# Development of an Active Balance Training Platform for a Gamified Physical Rehabilitation

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*Abstract:* – Balance problems affect a large number of people, especially stroke survivors, and can manifest even in simple activities of their daily lives. This paper will present the development of a gamified balance training system by incorporating active motor control on a balance board and providing variable in-game settings to allow individualized therapy. Both hardware and game settings can be customized to match the balance capacity of the patient. Any movement of the balance board corresponds to the movement of the game avatar and is tracked by an inexpensive Inertial Measurement Unit, the MPU6050. A stepper motor is used to implement the effect of having an active control of the balance board. Hardware settings that can be customized are the maximum sway angle and sway stability of the balance board. While in-game settings that can be adjusted are duration, intensity, bias, limits, and assistance level. The reliability of the IMU measurements are proven even after 5 hours of continuous use.

*Key-Words:* – Active balance board, gamified environment, variable game settings, individualized therapy
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## 1 Introduction

### 1.1 Background of the Study

Stroke is one of the major cause of disability worldwide ranking **3rd** overall of Disability-Adjusted Life Year (DALY) according to data from World Health Organization [1]. Daily activities of most people involve standing, sitting, and walking require a sufficient balance control of the entire body. It is estimated that **33%-42%** of stroke survivors require assistance for their daily activities 3 to 6 months after the onset of stroke, and of these individuals, 36% continue to be disabled even after 5 years later [2].

One of the after-effects of stroke is balance deficiency. And after medical stabilization on the onset of stroke, it is paramount that stroke survivors undergo physical and functional rehabilitation to help recover lost motor skills and improve overall quality of life. In recent years, therapists are exploring the idea of implementing a gamified environment for treating patients with balance disabilities. Using rehabilitation-relevant movements in the context of an engaging and motivational game can potentially deliver positive results in therapy. Time spent in therapy, together with having high repetition, supervision, and clear rewards are essential to maximize the effectiveness of rehabilitation and to promote faster functional recovery [3].

Research work utilizing commercial peripherals for exergaming such as Nintendo Wii Fit Board, Xbox Kinect, and Sony Playstation Move were carried out to aid for a gamified environment for therapy. However, for exergames to be used in therapeutic environment, the games should be able to measure the conditions of the exercise and utilize the movement information of the patient to control the gameplay directly [4-6]. Commonly, such games are catered for the general population and can't be modified to match the specific rehabilitation requirements of the user. Moreover, commercial force platform systems like the Biodex Balance System [7], NeuroCom Balance Master [8], and Thera-Trainer's Balance Trainer [9] are used in rehabilitation clinics as a training tool as well as an assessment device that only provides visual feedback for the user and doesn't come in a gamified environment.

This paper will discuss the development of an active balance training platform equipped with IMU and its associated virtual reality game that aims to aid therapists in creating a customized and individualized therapy. The balance board and game metrics can be varied to match the balance capacity of any user.

### 1.2 Statement of the Problem

Rehabilitation after illness or injury is a slow, steady, and progressive process that aims to help patients recover and live life as good as possible.

Unfortunately, there are patients who quit during the process thus stopping their recovery and reaching the 'point of plateau'. This is due to varying reasons that may include lack of commitment and motivation from the patient, adaptation to a standardized and repetitive regimen of the exercise; significant economic burden from the cost of rehabilitation, and poor treatment on gamified system for rehabilitation [2]. Also, there are anecdotal evidences that existing commercial games are not compatible with controlled and specific exercises required to meet therapeutic goals. Moreover, several developed hardware and gamified systems do not provide enough variable settings to match the specific needs and balance capacity of the user to provide a more individualized and optimized therapy [14,20,26].

As it is essential to increase patient motivation and engagement to facilitate faster functional recovery, this necessitates the development of a customizable games, applications, and hardware solutions to target individualized rehabilitation [10].

### 1.3 Objectives of the Study

The primary objective of the study is to develop an active balance training system, both hardware and software (game), that offers variability of hardware and in-game settings to specifically match the needs of the user. The author aims to use a stepper motor to actively move the balance board. Also, an existing sea-faring game will be modified to allow variable inputs from the therapist on key game metrics such as Duration, Intensity, Bias, Limits, and Assistance. Lastly, a reliability and validity test of the balance board will be conducted under loaded and unloaded conditions.

### 1.4 Scope and Limitation

This study only covers enhancements of both hardware and software (game) system and will not involve any balance intervention analysis of the user. Enhancements are done on the hardware balance platform and PC game first developed by Hadrian Lim, Marion Tan[11], and Jedd Chua [12]. The PC game will be built using C# programming language utilizing Unity3D game engine that will only work on Windows platform. This study will not discuss any change on game design principles used on the previous study such as theme and gameplay design, and will only focus on the addition of variable settings within the game that have the potential to improve results of undergoing rehabilitation using the balance trainer. Motivational analysis of the game will also not be covered by the study. Reliability and validity tests cover the accuracy and consistency of sway measurements of the IMU attached to the balance board across multiple in-game settings. Measurements will be compared with a commercial inclinometer/angle measuring tool, as well as from calculated angles based on position of the balance board with respect to the ground. The stepper motor was used to implement the effect of having an active balance board and was not tested to carry a full-sized adult or carry a load beyond 10kg of weight.

