the handrail measures 3.175 cm in diameter and 183.0 cm long. The ends insert into couples mounted on the force sensor boxes at each end. The distance between handrails is fixed at 67.0 cm from center to center.

Sensor box

Figure 6 shows the inside of the actual force sensor box with the handrail removed from its seat in the center of the four protruding deflection beams. The fully assembled force sensor box is shown

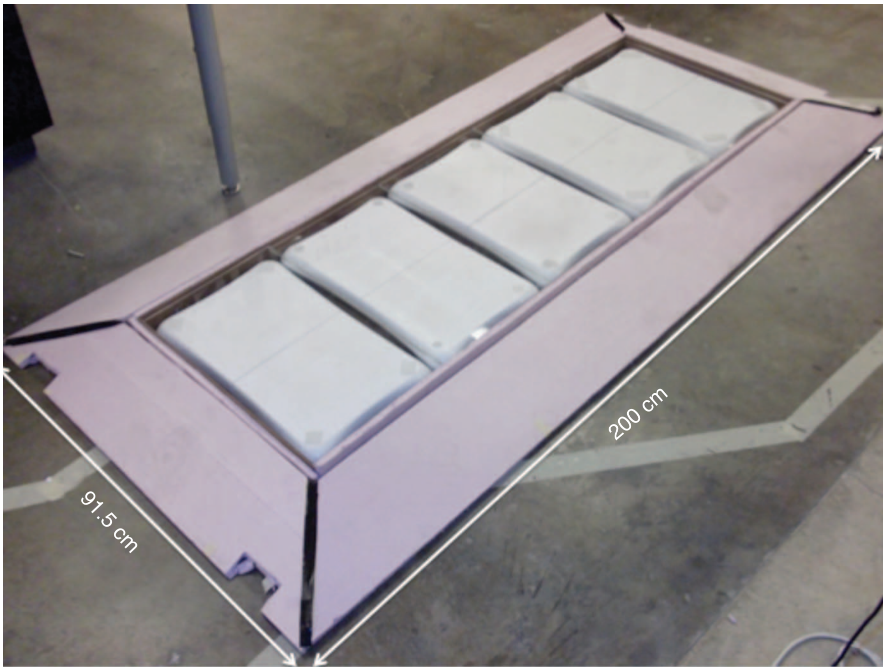

Fig. 4 View of the base with the Wii board array inside.

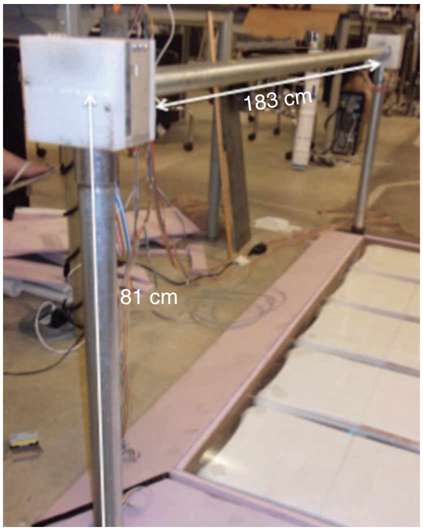

Fig. 5 Handrail subsystem of the Equiliberator.

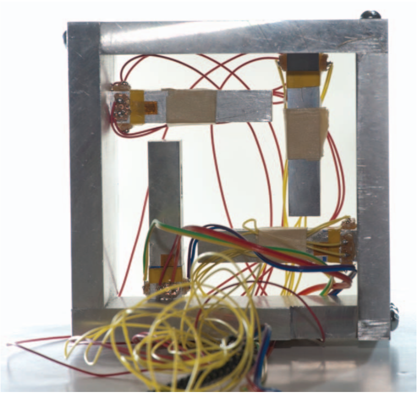

Fig. 6 Inside of a force sensor box.

in Fig. 5 at the top of the end of each handrail. This is a novel component of our device and can detect how much force is being applied to each handrail in any direction, but is not designed to measure torques. This measurement allows the user to track their progress over time by reducing the magnitude and frequency of forces applied during the exercises.

Each deflection beam is 6.35 cm long and fitted with an Omega SGD-5/350-LY13 linear strain gauge on three sides to create a design similar to a full Wheatstone bridge circuit to measure forces in the x, y, and z directions. The wiring from the strain gauges is run beneath the force sensor box into the vertical support where it can be fed out near the base and to a National Instruments 9219 DAQ unit to collect the data.

