

Instrumentation of a balance board

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Master Dissertation

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To all present along my journey.

Abstract

Balance is an important function for a good quality of life and good performance in sports activities. Factors such as age, disease, and medications can affect it, which happens to a large part of the population.

To improve balance, one can perform exercises that challenge the user to remain stable on an unstable surface. In order to help the user to perform this exercise, an instrumentation of an exercise platform called balance board is implemented. The board orientation is measured and wireless transmitted to a cloud database. The software applications were developed to provide a user graphical interface and access to stored data. The first one provides information about the orientation in real time and thus the user can react accordingly and perform the exercise better. The other, allows accessing the data that is in the database and shows it to the user in graphical or numeric view.

The instrumentation was done using an ESP32 board along with an IMU sensor and the applications were developed one to be used through the browser of computers or cell phones, the other is an application to run on Android devices.

A prototype of the instrumented balance board was then tested to evaluate the usability of the developed user interface software. The acoustic feedback provided in the user interface is found to be helpful in performing the proposed exercise.

Instrumentação de uma plataforma de equilíbrio

Resumo

O equilíbrio é uma função importante para uma boa qualidade de vida e um bom desempenho em desportos que o necessitam para uma melhor performance. Fatores como idade, doenças e medicações podem afetá-lo, o que acontece com grande parte da população.

Para a melhoria do equilíbrio, pode-se realizar exercícios que desafiam o usuário a se manter estável sobre uma superfície instável. Com o intuito de auxiliar a realização deste tipo de exercício realizou-se a instrumentação de uma plataforma de exercício chamada de plataforma de equilíbrio. Foi implementada a medição da orientação da plataforma, e o armazenamento dos dados em uma base de dados na nuvem, sendo utilizada uma comunicação sem fios. Foram elaboradas duas aplicações informáticas para utilização. Uma que disponibiliza a informação sobre a orientação da plataforma em tempo real e assim o utilizador pode reagir de acordo e realizar o exercício melhor. A outra que consulta os dados que estão na base de dados e os mostra ao utilizador.

A instrumentação foi feita com a utilização de uma placa ESP32 juntamente com um sensor IMU e as aplicações foram desenvolvidas uma para ser utilizada através do navegador de computadores ou celulares, já a outra é uma aplicação instalável em dispositivos Android.

Um protótipo da plataforma de equilíbrio instrumentada foi então testado para avaliar a usabilidade do software de interface com o utilizador. O feedback acústico fornecido na interface do utilizador mostrou-se útil para a realização do exercício proposto.

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Table of Contents

| | | |
|-----|--|----|
| 1 | Introduction | 1 |
| 1.1 | Problem and Motivation | 1 |
| 1.2 | Objectives | 3 |
| 1.3 | Dissertation Structure | 3 |
| 2 | Current balance boards | 4 |
| 2.1 | Balance boards without instrumentation | 4 |
| 2.2 | Instrumented balance boards | 7 |
| 2.3 | Conclusion | 11 |
| 3 | Balance board system definition | 12 |
| 3.1 | Instrumentation | 12 |
| 3.2 | Data storage and communication | 15 |
| 3.3 | User Interface | 15 |
| 3.4 | Chosen architecture and hardware instrumentation | 16 |
| 3.5 | Conclusion | 21 |
| 4 | Application development | 22 |
| 4.1 | Web APP | 22 |
| 4.2 | Android APP | 33 |
| 4.3 | Conclusion | 36 |
| 5 | Evaluation of the developed instrumented balance board | 37 |
| 5.1 | Test results | 38 |
| 5.2 | Conclusion | 42 |
| 6 | Conclusions and future works | 43 |
| | References | 45 |
| | Appendix A: Concept design flowchart | 48 |

List of Figures

| | |
|---|----|
| Figure 1.1 - Body CG representation [2]. | 1 |
| Figure 2.1 - The six degrees of freedom of a free body in space [21]. | 4 |
| Figure 2.2 - Wobble board example. | 4 |
| Figure 2.3 - Rocker balance board [26]. | 5 |
| Figure 2.4 - 2 Springs balance board [27] , [28]. | 5 |
| Figure 2.5 - Roller balance board [29]. | 6 |
| Figure 2.6 - Half balance ball [30]. | 6 |
| Figure 2.7 - Fluidstance balance board for standing desk [31]. | 6 |
| Figure 2.8 - SMARTwobble wobble board [32]. | 7 |
| Figure 2.9 - SMARTwobble test interface [32]. | 7 |
| Figure 2.10 - SMARTwobble rehabilitation interface [32]. | 8 |
| Figure 2.11 - BoBo Home balance board [33]. | 8 |
| Figure 2.12 - Exercise with BoBo Home balance board [33]. | 8 |
| Figure 2.13 - MFT-bodyteamwork challenge disc [34]. | 9 |
| Figure 2.14 - TOGU challenge disc [35]. | 9 |
| Figure 2.15 - Wii balance board [36]. | 9 |
| Figure 2.16 - Sensingfuture PhysioSensing [37]. | 10 |
| Figure 3.1 - General design architecture. | 12 |
| Figure 3.2 - Balance board choice for instrumentation. | 12 |
| Figure 3.3 - WEMOS Lolin32 board with Wi-Fi connection. | 14 |
| Figure 3.4 - Raspberry Pi Zero W. | 14 |
| Figure 3.5 - Smartphone architecture. | 16 |
| Figure 3.6 - Micro-controller architectures. | 17 |
| Figure 3.7 - Solution architecture diagram. | 17 |
| Figure 3.8 - Device assembly. | 18 |
| Figure 3.9 - Circuit wiring. | 18 |

| | |
|--|----|
| Figure 3.10 - Balance board maximum tilt measurement with protractor. | 19 |
| Figure 3.11 - Sensor characterization around X axis. | 20 |
| Figure 3.12 - Sensor characterization around Y axis. | 20 |
| Figure 4.1 - Tabs interface. | 22 |
| Figure 4.2 - Chart interface. | 23 |
| Figure 4.3 - Radar Map interface. | 24 |
| Figure 4.4 - Game interface. | 25 |
| Figure 4.5 - Input text box interface. | 25 |
| Figure 4.6 - Orientation interface. | 26 |
| Figure 4.7 - Buttons interface. | 26 |
| Figure 4.8 - Chart interface. | 26 |
| Figure 4.9 - Exercise target control interface. | 28 |
| Figure 4.10 - Exercise interface showing target at (7°, 9°), and Area of exercise around 13°. | 28 |
| Figure 4.11 - Game exercise. | 30 |
| Figure 4.12 - Database data structure. | 32 |
| Figure 4.13 - Data display List interface. | 34 |
| Figure 4.14 - Data display Chart interface. | 35 |
| Figure 5.1 - Average distance to the center for exercise. | 40 |
| Figure 5.2 - Center absolute distance reduction with feedback [°]. | 40 |
| Figure 5.3 - Inquire results about exercise execution without user interface visual feedback. | 41 |
| Figure 5.4 - Inquire results about exercise execution with user interface visual feedback. | 41 |

List of Tables

| | |
|--|----|
| Table 2.1 - Comparison of balance boards characteristics. | 11 |
| Table 3.1 - Data for X sensor characterization. | 19 |
| Table 3.2 - Data for Y sensor characterization. | 19 |
| Table 3.3 - Developed balance boards characteristics. | 21 |
| Table 5.1 - Interface test results with the eyes open. | 38 |
| Table 5.2 - Interface test results with the eyes closed. | 39 |

Symbols and Abbreviations

BLE - Bluetooth

CG - Center of Gravity

CSS - Cascading Style Sheets

DOF - Degree of freedom

ESP - Espressif Systems

HTML - Hypertext Markup Language

I2C - Inter-Integrated Circuit

IMU - Inertial Measurement Unit

IP - Internet Protocol

JSON - JavaScript Object Notational

PC - Personal Computer

SCL - Serial Clock

SDA - Serial Data

SPI - Serial Peripheral Interface

SPIFFS - Serial Peripheral Interface Flash File System

UI - User Interface

USB - Universal Serial Bus

1 Introduction

Balance is a term that describes the ability to maintain an upright posture. The term "postural balance" describes, more specifically, a person's ability to maintain the Center of Gravity (CG) by standing on a support base [1], as can be seen in the Figure 1.1.

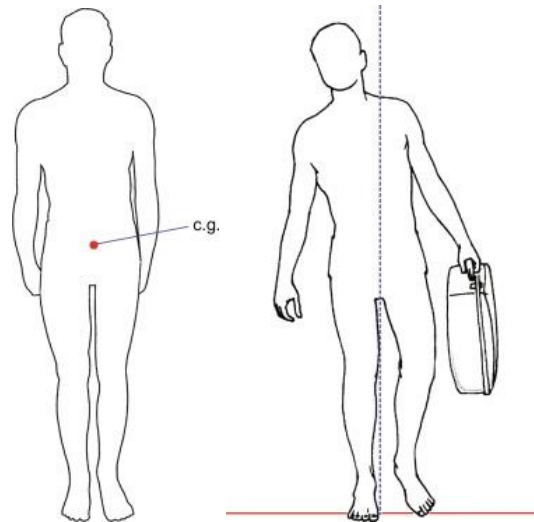


Figure 1.1 - Body CG representation [2].

Aging, diseases, and medications are some of the causes that affect balance. The first is because loss of muscle strength occurs as people get older, even if they are still active adults. The second, cause is due to neurological disorders (e.g., Parkinson's), arthritis, or sensory impairment. The third, cause results from medicines that have side effects such as confusion and dizziness [1]. Because of this, people who suffer from this condition use equipment that helps them to walk or stand, such as a cane, walker, or crutches, and that decreases the quality of life [3]. One way to improve balance and reduce or eliminate the need to use those products is through the practice of balance exercises [4]. The practice of balance exercises is also carried out in other contexts such as sport activities, by practitioners and athletes. Balance exercises can be performed without any special equipment but is common the use of balance boards.