## 2 Related Work and Literature

The study will mainly use the gamified balance training system first developed by Lim and Tan [11], and Jedd Chua [12], then slightly improved by Garcia and Rigor [13]. The hardware system consists of a tilt-limited balance board platform equipped with IMU MPU6050 interfaced with an Arduino-equivalent microcontroller. The complimentary software system is a sea-faring game called Balance-On-Action-Team or BOAT that has 3-quests to test both static and dynamic balance status of the user. Sway angle of the balance board can be set manually from $12^0$ to $18^0$, this is in accordance with the Philippine Orthopedic Center's standard limits of stability of up to $16^0$. The POC's standard states that any normal person can recover his balance from this limit, while beyond may cause the person to fall [11].

Aside from delivering positive impacts of using commercial exergaming peripherals as a tool for balance training [14,15], similar studies were carried out to determine the efficacy of exercises administered to stroke patients using other commercial balance training platform such as Balance Trainer from Thera-Trainer [6]. Also, a number of custom hardware systems were developed for the same purpose. One particular system was made by N. Amritha, M. Mahima et al. [16] called the AMBA or Amrita Balance Trainer which was designed to match the combined capabilities of Wii balance board and commercial force platform like the Biodex Balance [17] and the Balance Master [18]. The AMBA is composed of four force-sensing platforms that can also be tilted variably on two axes by 0, 5, 10, 15, and 20 degrees. The aim of the study is to simulate and enhance the activities of daily living (ADL) such as combing hair or brushing teeth while standing on the balance board. The system also comes with 3-game modes to test both static and dynamic balance of the user. Another hardware system developed was made by M. Lavarda et al. [19] wherein they used two force-sensing platforms as a tool to provide balance training accompanied by a virtual game. One platform is placed under the hip (sitting) and the other is placed under the feet. Additionally, the system utilized a webcam to track movements of the user by attaching luminous materials on parts of the body. The game allows the therapist to direct the location of game elements/targets that the patient needs to reach. These studies have shown positive effects on the standing balance of patients and even mentioned that doctors were interested in incorporating the technology in their clinical practice.

Providing variability for both hardware and game mechanics allow therapists to specify parameters according to the goals, needs, and capacities of patients. A research made by Ho-Suk Choi et al. [20] studied the effects of having a game-based Constrained-Induced Movement Therapy (CIMT) on balance of patients. Results showed that CIMT had a larger effect on static balance control and weight-bearing asymmetry of patients. The aim of providing CIMT is for the patients to move the more affected part/side of the body than the unaffected side.

## 3 Methodology

The primary objective of the study is to incorporate recommendations and enhancements for both the hardware and software systems on the study made by engineering students from 2016 to 2017 [11-13]. The methodology is divided into four main parts: Version Comparison, Design Framework, Hardware Components, and Software Settings.

### 3.1 Version Comparison

The enhancements on the previous systems aim to provide a customizable balance training exercises to tailor different balance needs of every patient. Tables 1 and 2 summarizes the differences of the previous version versus the proposed. While table 3 shows the current available quest from the game.

| Hardware Components | Previous Version | Proposed Version |
|---|---|---|
| Balance Board Stability | Mechanical Disc Brake with Manual Brake Lever | Mechanical Disc Brake with Variable Tension Shifter |
| Tilt-limiting mechanism | Adjustable threaded-screw | Slotted metal with locking pin |
| Tilt adjust range (degrees) | $12^0 – 18^0$ (measured manually) | $0^0 – 20^0$ with $5^0$ intervals (slotted and fixed) |
| Active Motor Control | N/A | Stepper Motor |

Table 1. Hardware Systems Comparative Summary of Functionalities

| Software Settings | Description | Previous Version | Proposed Version |
|---|---|---|---|
| Game modes | Quest type | 3 modes | 3 modes |
| Duration | Time length of exercise | 60 seconds (fixed) | 20 secs. to 45 minutes (10 sec interval) |
| Intensity | Difficulty of the exercise | Random | Variable (1 – 100%) |
| Bias | Spawn location of game objects | Random | Variable (1 – 100%) on left and right side of the screen |
| Limits | Sway sensitivity of the balance board | N/A | Variable (should match the hardware setting) |
| Assistance | Active support of the balance board | N/A | Variable (1-100%) |

Table 2. Software Systems Comparative Summary of Functionalities

| Quest | Objective | Corresponding Balance Metric |
|---|---|---|
| Collect the Crates | Collect crates floating throughout a specific area | Lateral Balance exercise measuring side by side balancing |
| Follow the Light | Stay within a moving spotlight area | Standing Balance exercise measuring posterior and anterior sway |
| Avoid the Bombs | Stand still for a set amount of time to avoid tripping the mines | Standing Balance, standing balances with eyes closed |

Table 3. Types of Quests with Corresponding Physical Therapy Assessment Criteria

The performance of the user on the game is assessed using specific balance metrics from the Tinetti Balance Assessment Tool and the Equilibrium Score (ES), as formulated by Alberts [21] in equation (1).

$$ES = \frac{\gamma - [maximum(sway(\theta)) - minimum(sway(\theta))}{\gamma} * 100\% \quad (1)$$

The Equilibrium Score calculates the maximum and minimum posterior, anterior, or lateral angles of the balance board, where $\gamma$ is the maximum sway angle of the balance board.