Video interface

The video interface of the Equiliberator system comprises two parts: the diagnostic

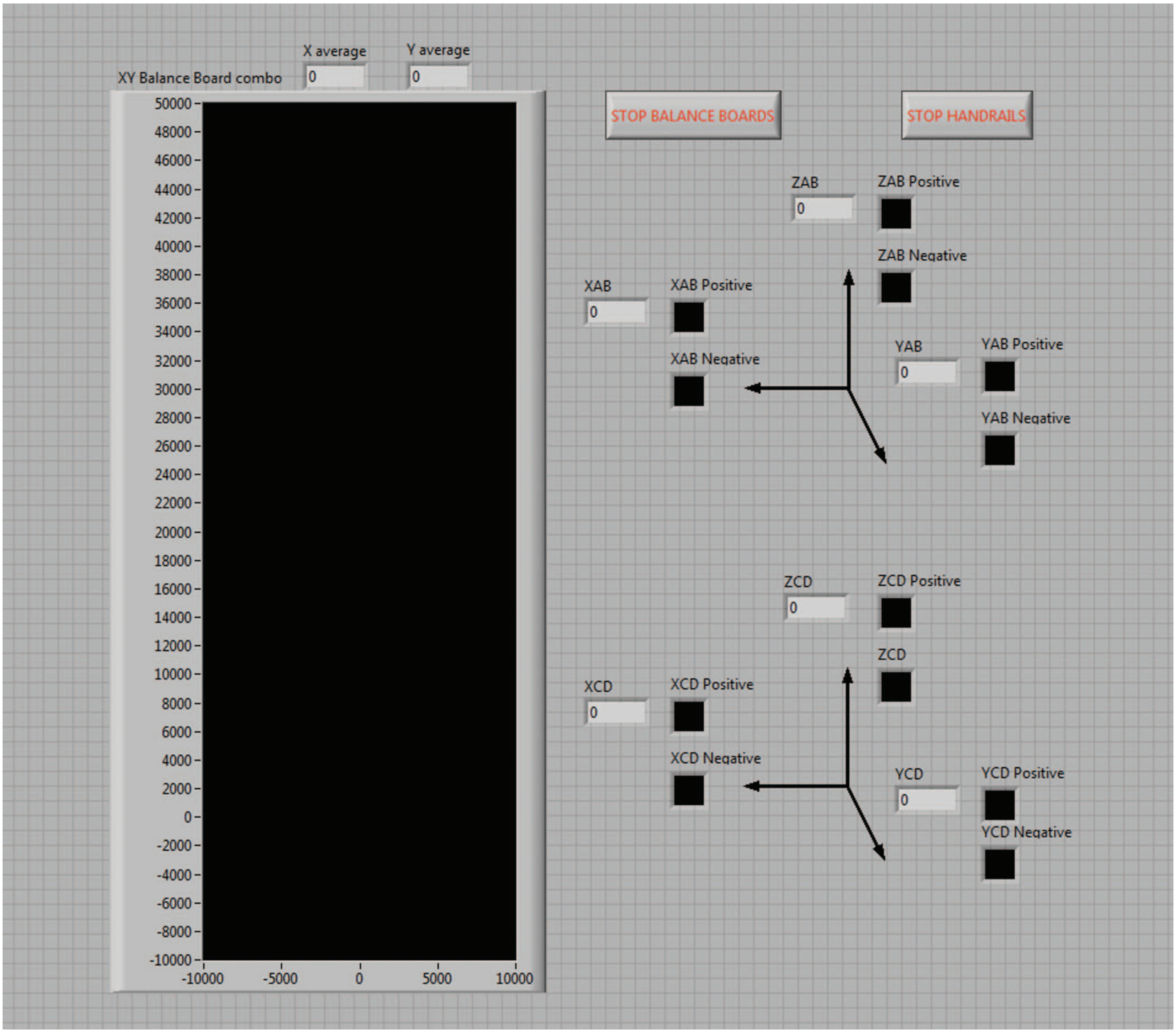

Fig. 7 Diagnostic video interface subsystem of the Equiliberator.

interface used by therapists and the video game interface used by patients. The diagnostic interface is controlled through LabVIEW 2009, a National Instruments software program. Using LabVIEW we have designed a user-friendly workspace to customize and translate inputs and outputs to meet the needs of our software. All data can be stored via USB drive inserted into the computer for transporting to the lab or home.