1.1 Problem and Motivation

Dizziness is one of the most frequent reasons for seeking specialized medical care in the emergency room. A study done in Portugal over a 4-year period showed that out of 40173 patients seen, a total of 4347 patients (10.8%) had to seek medical attention due to vertigo or balance disorders [5]. In the United States of America, approximately 90 million people look for treatment for vertigo, dizziness, and balance problems. These are the second biggest complaints doctors hear from patients, and they affect 70% of the population at some point in their lives [6].

Balance is a significant ability for day-to-day existence. It requires the mix of sensory information regarding direction of the body comparative with gravity and environment [7]. The vestibular system is responsible for this sense of balance having several inputs to support it, such as the balance organs of the inner ear, visual inputs, and inputs from the limbs and vertebrae [8]. Therefore, having a vision problem causes dysfunctions in movement and balance [9]. For that, balance exercises can help to restore or improve the walking function and increase mobility.

Most rehabilitation studies indicate that programs should begin as early as possible, be intense, and prolonged as possible for effective function recovery, preferably near the patient's home [10].

In balance exercises it is common to see the use of low-tech equipment, which does not allow obtaining data for monitoring purpose. Most balance boards [3] that are used in balance rehabilitation exercises do not provide monitoring functions. Traditional assessments rely on subjective evaluations and qualitative measures [11] and often cannot identify balance deficiencies in a reliably way [12]. Areas such as balance rehabilitation therapy and sports are experiencing innovations due to the growth of sensing and communication technologies [13].

With the growth of sensing and communication technologies, motor rehabilitation performed outside a clinic has expanded. Exercises can be done at home (Tele-rehabilitation) and monitored remotely through the instrumentation implemented in the rehab devices. In addition, the cost of putting sensors in rehabilitation equipment has been reduced due to their low price.

The two most promising technologies for instrumentation rehabilitation and wearable devices are inertial sensors (IMUs) and video motion capture systems [14]. IMU sensors can be used to track the motion of bodies and algorithms have been developed for tasks such as exercise recognition and evaluation [15], [16].

The need of use inertial sensors and video motion capture systems for healthcare and lower cost services has increased due to the aging population. Tele-rehabilitation is intended to improve the quality of service, not to replace professionals in the field. The use of wearable sensors allows for real-time tracking even at a distance, which allows for a continuous sampling of the patient's condition, which differs from clinical visits where data collection is restricted to the time the person is inside the facility. In this way, it is possible to establish more personalized and specific treatments, as well as to evaluate the quality of the task performed and whether the patient is dedicated to the remote treatment [17].

Within the field of balance exercises, there are already some solutions on the market that can monitor the activity. However, in this project, the focus is on implementing an instrumentation solution and on developing a software solution that performs data monitoring with database registration. Further, besides a user-friendly interface, the software application should be able to provide acoustic feedback, opening the possibility of users with vision problems performing the balance exercises.

To make the exercise more user-friendly, it is common to see a gamification of the required exercise. This approach has been shown to increase the captivation of children during treatment with a balance board [18].

There is not so much evidence yet to show that tele-rehabilitation is better than conventional treatment [17]. So, to validate and determine the reliability of the data obtained with the sensors, research is needed on their use in tele-rehabilitation [19].

1.2 Objectives

This work fits within the instrumentation and monitoring field, applied to equipment for human exercises. It is envisaged the instrumentation of a balance board so that the equipment can be used both for evaluation and training of body balance. The implementation of electronics and micro-controller based systems, combined with communications capabilities, allows the development of a prototype of a smart instrumented device prepared for e-Health.

This work will use a commercial balance board, used for body balance exercises, which must be fitted with a sensor to supply the orientation data. The monitoring system, which must be developed, will provide the data acquisition, transmission and storage of the relevant information regarding the use of the balance board. It is also envisaged to set up a graphical user interface (UI) to help the user in assessing the execution of balancing exercises.

It continues other developments conducted in the Laboratory of Instrumentation for Measurement in the field of instrumented devices for evaluation, monitoring, and rehabilitation.

The main tasks to be performed in this work are:

- Identify sensor solutions to instrument the balance board;
- Development of a sensor data acquisition solution;
- Develop a user interface application;
- Evaluate the solution.

1.3 Dissertation Structure

The dissertation is divided in six sections, which are:

- Section 1 - Introduction - In which this section is inserted, presents the topic of the dissertation, motivations and the objectives to be achieved;
- Section 2 - Current balance boards - This section shows the types of balance boards on the market and compare their characteristics;
- Section 3 - Balance board system definition - This section shows what technologies are available to compose the general architecture and presents the chosen architecture and components;
- Section 4 - Application development - This section presents the user interface development for the chosen architecture and its features;
- Section 5 - Evaluation of the developed instrumented balance board - This section evaluates the developed user interface and instrumentation for the balance board;
- Section 6 - Conclusions and future work - This section presents the main conclusions and suggests future works.

2 Current balance boards

This section looks at the types of balance boards on the market, whether instrumented or not, and compare their characteristics.

2.1 Balance boards without instrumentation

Balance boards are devices for individual use that help to improve balance through exercises. Among the types of balance boards without instrumentation, there are wobble boards, rocker balance boards, spring balance boards, roller balance boards, half balance balls [20], and the desk user boards. The most important characteristic of a balance board is how many degrees of freedom (DOF) (Figure 2.1) it has and how much instable it is.

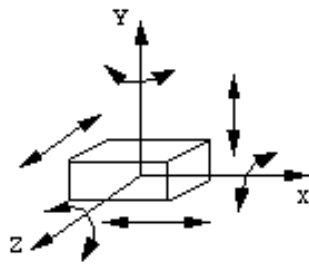


Figure 2.1 - The six degrees of freedom of a free body in space [21].

- Wobble boards

A wobble board is a board that has 3 DOF with instability in two axes. This boards uses a semi-sphere base responsible for creating the system imbalance and a flat surface [22] providing a support, as can be seen in Figure 2.2. It can be used for balance training, physical exercise, posture, and coordination.



Figure 2.2 - Wobble board example.

In physiotherapy it can be used to train elderly people to prevent falls [23] and improvement of upper and lower limb strength or rehabilitation [24], [25].

- Rocker balance boards

It has a flat and rectangular shape with a fixed semi-cylinder support as can be seen in Figure 2.3. In comparison with the others, this one is the easiest to use due to its base's geometry which only provides 1 DOF and is instable in this one. This makes it the most suitable for beginners, persons with balance problems and the elderly, as well as being an option for physiotherapy. It can even be used for office workers to prevent sedentariness without affecting focus [21].



Figure 2.3 - Rocker balance board [26].

- Spring balance boards

These boards use two plates connected by springs. The plates can have different shapes, such as rectangular (Figure 2.4-a), circular (Figure 2.4-b)) or elliptical (Figure 2.4-c)). The base is fixed, and the top plate is supported by springs that can vary the spacing between them, which influences the stability and consequently the difficulty of the exercise. This configuration gives 2DOF. To use a spring plate, the user needs to keep the balance while the springs push the plate. Spring balance boards provides a more intensive workout than wobble or rocker boards, because the user is higher relative to the ground which increases the range of motion [20].

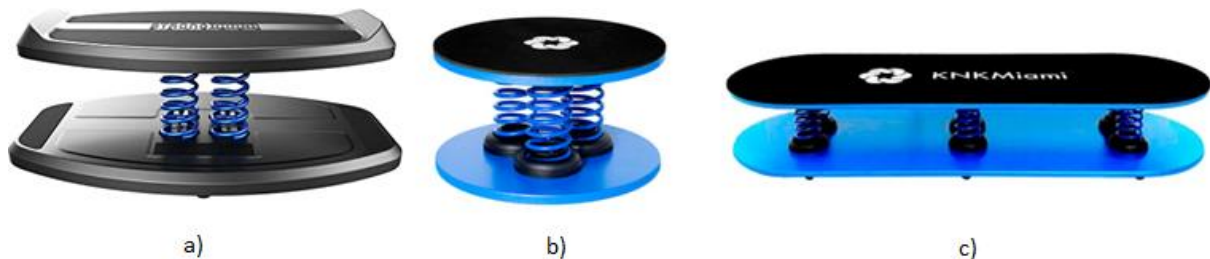


Figure 2.4 - 2 Springs balance board [27] , [28].

- Roller balance boards

This board uses a flat plate and a free rolling cylindrical base (as can be seen in Figure 2.5). This allows 3DOF, with 2 angular and 1 linear movement. Since the possible movements are similar to the ones involved in sports such as surfing, water skiing, snowboarding, or skateboarding, practitioners of these sports often use it for training.



Figure 2.5 - Roller balance board [29].

- Half balance balls

It consists of a circular flat plate base and an inflated dome (as can be seen in Figure 2.6). This configuration allows 3DOF.



Figure 2.6 - Half balance ball [30].

- Desk balance boards

Some companies like Fluidstance have developed balance boards that are intended to be used by people who spend their days working at desks and are looking for a healthier lifestyle. With a design that provides comfort and is not difficult to use (Figure 2.7), this particular balance board have limited application.



Figure 2.7 - Fluidstance balance board for standing desk [31].

2.2 Instrumented balance boards

Some companies saw the need in the market to have balance boards with technologies that could help in the execution of the exercises. Among the existing products, it was identified the SMARTwobble, Bo-Bo balance board, MTF challenge disc, TOGU challenge disc, Wii balance and Sensingfuture PhysioSensing.

- The SMARTwobble

As was presented in the section 1.1, an instrumented balance board allows to establish more personalized and specific treatments, as well as to evaluate the quality of the task performed. With that in mind, some companies have created instrumented versions of balance boards. SMARTwobble (Figure 2.8) has a simpler proposal than the competing balance boards as it relies on a computer application and no healthcare service provision.



Figure 2.8 - SMARTwobble wobble board [32].