## 3.2 Design Framework

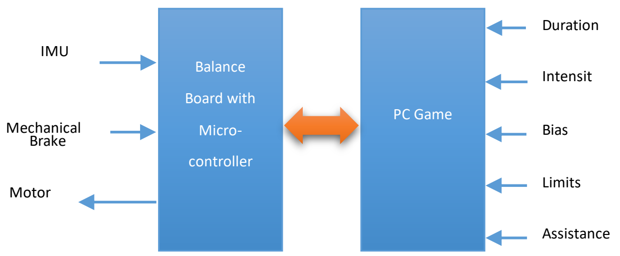


Fig. 1. Design Framework

The system is comprised of two main parts: 1) Balance board with the microcontroller, and the 2) PC game. The microcontroller is named Gizduino which is an arduino-equivalent device. The Inertial Measurement Unit (IMU) data along the roll axis (x-axis) is sent to the microcontroller for pre-data processing and tilt-angle measurement. It measures the sway angle of the balance board relative with its starting point and in relation with other settings set from the PC game. The mechanical brake serves as a mechanism to provide stability of the balance board while moving along its axis. Then, the motor is used to control the balance board in providing an active balance support for the patient. The intensity and extent of support the motor provides will depend on other in-game settings, primarily by the "Assistance" setting. Other in-game settings are Duration, Intensity, Bias, and Limits, which are all set by the therapist to enable individualized gamified therapy for every patient.

## 3.3 Hardware Components

### 3.3.1 Balance Training Platform

The overall outlook of the balance training platform is almost the same as the previous version except on the changes on how to set the maximum sway angle of the balance board and on how to apply pressure on the disc brake. Maximum sway can be adjusted per a fixed interval with angle limits in the order of 0, 5, 10, 15, and 20 degrees. Using paired and slotted metal bars positioned underneath the balance board, the mentioned angles can be achieved by locking the metal bars with each other through the slot holes.

Fig. 2. Balance Training Platform

### 3.3.2 Gizduino Microcontroller

The study used the Gizduino microcontroller as the main interface between the hardware and software components. Sensor data reading and calibration, temperature and motor control, and in-game setting translation are the procedures done inside the microcontroller. Computer interface with the microcontroller used wired Serial (RS-232) communication via USB port.

### 3.3.3 Inertial Measurement Unit

To control the game avatar, an inertial measurement unit is used as the input sensor. The IMU used is MPU6050, which is a 6-degrees of freedom (DOF) motion tracking device designed for low-cost, low-power, and high-performance requirements. This study used the library developed by Jeff Rowberg [22] and the offset-calibration method developed by Luis Rodenas [23]. During the offset-calibration process, the balance board should be set at $0^0$ and should stay still for at least 1 minute. This would be the starting point of the game, and any movement of the balance board will move the game avatar accordingly.

The IMU experiences inaccurate readings when there is a fluctuation in temperature from where it was initially calibrated. To compensate for this occurrence, the LM35 temperature sensor was used to monitor temperature fluctuations. When the temperature difference from initial setup reaches 5-degree Celsius, the Gizduino will reboot and recalibration will take place.

### 3.3.4 Mechanical Braking System

In order to control and stabilize the movement of the balance board, this study utilized a mechanical disc braking system paired with a variable tension shifter. The shifter locks in place to hold the tension along the braking line and to ensure almost constant braking intensity across the duration of the exercise.

### 3.3.5 Stepper Motor

In this study, the stepper motor was utilized to simulate the effect of having an active balancing support for the patient that is dependent on the assistance level set by the operator/therapist from the game settings. During the course of the game, both the hardware and software (game) system will calculate and evaluate the necessary support for the user and so the stepper motor rotates up to a certain degree. Doing this will help the user reach some parts of the exercise goal and aid the therapist on evaluating the status and progress of the patient in rehabilitation.

The motor used is a Nema 34 stepper motor that is rated at 48-volts supply, 3-amperes of current, and 45kg-cm of holding torque [25]. Shown at Fig. 3 is the block diagram of operation of the stepper motor. As mentioned, the limit of the motor movement is dependent on the Limits and Assistance setting from the game. And to ensure the exact rotation and position of the motor shaft, IMU's tilt data serves as the feedback mechanism for the motor controller.

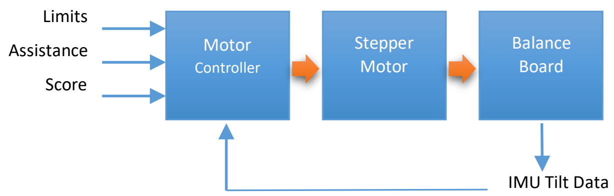


Fig. 3. Motor Controller Block Diagram

## 3.4 Software Settings

### 3.4.1 Duration

Duration is simply how long each of the selected exercise is going to be performed by the user. Range of time that can be set from 20-seconds to 45-minutes. The basis of the duration setting is the recommendation from rehabilitation guidance of National Institute of Health and Care Excellence (NICE) from United Kingdom, as well as from Canadian Best Practice guidelines which stated that patients should receive a minimum of 45 minutes of relevant rehabilitation therapy, for five days a week [24].