The interface, shown in Fig. 7, consists of a bird's eye view of the system with numerical displays. The numerical displays show the forces being applied to the floor (left display) and handrail (right display) and is available in a variety of units as the user prefers. The center image tracks the user's center of balance indicated by a dot and tracking line as they move along the platform.

The video game component does not interface with the LabVIEW system. The Bluetooth signals are capable of communicating with the computer running LabVIEW and another computer running the video game without interference, so the two programs run independently of one another.

In designing a video game for the Equiliberator system, our goal was to entertain patients while providing valuable therapy in a way that is inexpensive and easily installed in a hospital or a home environment.

The video game

Overview

In designing a video game for the Equiliberator system, our goal was to entertain patients while providing valuable therapy in a way that is inexpensive and easily installed in a hospital or a home environment. The game is designed to be used by a single player for 30 min to an hour, during which the player performs a series of therapeutic movements that allow him or her to progress in the game. The movements required from a player are walking forwards and backwards and maintaining center of balance in the middle of the balance board or shifting it left and right.

Game Components

The software for the game is a Windows stand-alone executable, designed and tested on 32-b machines running Windows 7. The Wii boards are connected to the PC via Bluetooth; if a PC has a built-in Bluetooth, the game automatically connects the Wii boards. For machines without it, a Bluetooth USB adapter is required to communicate with the PC. We tested our game on an HP Pavilion t × 2500z Notebook Laptop PC, 2.1 GHz AMD Dual-Core Processor, 3GB RAM with Bluetooth, and a Windows 7 desktop, using Rocketfish Bluetooth USB Adapter RF-FLBTAD.

Game mechanics

Each Wii Balance Board has four pressure sensors. Each sensor sends raw input data to the PC via Bluetooth, and together those signals indicate the player's center of balance and weight. The sensors accurately measure weight up to 330 lbs, but can withstand forces up to 660 lbs, making them usable for patients of all ages. Each board uses four AA batteries that last up to 60 hours, or a plug-in battery pack. Each Wii Balance Board has a sync button that connects it to the PC,

Fig. 8 A screen shot of the game.

and they must be individually paired before gameplay can begin. Once all five boards are connected, the game starts a loading phase, during which the Wii boards are calibrated to get accurate measurements. Eventually, signals from the instrumented handrails will also be incorporated so that the game can notice when the player relies on them for balance and provide an appropriate disincentive such as faster enemies or a loss of points.

Graphical user interface

We developed a graphical user interface for the game that is easy to read and understand and that provides visual and audio feedback. Figure 8 shows what the player sees during game play.

The top right panel shows an array of five Wii Balance Boards, which matches the arrangement of boards on the floor. The red square shows the player's location on the walkway and his/her center of balance. The bars at the bottom right corner show the level progress and the score. The level number and objective (enemies left to destroy) are shown at the top of the screen. Overall game progress bar, pause, mute, and quit buttons are at the bottom of the screen. The game can be paused and resumed at any time by clicking the button or hitting the space bar on the PC.

Game play

The game objective is to protect against the oncoming enemies. The player controls two, three, or five Wii boards, depending on which of the difficulty settings has been selected. Easy mode uses only two boards, medium uses three boards, and hard uses all five. Each Wii board corresponds to one of five different elements—fire, water, earth, wind, and metal. By shifting his/her balance to the left, the player shoots out an element toward an approaching enemy. There are five types of enemies that correspond to five elements. To successfully destroy an enemy, the player must match the element of the enemy to the element at which he/she is shooting. The enemies come in random order, so the player may be required to swap elements between Wii boards. When the player shifts his/her balance to the right, he/she picks up an element from that board and can carry it to a different board and execute the swap by leaning right again. The game play consists of moving back and forth on the walkway and shifting balance left and right to destroy enemies of matching color. Sound and visual effects guide and entertain the player.

The body weight of the player does not affect the game play because only the center of balance and the location on the walkway are taken into account. When the player is required to shift balance, the required amount is calculated as a percentage of his/her total weight. Therefore, the players can switch during the game play without restarting the game.