According to their website, SMARTwobble encompasses state of the art technology housed within the wobble board dome which monitors the tilt of the board and communicates wirelessly via Bluetooth to the SMARTwobble Personal Computer (PC) software [32]. Its software has an easy-to-use interface, providing the rehabilitation professional with the options of 'test' or 'rehabilitation'. The 'test' option allows clinicians and patients to perform exercises with real-time feedback on the screen (Figure 2.9), before generating a report. This report describes and quantifies balance and proprioception performance in relation to time spent on the degrees of tilt. The 'rehab' provides the patient with a gamified interface (Figure 2.10) that is controlled by the orientation of the board [32].

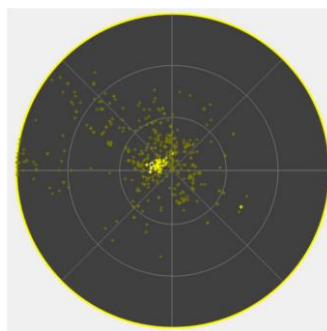


Figure 2.9 - SMARTwobble test interface [32].

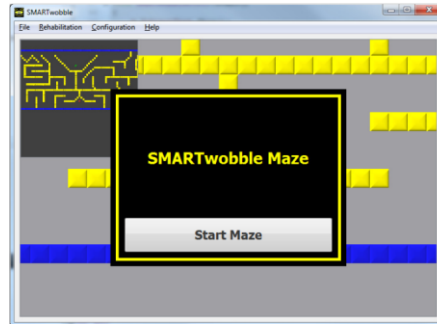


Figure 2.10 - SMARTwobble rehabilitation interface [32].

- The BoBo balance board

In the BoBo device, in addition to the equipment, an application is provided to help the user perform the exercises, as well as monitoring by physiotherapy professionals. They offer a cloud-based product that benefits physiotherapy clinics, professional fitness centers, hospitals, sports facilities and personal trainers [33]. Unlike SMARTwobble, BoBo uses an instrumented flat plate (Figure 2.11), that is placed on a spherical or semi-spherical base to perform the exercises, as can be seen in the Figure 2.12.



Figure 2.11 - BoBo Home balance board [33].



Figure 2.12 - Exercise with BoBo Home balance board [33].

- MTF challenge disc and TOGU

With the same perspective companies as MFT-bodyteamwork[®] (Figure 2.13) and TOGU[®] (Figure 2.14) have developed their versions of instrumented balance boards and call them challenge discs. Both have a gamified exercise interface and are supported by professionals in the field [34], [35].



Figure 2.13 - MFT-bodyteamwork challenge disc [34].



Figure 2.14 - TOGU challenge disc [35].

- Wii balance

The Wii balance (Figure 2.15) is a device created by Nintendo[®] (developer and publisher of electronic games and consoles), for the Wii console. It has the objective of turning physical exercise into a game. The board uses four load cells placed at the corners of the plate that allows to track the user's center of balance.



Figure 2.15 - Wii balance board [36].

However, in this case, the board is completely flat, and the position of the CG is found depending on the force applied to the board. Unlike the wobble board, the Wii balance is a stable base.

- Sensingfuture PhysioSensing

Sensingfuture[®]'s solution (Figure 2.16) is a flat platform created with a focus on clinical use by rehabilitation professionals. Among its application areas are rehabilitation: vestibular, neurological physics, orthopedic physics, and sports. To do so, it uses pressure mat sensor in the plate that map pressure points.



Figure 2.16 - Sensingfuture PhysioSensing [37].

Table 2.1 presents the main characteristics of the referred balance boards. It can be notice that none of the presented boards have acoustic feedback.

Table 2.1 - Comparison of balance boards characteristics.

| Boards | DOF | Instrumentation | Communication | Data Storage | Software |
|-----------------------------------|------|--------------------|---------------|--------------|----------|
| Half balance Ball (BOSU) | 2 | No | No | No | No |
| Rocker balance boards (StrongTek) | 1 | No | No | No | No |
| Wobble board (Crivit) | 3 | No | No | No | No |
| Spring balance boards (KNK Miami) | 2 | No | No | No | No |
| Roller balance boards(4thBee) | 2+1* | No | No | No | No |
| Fluidstance balance board | 3 | No | No | No | No |
| Wii balance (Nintendo) | 0 | Yes (Load cells) | BLE | No | No |
| SMARTwobble(Theta Metrix) | 3 | Yes (IMU)** | BLE | Local | Yes |
| BoBo balance board | 3 | Yes (IMU)** | BLE | Local/Cloud | Yes |
| MFT-bodyteamwork challenge disc | 2 | Yes | BLE | No | Yes |
| TOGU challenge disc | 2 | Yes | BLE | No | Yes |
| Sensingfuture PhysioSensing | 0 | Yes (Pressure mat) | USB | Local | Yes |

*2 angular and 1 linear motion. ** Inertial Measurement Unit.

2.3 Conclusion

It is concluded that there are several balance boards available to assist in balance improvement activities, either for sport or for medical needs. Besides, there is a growing number of boards that take advantage of sensors to quantify the exercises performed and, in this way, trace the user's evolution. There is still room for innovation because none of the existing solutions have acoustic feedback, which restricts the use of these platforms, by people with sight problems.

3 Balance board system definition

When instrumenting an existing platform, some factors must be taken into account, such as whether there is enough space to install all the necessary hardware; whether the positioning is ideal for reliable data acquisition; and whether the placement of the device will affect the use of the equipment for the purpose of assisting on exercises and rehabilitation.

The adopted general design architecture for an instrumented balance board is shown in Figure 3.1. It is necessary to select what components are appropriate for measuring the board orientation, in addition, how to transfer the data, where to store the data, what user interface to use (PC or smartphone), and the software development tools to use.

The flowchart in Figure A.1 in Appendix A shows the process flow on what is available and necessary to develop an instrumented solution for the balance board.

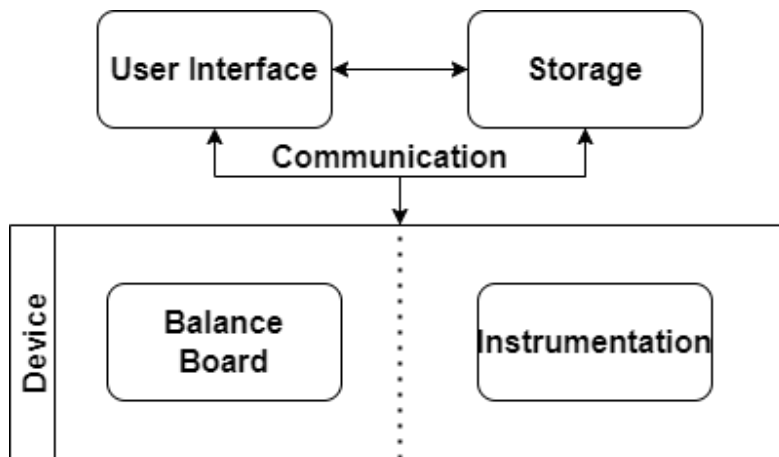


Figure 3.1 - General design architecture.

3.1 Instrumentation

The available balance board is a Wobble board. To instrument it is necessary to install a sensor capable of measuring the board orientation (3DOF) and a Control Hardware (e.g., microcontroller) compatible with the sensor communication protocol.

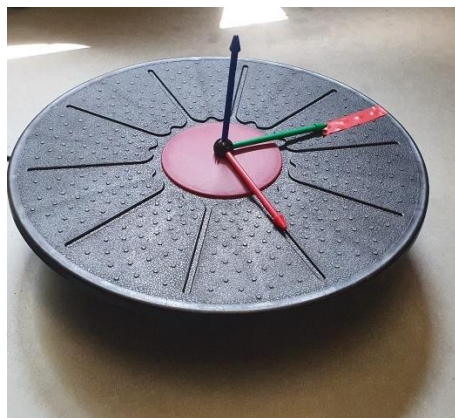


Figure 3.2 - Balance board choice for instrumentation.

Orientation measurement

For measuring angles there are multiple transducers such as Tilt Sensors, Angle Sensors, Hall Sensors, Rotary Inductive Position Sensors, Potentiometers, Encoders, and Inertial Measurement Unit sensor (IMU).

The tilt sensor is not capable of continuous measurement, so it does not satisfy the need. Since the chosen balance board has 3 DOF, to use a sensor, other than an IMU, it would be necessary to make a complex base for fixing the sensor in a way that it can move with the balance board when the made movement is not around the axis that the particular sensor is measuring. Furthermore, as these other sensors only measure in 1 DOF, it would be necessary to implement 3 of them, that would increase the cost of instrumenting the balance board. However, the IMU is compact solid-state sensor that measures orientation in all the three axes. This allows to position it inside the balance board, with a simple assembly procedure. That is why the IMU is the chosen sensor.

IMUs sensors have up to 9 DOF and are composed by three main sensors: accelerometer, gyroscope, and magnetometer. By combining the three sensors it is possible to track the motion of the object in mid-space. An IMU with 9 DOF is thus able to measure angular velocity (on 3 axis), linear acceleration (on the same 3 axis) and the magnetic field (on the referred 3 axis). Thus, it is important to understand how the constituent sensors work.

- Gyroscope

To measure the speed of a body, the gyroscope takes advantage of the Coriolis effect. It contains vibrating masses which vibrates along a drive axis. When the gyroscope is rotated, the mass displaces from its original path due to a secondary vibration that is induced in the perpendicular axis. The mass displacement introduces capacitance changes, and the sensor detects it. With that the angular velocity can be measured and integrating the signal, it is possible to get the orientation [38].

- Accelerometer

The principle of accelerometer operation is Newton's second law applied to a spring-mass system. The sensor measures the mass linear accelerations, as well as, measuring vibrations. To obtain the displacement of the mass it is needed a double integral in time of the measured acceleration [38].

- Magnetometer

The magnetometer is a sensor that measures the Earth's magnetic field, thus it is used to estimate an orientation reference for the IMU [39]. This sensor is an electronic compass, and it can work by using three solutions, the Hall effect, magnetic induction, or magnetic resistance [40].

Typically, the IMU sensor board provides the Inter-Integrated Circuit (I2C) protocol for connection with the microcontroller. The I2C is a bus interface connection protocol built into devices for serial communication. It uses 2 bidirectional lines for data communication called Serial Data (SDA) and Serial Clock (SCL). The data transfer goes through the SDA line, while the clock signal goes through the SCL line. Furthermore, I2C can operate in either Master or Slave mode [41].