### 3.4.2 Intensity

For this study, intensity is defined as the difficulty level of the exercises. The effect of intensity varies depending on the type of quest, with details summarized on Table 4.

| Quest | Effect of Intensity Settings |
|---|---|
| Collect the Crates | Number of spawning game objects (crates) and their distance from one another |
| Follow the Light | Sensitivity of game avatar's movement over a slight movement of the balance board |
| Avoid the Bombs | Number of spawning game objects (bombs) and their distance from one another, and sensitivity of game avatar's movement |

Table 4. Effect of Intensity Settings on the Type of Quest

### 3.4.3 Bias

Balance disorder affects patients differently, this could be from minimal to extreme, or from left to right side of the body. Weight-bearing asymmetry is a common symptom of stroke survivors suffering from balance deficiency, where the unaffected side of the body bears more weight than the affected side, also movement is reduced on the affected side. To address this phenomena, Constraint-Induced Movement Therapy (CIMT) is one of the alternate methods for rehabilitation by suppressing movement on the non-affected side and forcing or inducing movement on the affected side [20]. To provide a method for CIMT, the study used the Bias setting of the game that allows therapists to adjust and direct the spawn location of game elements to either left or right side of the screen, or the sensitivity of the balance board in accordance with the capacity of the patient. The setting inversely adjusts bias on both left and right sides and is adjusted by percentage value with a total always set at 100%. Spawn location of game objects are determined by the equation (2).

$$Location = \text{random.range(weighted bias)} + \text{game avatar's location} \quad (2)$$

### 3.4.4 Limits

The balance board provides an adjustable limit for its tilt angle that goes from 0 to 20 degrees, with interval of 5 degrees. This setting allows to have a customized range of motion of the balance board depending on the balance capacity of the patient. The setting is based on the recommendations from Philippine Orthopedic Center's standard limit of stability at $16^0$, and stated that any person can recover balance from this angle while beyond can cause the person to fall [13].

Once the hardware limit is decided by the therapist, the corresponding value in degree-angle is set within the game. Since tilt-limit can be varied, the sensitivity of the game avatar's movement with respect to how the balance board moves should be adjusted correspondingly. If limit is low, a slight movement on the balance board should translate to a bigger movement of the game avatar. Conversely, if the tilt limit is high, the balance board should be moved more deeply to correspond bigger movement of the game avatar. This adaptation is automatically done by both the hardware and software systems following the formula in equation (3).

$$Avatar\ movement = \text{sway angle} * \text{limit ratio} \quad (3)$$

### 3.4.5 Assistance

The Assistance level is defined as the extent of support the hardware balance board will provide for the patient during the course of the exercise. This setting is responsible for dynamically controlling the movement of the stepper motor. The higher the set assistance level, the higher the meddling effect of the balance board, and vice versa. The movement of the stepper motor will be based on the combined set values from the other in-game parameters, the Intensity and the Bias. The intensity affects the number of occasions the stepper motor will move, while the bias influences its direction. This setting can also be used to assess the progress of the patient through the rehabilitation process by relating assistance level to the acquired Equilibrium Score at the end of the exercise.

## 3.5 Reliability and Validity Tests

Reliability and Validity tests of the system correspond to the consistency of sway angle measurement of the IMU/balance board under loaded and unloaded conditions. Measurement will be comprised of multiple combination of game settings that will run continuously from 1 to 5 hours before conducting a comparative measurement. The order of tests would be to use the system for 1 hour, then conduct reliability test. Proceed with continuous 2-hour use, then reliability test again. Repeat the process for 3-, 4-, and 5-hour continuous tests.

IMU's data will be compared with two other measurements; 1) from a commercial digital inclinometer shown in Fig. 4 that is placed rigidly on top of the balance board, and 2) from calculated angle using trigonometric function by getting the arcsine of the height of the IMU's location from the ground and the length of a projected line that is parallel with the balance board from the IMU's location down to the edge to which it touches the ground (hypotenuse) as shown on Fig. 5.


Fig. 4. Digital Inclinometer

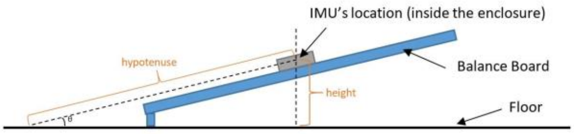


Fig. 5. Calculated Angle from Measured Lengths

# 4 Results and Discussion

## 4.1 Hardware Implementation

### 4.1.1 Upgrades

The study implemented the upgrades on the sway limit and stability, as well as the active control of the balance board. Fig. 6-8 show these changes.