Final criteria

The only original design criteria we failed to meet was the footprint size prescribed to the device. With the late addition of the ramps around the edges, we extended the covered floor space of the device. The total cost of the device fell far below the maximum of US$2,000, providing us funding for another prototype with some additional modifications.

Data and accuracy

Fortunately, the Wii Balance Board is designed for users in the age range demanded for our project, and the accuracy has been shown to fall within a half of a pound up to 330 lbs. The sampling rate of the Wii board is 100 Hz, well above the 30 Hz minimum. The sampling rate of the strain gauges can be set to meet our desires and needs. Accuracy for the different settings needs testing.

Breakdown of the device

The Equiliberator weighs in close to the maximum set in our original criteria. The steel base supports for the vertical handrail supports added significant weight to the project. Steel was also used in the upright supports and is a heavy material relative to plastic, but the durability and consistency of the material is necessary for optimal performance. The device is designed to be broken into several parts. The vertical supports and horizontal handrails may all be disassembled from one another to make for easier storage and portability. There are couple connections at both ends of the vertical uprights as well as on each sensor box to release the handrail. The Wii boards may even be removed from the frame if necessary. No single component of the device weighs more than 20 lbs, allowing for easy assembly of the device by two therapists or nurses in 10–15 min.

Steady steps forward

Our prototype is functional as it stands, meeting all of the goals and criteria listed in earlier sections. We conducted pilot testing on a single eight-year-old boy with cerebral palsy recovering from bilateral leg surgery. He adapted quickly to the new gaming system and stayed engaged for over 20 min of play-therapy. Our observations during testing and comments from the child will help guide further development. It is clear that each of the three main components of the design have room for optimization going into subsequent generations.

Base

Breaking the base component down into its individual components, we have three pieces to discuss: the Wii boards, the frame, and the safety ramps.

It is our conviction that there is no better option for measuring center of balance than the Wii boards. The frame that we have designed is made of thin, light, and strong Eucaboard and has many useful features but could be improved in a second generation with the following tweaks:

- easy access to the battery and sync button compartment
- handles and wheels for easier transportation
- easier method for removing the boards for transportation or service
- construction with stronger material such as aluminum.

The last component, the safety ramps, is not related to the device's function, but as the name suggests, purely there for the sake of patient safety. For that reason, our recommendation is that they be made out of a more robust material than the foam used in our current prototype.

Handrails

The instrumented handrails in this project was the location of the most innovation, and for that reason, should also be the focus for the most improvement. Our current design is made of galvanized pipe uprights and rails welded to 5/8-in-thick steel strip and to the aluminum sensor boxes. The sensor boxes are accurate and relatively inexpensive compared to alternatives. This design should be reworked to improve its weight, ease of creation, and safety.

- Sensor box edges and corners need to be rounded off and padded.
- Pipe and steel handrail setup may be made lighter and stronger by replacing with standard therapy handrails cut to accept sensor boxes.

• Spacer pieces in the sensor box need not be machined from aluminum.

• The sensor box is stronger than it needs to be: reduce the number of screws

• The rails could be better designed to aid in cable management.

Electronics and software

Our device's diagnostic interface is housed in National Instruments' LabVIEW 2009 program and is highly functional. Our electronic interface from the strain gauges in the sensor boxes to the computer could be improved. Currently, we are using three NI 9219 DAQ Cards and a cradle that holds them, at an equipment cost of over US$1,000. The next generation of this device could have its total cost cut in half by replacing those components with custom designed bridge circuits, which should be an reasonable task for an undergraduate electrical engineer. Additionally, further testing to determine if significant accuracy is lost when certain strain gauges are removed could continue to drop costs and simplify the system.

Acknowledgments

The Equiliberators would like to thank Rice's Oshman Engineering Design Kitchen, Patricia Mabray and the Ladies Oriental Shrine of North America, and Shriners' Hospital for Children–Houston for funding, as well as their mentors: Dr. Marcia O'Malley, Dr. Maria Oden, Dr. Warren, and Mr. Steven Irby. The project also could not have been done without the guidance and technical expertise of Carlos Amaro and Joe Gesenhues.

Jesus Cortez, Nick Zhu, and Jennifer Humphreys also contributed to the development of the video game component.

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Digital Object Identifier 10.1109/MPOT.2011.943669