Control Hardware

To transfer the data obtained from the sensor to the computer, database and/or application, it can be used programming systems such as Arduino based, Raspberry Pi or Espressif Systems (ESP) based. These are the powerful alternative since their use is simple and intuitive, with several available libraries and peripherals.

Arduino is an "open-source" electronic platform in both hardware and software. Arduino controllers consist of the microcontroller and software that runs on a computer for programming the microcontroller. They have analog and digital input and output ports. In addition, the controllers vary in terms of components, which allows to choose the one that best fits the solution needed, either by size or by components that allow remote connection such as Wi-Fi. ESP32 based controller, such as the WEMOS Lolin32 (Figure 3.3) are compatible with Arduino systems and has already an integrated Wi-Fi connection card.



Figure 3.3 - WEMOS Lolin32 board with Wi-Fi connection.

Since the Raspberry Pi is a microcomputer and not a microcontroller like the ESP32, an operating system like Linux is required. Thus, it is necessary to connect a keyboard, mouse and monitor to be programmed. Both the ESP32 WEMOS Lolin32 and the Raspberry Pi Zero W (Figure 3.4) feature Wi-Fi connection, packed in a small board.



Figure 3.4 - Raspberry Pi Zero W.

The ESP has the advantage of being plug and play hardware, so that when it is powered or connected to the computer, it starts running the program. The Raspberry Pi, having an operating system, needs to be started and cannot be unplugged without being shut down properly.

An alternative to these devices is a smartphone, since it is programable and has sensors available on it that can measure the orientation and have native communications capabilities, such as Wi-Fi.

3.2 Data storage and communication

The data storage can be done locally or in a cloud. To allow the data obtained by instrumenting the balance board to be accessed in real time on any device with access through a proprietary application, these data must be stored in an online database. There are multiple cloud storage options:

- Amazon Web Services;
- Google Cloud Platform;
- Microsoft Azure SQL Database;
- IBM Db2 on Cloud;
- Oracle Database.

The Google's service Firebase, that connects with the Google Cloud, stands out for having the libraries and extensions needed to develop Android applications and interface with Arduino platforms, thus simplifying the developing process of sending data to the database and the storing it.

The communication between the balance board instrumented hardware, data storage and APP can be done by Universal Serial Bus (USB), Bluetooth (BLE) or Wi-Fi. As the storage will be done in a cloud service and the application is Web based, the use of a Wi-Fi communication simplifies its implementation.

3.3 User Interface

The user interface application can be developed for PC or smartphone, either to be installed or accessed through a browser. Thus, a web application that can be accessed by both devices through a browser and an application for android smartphones, provide a possible software solution.

The user interface should provide visual and acoustic feedback. The visual feedback can be done through the application's screen, either by graphics, numerical indicators, radars, etc. On the other hand, the acoustic feedback can make use of the APP software (the application will play a sound in the device that is running), or a using specific hardware connected to the controller (Control Hardware), either by buzzers or speakers.

Web application

One way to create an application that can be easily accessed by any device that has a current browser (e.g., Google Chrome[®]) is with a Web Server. That way, when the server is online, all that is necessary to do is to type the server's Internet Protocol (IP) in the user smartphone or PC browser. No need to download a file to the device.

To create a Web Server, it is necessary to configure three files, Hypertext Markup Language (HTML), Cascading Style Sheets (CSS), and JavaScript. The HTML file is responsible for defining the content of the web page. It describes the structure of a Web page, and its elements tell the browser how to display the content [42]. The CSS file define the styles for the Web page, i.e., the design, layout, and variations in screen sizes [43]. The JavaScript file is needed to program the behavior of the web page (handle web server responses and events) [44]. It makes the relationship of the controller being used with the server, because it is through the script that the data sent from the hardware can be received, the necessary functions can be performed and the attributes that are being shown by the HTML to the user can be modified.

Android Application

To create an Android application, Google's Android Studio[®] can be used. The application must be able to connect to Google Firebase and this authoring software has a tool that facilitates the integration of these systems. The communication between the application and Firebase uses the functions necessary to collect the data stored there.

3.4 Chosen architecture and hardware instrumentation

Based on the general design architecture and on possible hardware options, two architectures implementations were considered:

The first one using a smartphone feature (IMU and Wi-Fi) for measuring the board orientation and send the data to the application and the database. The data can be sent first to the database and the application retrieve this stored data (Figure 3.5-a)), or first to the application and then sent to the database (Figure 3.5-b)), or sent simultaneously to the APP and database (Figure 3.5-c)). When the connection is made between smartphone and smartphone/PC it can be through Wi-Fi or BLE.

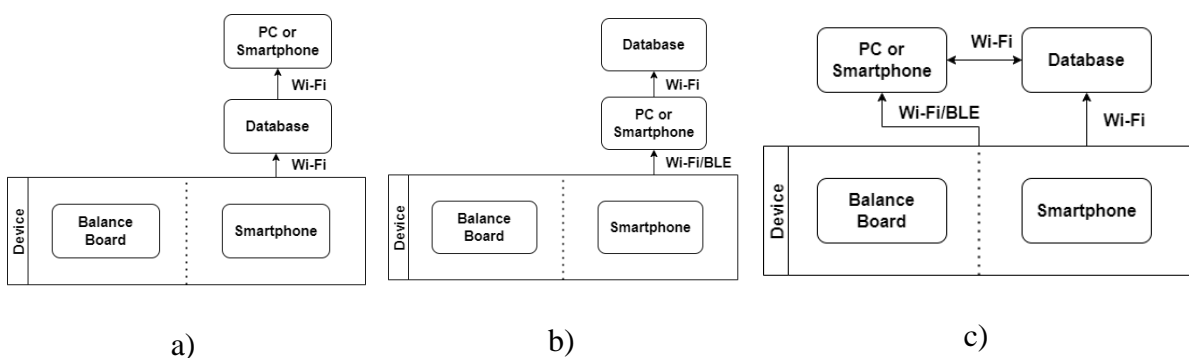


Figure 3.5 - Smartphone architecture.

The second architecture uses a sensor and micro-controller for measuring and processing the orientation. The board orientation data is sent to a database and to the application of the same three ways as in the previous case (Figure 3.6 -a, Figure 3.6-b and Figure 3.6-c)).

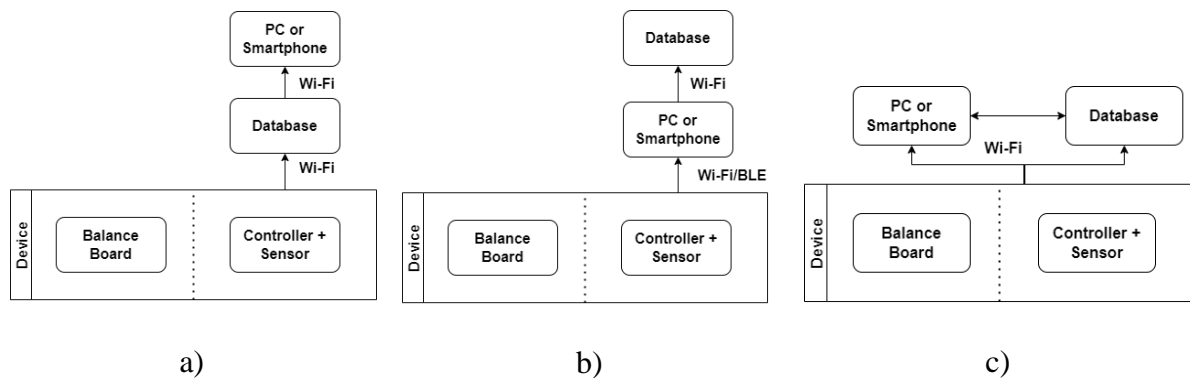


Figure 3.6 - Micro-controller architectures.

The problem with architectures solutions that send the data through the database is that the frequency of updating the data shown to the user would be lower when compared to sending it directly to the application. This would harm the use of the APP, since to have a timely reaction from the user, the time it takes to receive this information should be as short as possible.

To achieve a high frequency of data transmission to the application, it was chosen an architecture where the data is sent to the APP which the user will use to accomplish the exercise. The adopted architecture is presented in Figure 3.7. Its implementation involves fitting the balance board with a ESP32 microcontroller (WEMOS lolin32 Wi-Fi) and an IMU with 9 DOF. The controller reads the orientation, runs a web server and sends the collected data to the Firebase database.

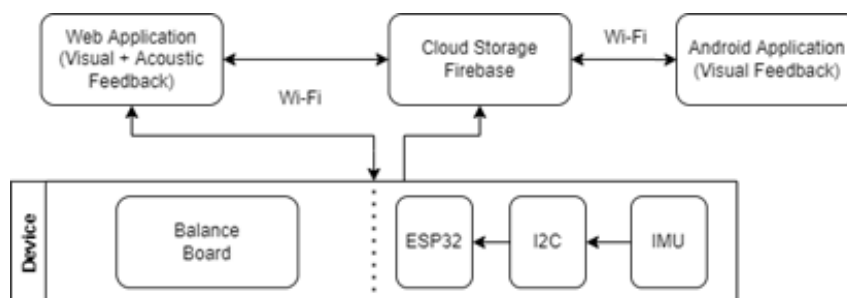


Figure 3.7 - Solution architecture diagram.

To implement this system, two applications were developed, one that retrieves the stored data that is in the cloud and shows it with a user-friendly interface and another (Web APP) for a faster understanding of the state of the balance board with customizable exercises.

Hardware assembly

The hardware solution involves only the use of two main components, the ESP32 controller and the IMU 9 DOF (Figure 3.8-a). These two components are assembled inside the balance board. The controller is powered through a portable power bank that connects to the ESP32 (Figure 3.8-b)) and the connection is done through just four lines two for power supply and two for the I2C bus (Figure 3.9).