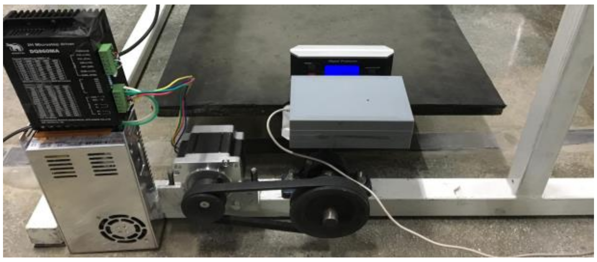

Fig. 6. Stepper Motor Installed

Fig. 7. Adjustable Tilt-Limit

Fig. 8. Variable Tension Shifter

The circuit (gray) box on Fig. 6 houses the microcontroller, temperature sensor, and IMU MPU6050. Wired serial communication was used to minimize the chances of having connectivity issues, as opposed to previous study which used Zigbee [12]. The IMU's placement inside the box was ensured to be in parallel axis with the balance board to avoid discrepancies on measurements against the digital inclinometer and the calculated angle.

### 4.1.2 IMU Pre-calibration

Prior to reliability tests, the IMU was tested for its accuracy by getting 21 data points from -20$^0$ to +20$^0$ separated by 2$^0$. Results from 3 trials showed that IMU data was off by an average of 31.92% from the inclinometer reading. Fig. 9 shows the relationship between inclinometer measurements from IMU's average from all 3 trials.

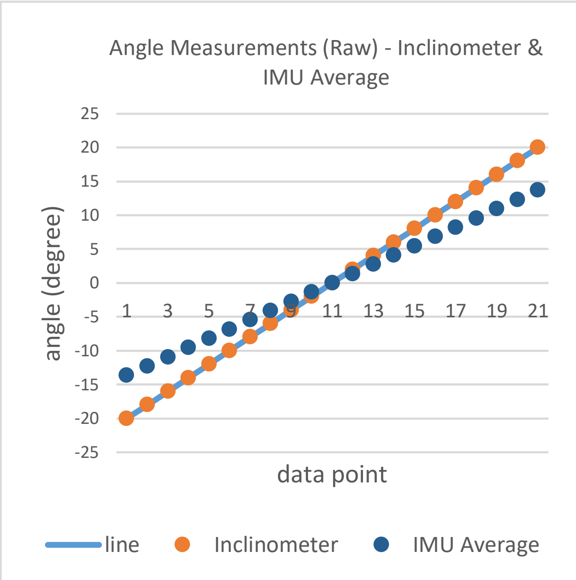


Fig. 9. Balance Board's Angle Measurements (Raw) – Inclinometer vs. IMU Average

Even though the IMU measurements are off from the actual values, it similarly showed a linear response. To calibrate the IMU, a simple linear regression method was applied using equations (3) and (4).

$$slope\ (m) = \frac{y2 - y1}{x2 - x1} \quad (3)$$

$$intercept\ (b) = y - mx \quad (4)$$

where: $y$ = inclinometer values
$x$ = IMU trial values

Using the 2 extreme points from each trials, calibration equation defined at equation (5) was derived.

$$Sway\ angle\ (\theta) = (1.1657 * IMU_{raw}) - 0.0464 \quad (5)$$

Applying the equation (5) on IMU measurements resulted in angle values with correlation coefficient of **r=0.9999** compared with the digital inclinometer. Table 5 shows the calibrated data set while Fig. 10 displaying its graphical representation.

| Initial Data in degree-unit (Calibrated) | | | | | |
|---|---|---|---|---|---|
| Set # | Inclinometer | Calculated | IMU | | |
| | | | Trial 1 | Trial 2 | Trial 3 |
| 1 | -20 | -19.95 | -19.98 | -20.01 | -20.01 |
| 2 | -18 | -18.02 | -18.06 | -18.05 | -18.05 |
| 3 | -16 | -16.04 | -16.05 | -16.07 | -16.04 |
| 4 | -14 | -13.97 | -14.04 | -14.06 | -14.07 |
| 5 | -12 | -12.03 | -12.07 | -12.08 | -12.04 |
| 6 | -10 | -10 | -10.06 | -10.07 | -10.03 |
| 7 | -8 | -8.03 | -8.02 | -8.08 | -8.02 |
| 8 | -6 | -5.95 | -6.06 | -6.09 | -6.01 |
| 9 | -4 | -4 | -4.05 | -4.08 | -4.06 |
| 10 | -2 | -2.05 | -2.10 | -2.10 | -2.03 |
| 11 | 0 | 0 | -0.02 | -0.02 | -0.03 |
| 12 | 2 | 2.05 | 1.90 | 1.89 | 1.99 |
| 13 | 4 | 4 | 3.94 | 3.88 | 4.04 |
| 14 | 6 | 5.95 | 5.88 | 5.88 | 5.99 |
| 15 | 8 | 8.03 | 7.90 | 7.90 | 7.99 |
| 16 | 10 | 10 | 9.94 | 9.95 | 10.02 |
| 17 | 12 | 12.03 | 11.97 | 11.93 | 11.97 |
| 18 | 14 | 13.97 | 13.94 | 13.91 | 13.98 |
| 19 | 16 | 16.04 | 15.96 | 15.93 | 15.99 |
| 20 | 18 | 18.02 | 17.97 | 17.95 | 18.07 |
| 21 | 20 | 19.95 | 20.00 | 19.98 | 20.02 |

Table 5. Angle Measurements with Calibrated IMU data

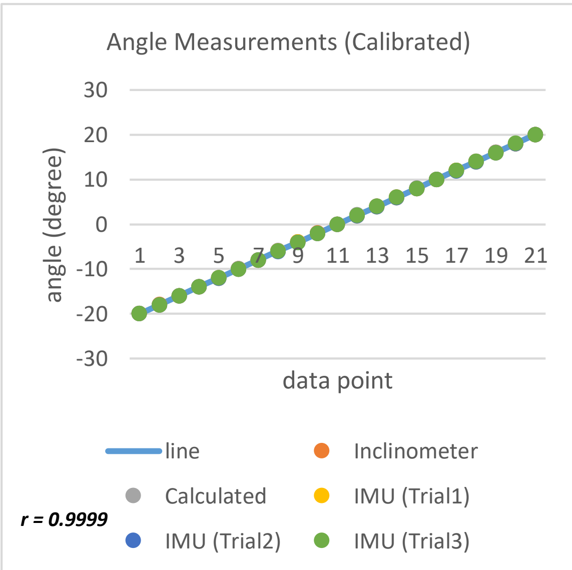


Fig. 10. Plotted points of Balance Board's Angle Measurements (Calibrated)

### 4.1.3 Hardware Issues

The IMU offset-calibration usually takes up 1-2 minutes during the initial power-up of the device. However, 1 out of 8 tries the IMU failed to output a value. One possible reason is that the IMU experienced movement or alterations on its state during this process resulting for the IMU to unable to verify the offset value. A workaround was to disconnect-reconnect the Serial-USB cable or reboot the Gizduino to restart the procedure.

Another issue regarding the stepper motor was revealed from the functionality tests for active motor control of the balance board. Results showed that under loaded condition, the stepper motor was only able to carry a maximum load of 10kg. The selected stepper motor can't be used to provide a mechanical assistance to a full-sized adult. Thus, the motor was used only to simulate the effect of having an active balance board.

## 4.2 Game Implementation

The game provides variability of in-game settings as described under section III. After every exercise on any of the game modes, the balance board re-centers itself to the $0^0$ starting position.

### 4.2.1 Free-mode (Edit In-game Settings)

In this mode, the user is requested to make himself/herself comfortable with the balance board before starting the exercise. The sway stability and maximum tilt of the balance board are also adjusted. And most importantly, the in-game settings are edited in this mode as shown in Fig. 11.

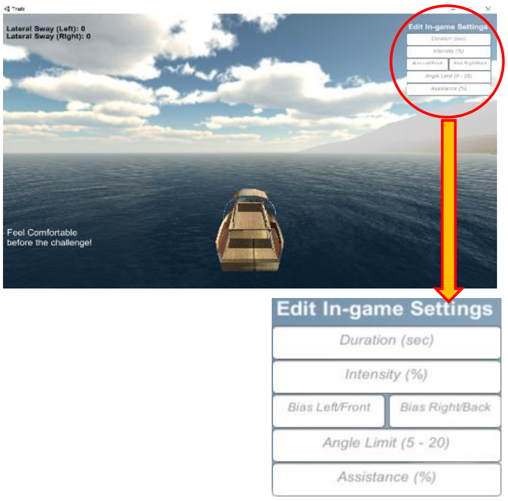


Fig. 11. BOAT's Free Mode

### 4.2.2 Effects on Game Modes

Each of the game settings directly affects the gameplay on each mode as discussed on section III. For the Collect-the-Crate mode, Intensity influences the number of spawning game objects (crate) and their distance with each other. The higher the intensity, more crates appear and farther from one another thus requiring the patient to move more. Bias setting dictates the chances whether the crate appear on the left or right side of the screen relative to the current location of the boat. While Assistance affects how the boat (through the balance board and the motor) moves towards the crates. Fig. 12 and Fig. 13 show the effect of varying Intensity, while Fig.14 and Fig. 15 shows the effect of changing the Bias setting.


Fig. 12. Collect-the-Crates, Intensity=100%


Fig. 13. Collect-the-Crates, Intensity=10%


Fig. 14. Collect-the-Crates, Bias Left=100%; Bias Right=0%


Fig. 15. Collect-the-Crates, Bias Left=50%; Bias Right=50%

As for the assistance setting, the average lateral sway of the balance board and the acquired game score during the course of the exercise was used to verify its effect. Table 6 shows sample data with varying assistance value while all other game settings remain constant. The trend generally shows that as the assistance setting decreases, the average lateral sway on both left and right also decreases. The game score also decreases alongside the assistance.