The sensor used was the Adafruit's 9DOF breakout board based on the LSM303DLHC (accelerometer and magnetometer) and the L3GD20 (gyroscope). With this it is possible to capture nine distinct types of motion or orientation related data: 3 degrees each of acceleration, magnetic orientation and angular velocity [45].

The sensor is placed inside the balance board (in the geometric center of the balance board in a flat surface). The reference of the 3 DOF axis can be seen in the Figure 3.8-b). The available software library provides the necessary algorithms to obtain the absolute orientation expressed in Euler angles.

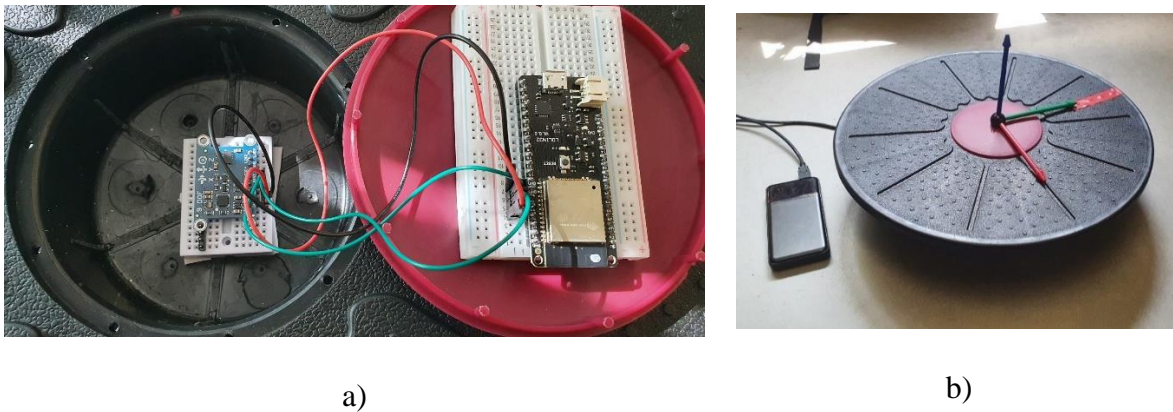


Figure 3.8 - Device assembly.

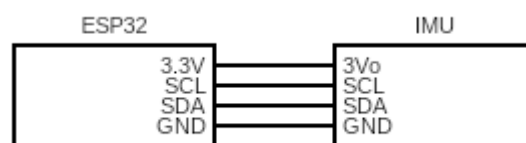


Figure 3.9 - Circuit wiring.

Sensor characterization

For the sensor characterization, the balance board maximum angle was measured with a protractor for reference (as can be seen in the Figure 3.10). The procedure compares the value measured by the sensor to the reference value. The maximum, minimum and zero angles around the X and Y axes were considered.



Figure 3.10 - Balance board maximum tilt measurement with protractor.

The maximum angle that the balance board makes is 16° . Because of its shape, the limit values around X and Y are $[-16^\circ, 16^\circ]$. Table 3.1 and Table 3.2 present the values obtained with sensor and with the measuring protractor instrument regarding the rotation around X and Y axis. With linear regression using Excel, the respective functions for X (Figure 3.11) and Y (Figure 3.12) represents the sensor characterization. With these equations, by considering the inverse function, Equation 3.1 and Equation 3.2 were obtained. These equations are then used in the developed program to obtain the balance board orientation based on the sensor readings.

Table 3.1 - Data for X sensor characterization.

| Angle | Measured by the protractor | Measured by the sensor |
|-------|----------------------------|------------------------|
| X | -16.0° | -15.0° |
| | 0.0° | 3.0° |
| | 16.0° | 20.6° |

Table 3.2 - Data for Y sensor characterization.

| Angle | Measured by the protractor | Measured by the sensor |
|-------|----------------------------|------------------------|
| Y | -16.0° | -20.4° |
| | 0.0° | -2.8° |
| | 16.0° | 15.0° |

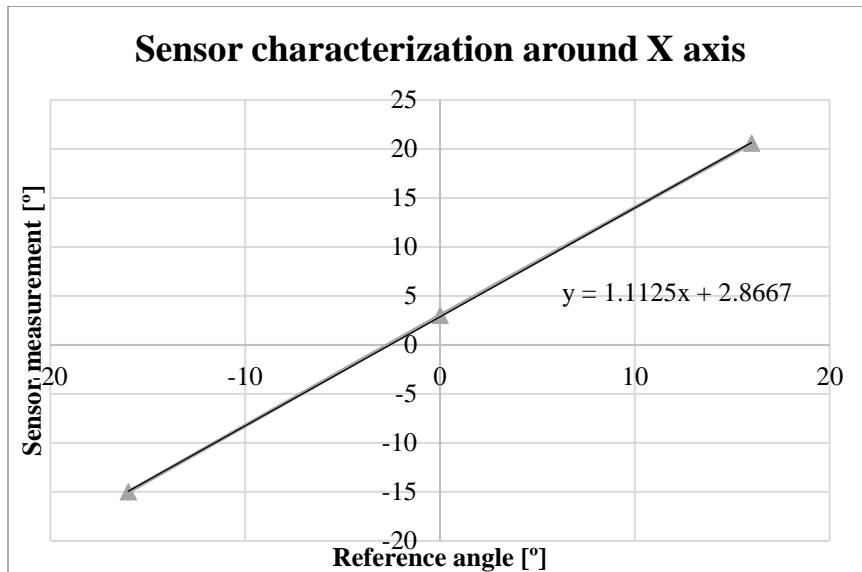


Figure 3.11 - Sensor characterization around X axis.

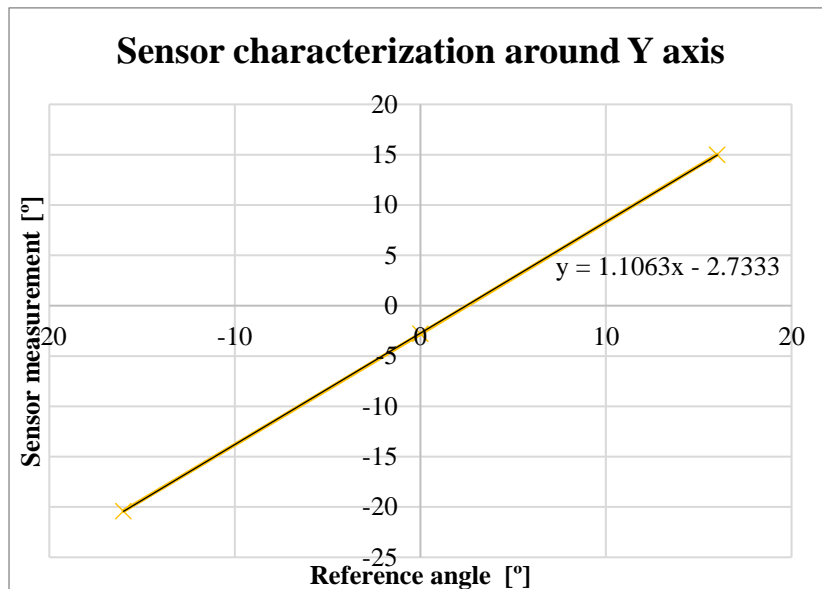


Figure 3.12 - Sensor characterization around Y axis.

$$X_{adjusted} = 0.8988 X_{sensor} - 2.58 \quad (3.1)$$

$$Y_{adjusted} = 0.9039 Y_{sensor} + 2.47 \quad (3.2)$$

Where:

- X_{sensor} , is the sensor orientation reading around X axis.
- Y_{sensor} , is the sensor orientation reading around Y axis.
- $X_{adjusted}$, is the adjusted orientation value around X axis.
- $Y_{adjusted}$, is the adjusted orientation value around Y axis.

3.5 Conclusion

This chapter presented the adopted hardware instrumentation for the balance board and the global system architecture. It is a Crivit balance board (Wobble board) that has 3 DOF, instrumented with an ESP32 controller and an IMU sensor. The communication is done wireless (Wi-Fi), with the board orientation data been sent to a cloud database (Google Firebase) and to two user interface applications. One is Web based and the other is for Android devices.

The Table 3.3 presents the main characteristics of the designed balance board system.

Table 3.3 - Developed balance boards characteristics.

| | A.V.F. (Acoustic and Visual Feedback) Balance Board |
|----------------------------|--|
| DOF | 3 |
| Instrumentation | IMU + ESP32 |
| Communication | Wi-Fi |
| Data Storage | Google Firebase Cloud Database |
| Software | Web APP through browser + Android APP |
| Acoustic Feedback | Yes |
| Data frequency update rate | 3 Hz for user interface with cloud storage 50 Hz for user interface without cloud storage |

4 Application development

To attend the chosen architecture, two applications were developed. The first one is the Web APP which the user access through a browser. It presents the real time orientation data and has features to assist the execution of the exercise in a user-friendly interface. The second one is an APP for smartphone where the user can retrieve the stored data from the cloud database and see it in a table format or as a chart.

As the chosen controller is ESP32 based, the acoustic feedback could use some Arduino functions to tune a sound to be played in a buzzer connected to it. However, to minimize the use of extra components, the acoustic feedback is implemented through the Web APP along with visual feedback.

4.1 Web APP

- Web server

To access the APP the user device must be connected in the same Wi-Fi network as the ESP32. The ESP32 Wi-Fi connection is set through the Arduino IDE compiler in the PC and the IP is obtained in the IDE serial monitor. Once the connection is set and the IP address saved, there is no need to connect the controller in the PC for the same Wi-Fi network. This procedure must be done for every new Wi-Fi connection.

To provide the user with a simple interface to visualize the data, the app uses a tabbed structure to organize the data and provide the required functions in each activity. So, it was implemented three tabs (Figure 4.1).

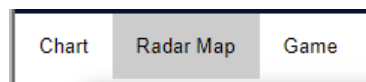


Figure 4.1 - Tabs interface.

The first tab is the “Chart”. It has a chart, input text, a numeric angle display and buttons for other functions (Figure 4.2).