| Settings | | | | | | Trial 1 | | | Trial 2 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Duration | Intensity | Bias Left | Bias Right | Limit | Assistance | Ave. Sway | Ave. Sway | Score | Ave. Sway | Ave. Sway | Score |
| 120 | 100 | 50 | 50 | 15 | 100 | 5.63 | 5.47 | 7 | 4.94 | 5.70 | 5 |
| 120 | 100 | 50 | 50 | 15 | 50 | 4.93 | 2.94 | 4 | 3.57 | 3.75 | 3 |
| 120 | 100 | 50 | 50 | 15 | 25 | 3.61 | 3.02 | 3 | 3.75 | 2.61 | 2 |
| 120 | 100 | 50 | 50 | 15 | 0 | 0.00 | 1.01 | 2 | 0.00 | 0.99 | 1 |

Table 6. Effect of Assistance setting on average lateral sway and game score

As for the Avoid-the-Bombs, the Intensity setting affects the distance of the sea bombs from each other and from the boat. The higher the intensity, the closer the bombs both from each other and from the boat. Bias setting works similarly with Collect-the-Crate wherein spawning sea bombs appear more on the side with the higher bias. As for the Assistance, it controls the balance board to remain as close to $0^0$ as possible. Fig. 16-19 show these effects on the gameplay.


Fig. 16. Avoid-the-Bombs; Intensity=100%


Fig. 17. Avoid-the-Bombs, Intensity=10%


Fig. 18. Avoid-the-Bombs, Bias Left=100%; Bias Right=0%


Fig. 19. Avoid-the-Bombs, Bias Left=50%; Bias Right=50%

Lastly in the Follow-the-Light game mode, the Intensity setting defines the speed of the spotlight while moving away from the boat. The higher intensity, the faster the movement of the spotlight. Bias setting dictates the direction of the spotlight's movement to either front or back of the boat to test anterior and posterior sway respectively. The Assistance setting helps the patient maintain the location of the boat within the boundary of the spotlight by moving the balance board when a certain distance threshold has been met. Fig. 20 shows the spotlight moving towards the back of the boat.


Fig. 20. Follow the Light, Bias Back

### 4.2.3 Data Availability

Patient's performance on each of the exercise as well as the game settings are saved on an external .txt file for future reference. The file contains the name of the patient, time and date, in-game score, average lateral or ante-posterior sways, Equilibrium Score (ES), and the in-game settings.

### 4.3 IMU Reliability

The balance board with the IMU was subjected to continuous use in periods of 1, 2, 3, 4, and 5 hours, then performed an independent reliability test of sway angle measurement at the end of each period. The position of the inclinometer remained still across the duration of the test procedure to ensure the consistency of measurements. For each period, mean value from 3 trials of IMU readings were collected, shown in Table 7.

| Angle Measurement - Reliability Test | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Set # | Inclinometer (degree) | Initial (degree) | %error | ~2 hours (degree) | %error | ~3 hours (degree) | %error | ~4 hours (degree) | %error | ~5 hours (degree) | %error |
| 1 | -20 | -20.00 | 0.00 | -20.02 | 0.10 | -19.93 | 0.34 | -19.96 | 0.22 | -19.99 | 0.05 |
| 2 | -18 | -18.05 | 0.28 | -18.03 | 0.15 | -17.97 | 0.18 | -17.97 | 0.15 | -18.00 | 0.01 |
| 3 | -16 | -16.05 | 0.33 | -16.05 | 0.30 | -15.98 | 0.13 | -15.97 | 0.16 | -16.00 | 0.02 |
| 4 | -14 | -14.06 | 0.42 | -14.03 | 0.25 | -13.98 | 0.17 | -13.98 | 0.17 | -13.99 | 0.10 |
| 5 | -12 | -12.06 | 0.50 | -12.07 | 0.59 | -12.00 | 0.02 | -12.01 | 0.06 | -12.03 | 0.26 |
| 6 | -10 | -10.05 | 0.53 | -10.05 | 0.53 | -10.00 | 0.04 | -10.01 | 0.13 | -10.04 | 0.38 |
| 7 | -8 | -8.04 | 0.49 | -8.05 | 0.62 | -8.00 | 0.01 | -7.99 | 0.18 | -8.01 | 0.13 |
| 8 | -6 | -6.05 | 0.85 | -6.04 | 0.69 | -5.97 | 0.45 | -5.99 | 0.13 | -6.00 | 0.04 |
| 9 | -4 | -4.06 | 1.56 | -4.07 | 1.81 | -4.04 | 0.95 | -4.01 | 0.34 | -4.04 | 1.07 |
| 10 | -2 | -2.07 | 3.70 | -2.06 | 2.97 | -1.99 | 0.45 | -2.00 | 0.04 | -2.04 | 1.99 |
| 11 | 0 | -0.02 | 0.00 | -0.02 | 0.00 | -0.01 | 0.00 | -0.01 | 0.00 | -0.03 | 0.00 |
| 12 | 2 | 1.93 | 3.63 | 1.92 | 4.12 | 2.00 | 0.21 | 1.97 | 1.43 | 1.95 | 2.41 |
| 13 | 4 | 3.96 | 1.12 | 3.93 | 1.86 | 3.98 | 0.51 | 4.00 | 0.02 | 3.96 | 1.12 |
| 14 | 6 | 5.91 | 1.43 | 5.92 | 1.35 | 5.98 | 0.29 | 6.00 | 0.04 | 5.94 | 0.94 |
| 15 | 8 | 7.93 | 0.91 | 7.95 | 0.67 | 7.99 | 0.18 | 7.99 | 0.12 | 7.97 | 0.36 |
| 16 | 10 | 9.97 | 0.31 | 9.94 | 0.60 | 9.99 | 0.11 | 10.02 | 0.18 | 9.95 | 0.55 |
| 17 | 12 | 11.96 | 0.35 | 11.94 | 0.51 | 12.01 | 0.06 | 12.02 | 0.14 | 11.98 | 0.15 |
| 18 | 14 | 13.94 | 0.42 | 13.93 | 0.52 | 14.00 | 0.03 | 14.02 | 0.14 | 13.99 | 0.10 |
| 19 | 16 | 15.96 | 0.25 | 15.95 | 0.31 | 16.02 | 0.11 | 16.03 | 0.20 | 16.01 | 0.05 |
| 20 | 18 | 18.00 | 0.02 | 17.97 | 0.18 | 18.03 | 0.15 | 18.06 | 0.34 | 18.02 | 0.12 |
| 21 | 20 | 20.00 | 0.00 | 19.97 | 0.17 | 20.03 | 0.15 | 20.00 | 0.02 | 20.01 | 0.07 |

Table 7. Sway angle measurements of IMU after periods of continuous use

Fig. 21 shows the graph of data with the largest error-difference occurring at -2$^0$ and +2$^0$ and follows a general decreasing trend as the angle increases. This can be attributed to the calibration equation used from Eq. 5 where the data points used were from the two end-points of measurement which is the -20$^0$ and +20$^0$. As well as from the general equation of error difference where the lower the divisor results in a larger quotient.

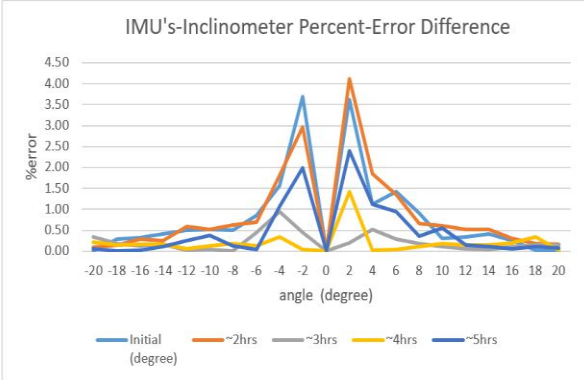


Fig. 21. IMU's Reliability Measurement (%-error)

The study also aims to estimate the time when the IMU will lose its calibration. Data suggests that even after continuous use for more than 5 hours, the IMU readings are still within the 3% error-margin indicated on its specification. Taking the average of error from each trial, Fig. 22 illustrates that there has been no significant trend to warrant the conclusion on when the IMU needs re-calibration. There is a need to conduct more extensive tests on the reliability of the IMU measurements to properly estimate its range of operation.

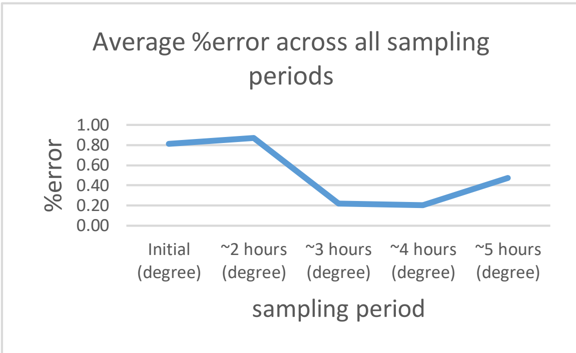


Fig. 22. IMU's Average %-error Across all Test Periods

### 4.4 IMU Re-calibration

Even though the study was not able to properly estimate the duration of when the system will lose its calibration, the system has an added feature that allows the user to re-calibrate the IMU whenever it is needed. A re-calibration procedure can be accessed from the main menu of the game. Calibration equations and values are saved on a configuration file saved and accessed by the game. Fig. 23 shows the window of the re-calibration procedure.

Fig. 23. IMU Re-Calibration Window

## 5 Conclusion and Recommendation

The study successfully implemented enhancements on a balance training platform both on hardware and software systems as described on the objectives. The system incorporated an active balance board using a stepper motor, though not sufficient to carry a full-sized adult, it is enough to simulate the expected effect. A more powerful motor is needed to fully test the effectivity of having an active balance rehabilitation system. Also, the jerky movement of the balance board needs to be addressed. The Constraint-Induced Movement Therapy (CIMT) method used in rehabilitation can be manifested by adjusting the appropriate in-game settings. The variability of settings on both hardware and software systems allow the therapist to design a training exercise suited on the balance capacity of the patient, though the system is yet to be implemented using a test subject. The main beneficiaries of the system are stroke patients suffering from balance problems, however the system needs to be tested first on healthy individuals to limit the risk of injury. The IMU MPU6050 was proven to be reliable even up to 5 hours of continuous use. Since the system is aimed to be used on a clinical and rehabilitation environment, it needs to be robust and calibrated. A more extensive reliability tests are needed to properly identify the period on when the system will need to be re-calibrated.

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