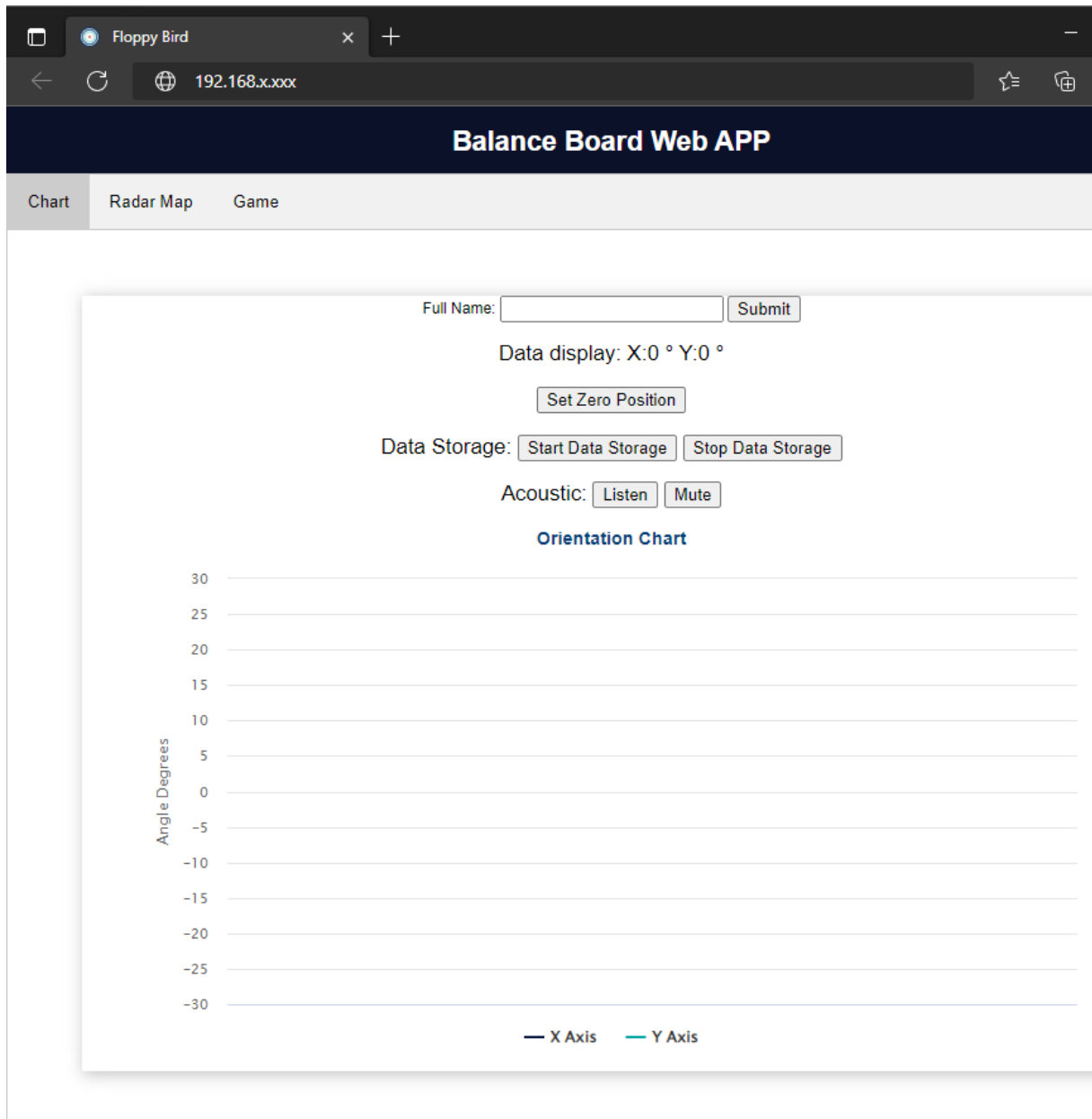


Figure 4.2 - Chart interface.

The second tab is the “Radar Map”. It has a radar map where can be seen the angle of the balance board through a moving target, the same buttons, the same input text and three range sliders to control the “target exercise” and the “area exercise” (Figure 4.3). These sliders allow to customize the exercises.

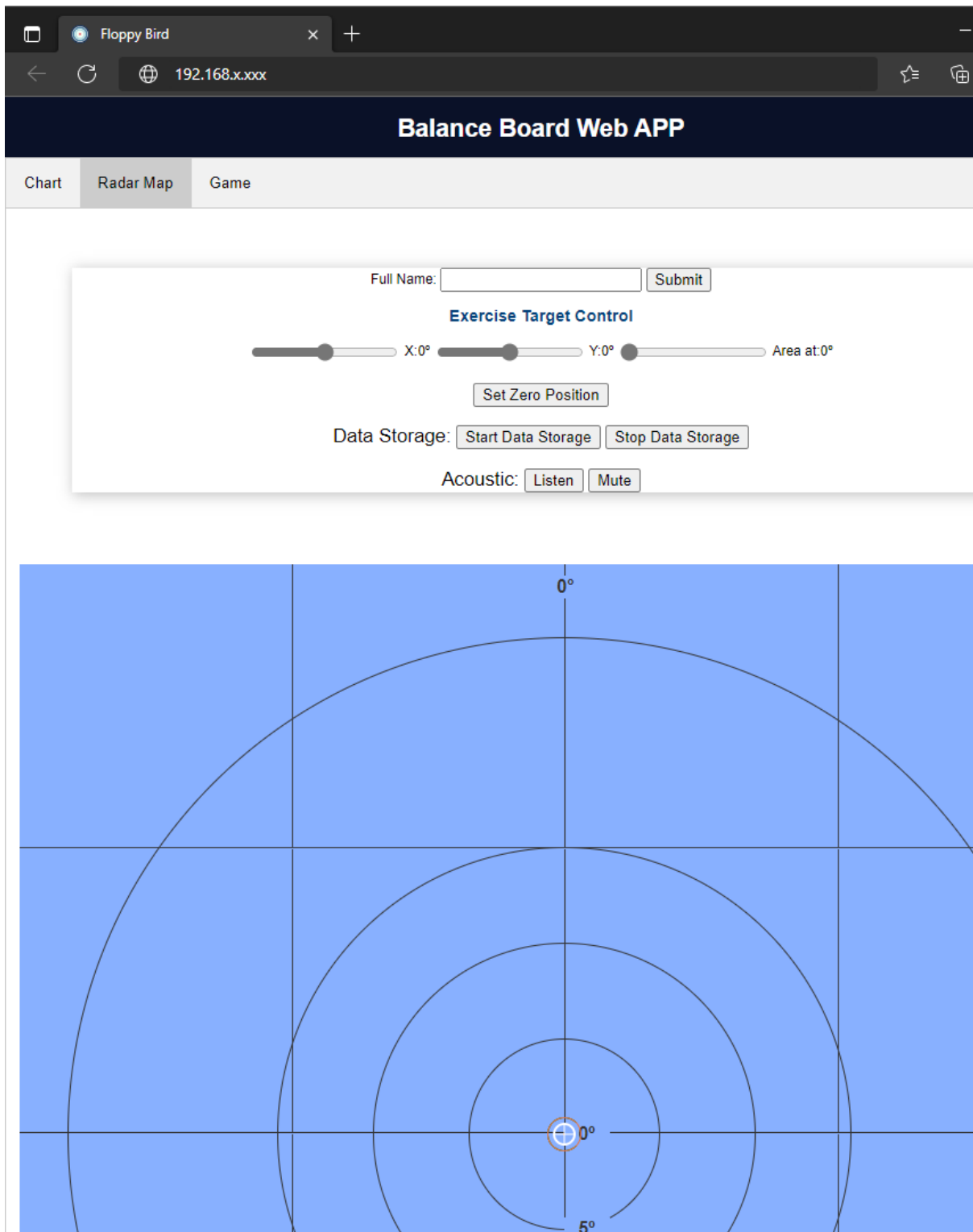


Figure 4.3 - Radar Map interface.

The third tab is the “Game”. It gives access to a particular developed game, provided with two range sliders for game configuration and a button to start the game when played in a smartphone browser (Figure 4.4). This interface provides an example of a gamified way of doing balance exercises.

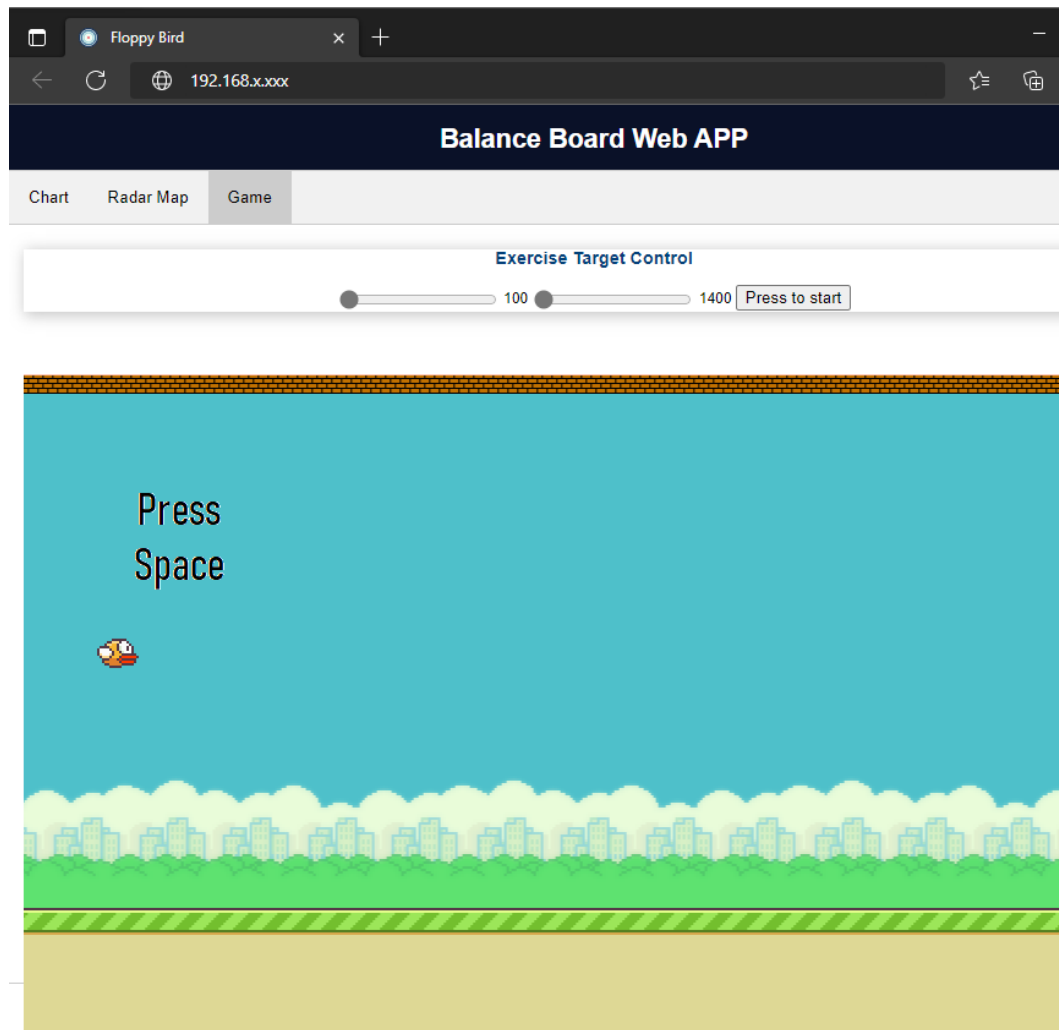


Figure 4.4 - Game interface.

The features implemented in these interfaces are:

- Input Text

To store the user’s name on the data base, the Chart and Radar Map interfaces provide a text box (Figure 4.5-a)) where the user writes his name and submit it. Then a pop-up window (Figure 4.5-b)) shows to let the user know that the name was correctly stored.

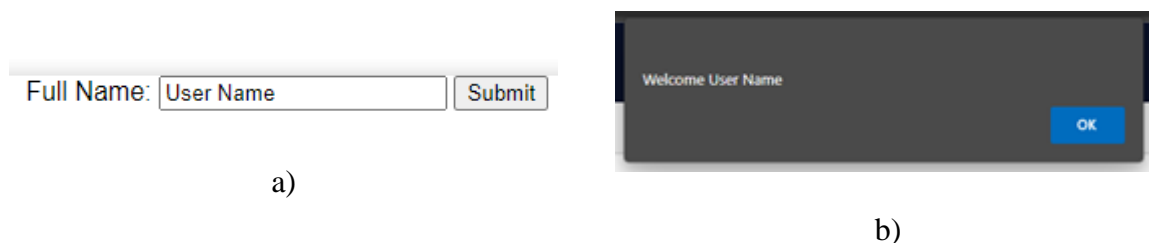


Figure 4.5 - Input text box interface.

- Data display

In order to have a simple way of reading the data (Figure 4.6), the X and Y angles are presented in plain text in the Chart interface, to have a quick understanding of the orientation of the balance board.

Data display: X:0 ° Y:0 °

Figure 4.6 - Orientation interface.

- Controllable functions

The Chart and Radar Map interfaces provides five buttons for multiple functions (Figure 4.7). The first one, “Set Zero Position”, is used to offset the read value and make it the new "zero" of the system. The second, “Start Data Storage”, and the third, “Stop Data Storage”, are used to control the data storage function, which allows the user to store the data in the database only when necessary. The fourth, “Listen”, and fifth, “Mute”, are used to control the acoustic function, which allows the user to mute or to listen.

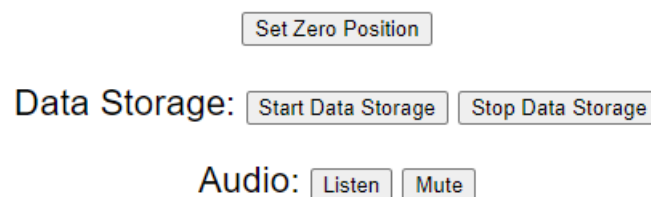


Figure 4.7 - Buttons interface.

- Chart

The Chart interface presents the data from the balance board, the orientation angles around X and Y axis in a format of a strip chart. In this way it is possible to visualize (Figure 4.8) the angles over the time.

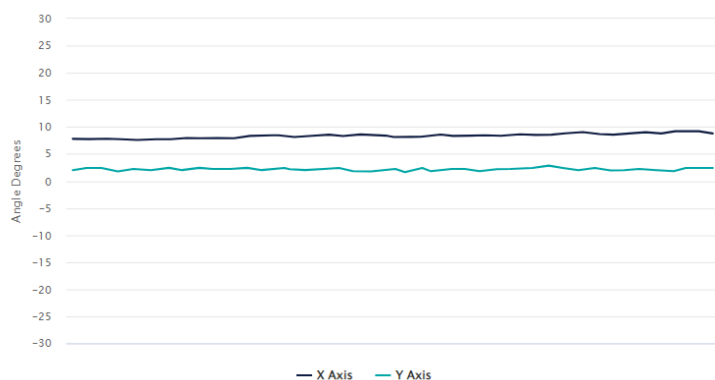


Figure 4.8 - Chart interface.

- Acoustic feedback

To allow users with reduced sight to use the application, an acoustic guidance system is provided in the Chart and Radar Map interfaces. This component allows the JavaScript code to import a track and implement the defined behavior. The *Listen* button starts it and can be muted by clicking on the *Mute* button. The sound that is played to has its frequency altered according to the angle that the balance board is at, becoming low pitch (lower frequency until 0Hz-no sound) with angles tending to zero and higher pitch (higher frequency) as the angles increase.

For this purpose, it was defining a rate parameter by the Equation 4.1 that controls the sound frequency. The 0.2 constant was found empirically to not let the sound be so high pitch but keep a good sensibility to the orientation changes and improve the user experience.

$$Rate = 0.2 \sqrt{(X - X_{target})^2 + (Y - Y_{target})^2} \quad (4.1)$$

Where:

- X, is the measured angle around $X \in [-16^\circ, 16^\circ]$.
- Y, is the measured angle at around $Y \in [-16^\circ, 16^\circ]$.
- X target, is the angle where the exercise target is at $X \in [-16^\circ, 16^\circ]$.
- Y target, is the angle where the exercise target is at $Y \in [-16^\circ, 16^\circ]$.

A function receives the JSON from the ESP32 and manages it for use in the audio, graph and target movement functions seen previously.

- Radar Map

The Radar Map interface presents the balance board orientation angles on a form of a radar map. To illustrate the potential use of the instrumented balance board two simple exercises were implemented. To define the target and/or an area, the user has available a slider (Figure 4.9) that has a range from -16° to 16° .



Figure 4.9 - Exercise target control interface.

In this way the user can position the target and/or the area in any desired place within the limit of the balance board and thus perform personalized exercises according to their needs. The first exercise involves the definition of a target (Green) orientation for the user to reach and keep the tracking target (White) inside the exercise target (Figure 4.10). The second is a circular area (Orange) where the user should try to make the tracking target move in it when standing on the balance board.

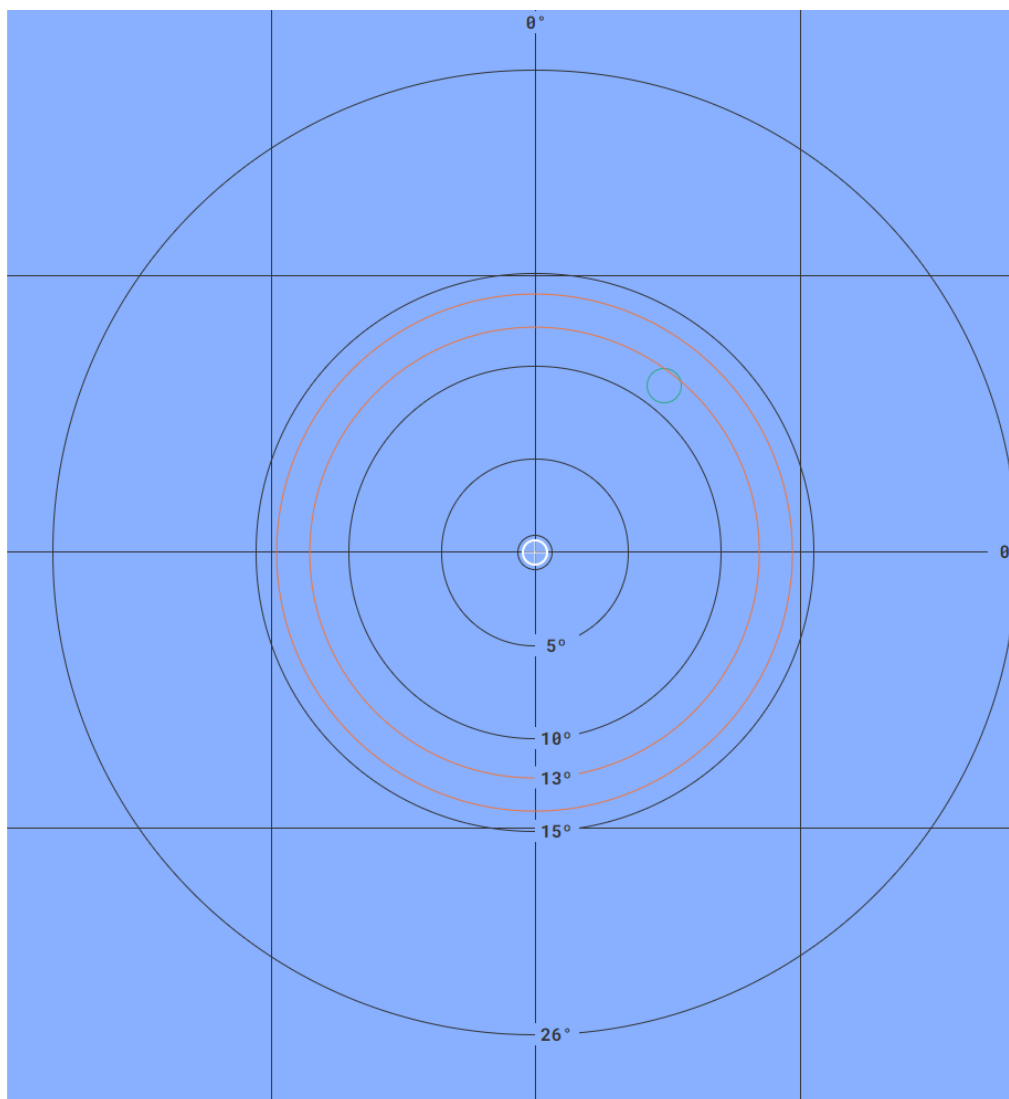


Figure 4.10 - Exercise interface showing target at (7° , 9°), and Area of exercise around 13° .

The target was defined in the CSS file, as well as the target that indicates the angle of the balance board. To change the position parameter, in the JavaScript code a function receives the value of the slider each time it is run and changes the top and left parameters of the exercise target, besides changing the value that is shown next to the slider, so the user knows which angle is selected.

To assist users with reduced sight, the acoustic feedback was developed and implemented as a way of knowing the distance between the orientation target and the exercise target, therefore modify the sound rate with that parameter and give the user a way to know how far from the objective it is. Note that it is not possible to present the direction the user must go since the movement is made in two directions and there is only one sound source.

- Game

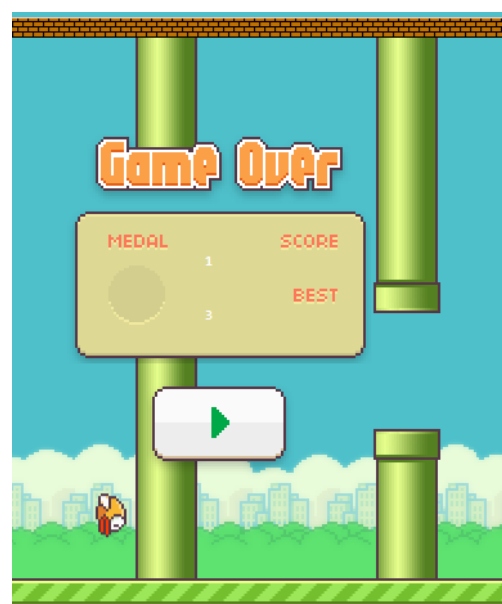
To make a more attractive way of doing balance exercises, it was implemented an example of a game based on the already known Flappy Bird (Figure 4.11-a)). The difference is that instead controlling the bird movement with touches in the screen, the bird position along the height is based on the orientation of the balance board in the Y axis. The user can start the game by pressing the “Press to start” button on the space bar in the keyboard when played in PCs.

When the bird hits the pipe, a game over screen shows the score in that last run and the high score ((Figure 4.11-b)). The high score is stored by using browser cookies and is linked to the device (PC or Smartphone) browser used to play.

One important featured implemented is that the distance between the pipes and their gap height is selectable through two input sliders. The distance between pipes is set by the time in milliseconds which a new pipe column is generated and the slider value has a minimum of 1400 ms and a maximum of 3000 ms. The gap height between two pipes has a minimum of 100 pixels and a maximum of 250 pixels. The Figure 4.11-c) shows the case where the gap height is set to 100 pixels and a new pipe is generated every 1400 ms. The Figure 4.11-d) shows the case where the gap height is set to 250 pixels and the time to 3000 ms.



a)



b)

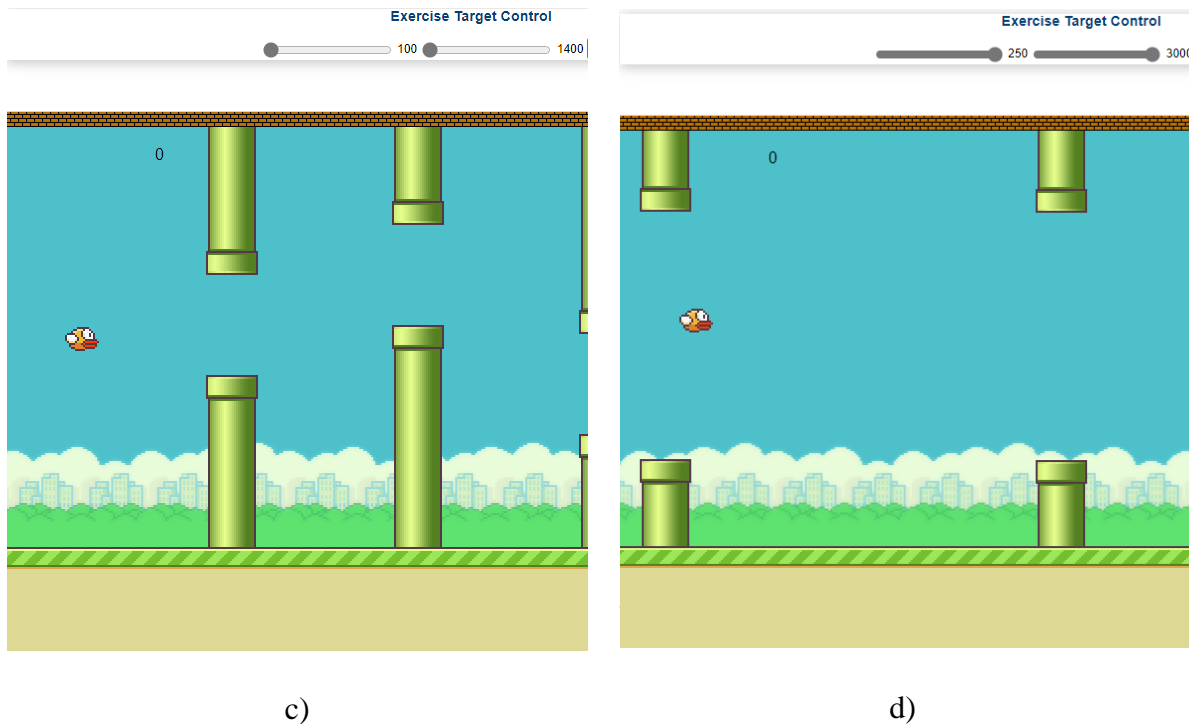


Figure 4.11 - Game exercise.

- ESP32 background code

In parallel with the Web Server creation, the ESP32 code was developed. This section presents the programming of the microcontroller and how it is connected to the application developed for the Web. The programming was done in C++ language with libraries available to support the development of components such as communication between the controller and the sensor, the Web Server, the Wi-Fi connection and connection with Google Firebase.

To create the Web Server in the ESP32, ESPAsyncWebServer and Serial Peripheral Interface Flash File System (SPIFFS) libraries were used.

Since the controller is not an Arduino, a driver had to be installed to enable the Arduino IDE software to communicate with the controller and its programming.

The program is structured into several steps:

First, with the data (Network name and password) from the Wi-Fi Internet network entered, the controller establishes an Internet connection and shows the user the IP of the Web Server.

After that the files that make up the Web Server (HTML, CSS and Javascript) are compiled with the SPIFFS. SPIFFS is a filesystem created for microcontrollers with a flash chip, which is connected by Serial Peripheral Interface (SPI) bus, like the ESP32 flash memory [46].

Then, the sensor is initiated and the connection to the database is established, which requires the address provided by Firebase. With all the initializations done, the server can be started in the program setup which initialize the Web server, an interaction is made between events that occur in the application and the script that is running in the controller. One interaction is implemented when the user clicks on the start button to start recording data to Firebase.

This set the “Record” variable with the value TRUE. Click on the stop recording button resets the same variable. This is used to control sending of this data to the database. As the server is online, the data obtained from the sensor can be sent via JavaScript Object Notational (JSON) file.

The sensor data is obtained, being read the orientation around X and Y axis along time. The data relative to Z axis is not used. The values obtained are adjusted using the equations (Equation 3.1 and Equation 3.2).

With the new values, another offset adjustment was created that can be used when the user wants a new zero position, defined from the Web APP. For this, the Equation 4.2 and Equation 4.3 are used.

$$X = X_{adjusted} - X_{zero} \quad (4.2)$$

$$Y = Y_{adjusted} - Y_{zero} \quad (4.3)$$

Where:

- X_{zero} , is the orientation value around X axis when the button is pressed;
- Y_{zero} , is the orientation value around Y axis when the button is pressed;
- X , is the new orientation value around X axis;
- Y , is the new orientation value around Y axis.

In addition, to reduce the noise of the sensor, it was decided to average the values. That means, it is stored/send the average of five consecutives sensors readings.

The EPS32 is programed to read the sensor data at a given frequency and send the data to the database and/or to the Web App. Taking into consideration the limitations imposed by the communication through Wi-Fi and the time to store the data in the cloud, it is only possible to achieve a frequency of 3Hz when the database is receiving it and 50Hz when it is only sending data to the Web APP.

- Sending data to database

To organize the data and simplify the access and collection of these data for post-processing, a directory contains all the data sent (**Orient_readings**), which stores the data according to the structure presented in Figure 4.12-a). For each current **Data and time**, it is recorded the values of **Xorientdeg** and **Yorientdeg** in each **Sample** time. The variable **Sample** is the time in milliseconds that the program is running; **Xorientdeg** and **Yorientdeg**, are the values of the angles in X and Y axis obtained by the sensor, corrected, but without rounding. Storing the name of the user and the time and data when the record started is a way of knowing who the user was and when the exercise was made.

The stored data can be downloaded directly from the Firebase database in a JSON file form and converted to Comma-Separated Values (CSV) format for future analysis. Since for the user having many decimal digits would not be important, but for a professional treating this data it may be, the data is stored with 5 decimals cases. The data structure in the Firebase database is shown in Figure 4.12-b).

| Name | | |
|---------------|------------|------------|
| Data and time | Xorientdeg | Yorientdeg |
| Sample_1 | X° | Y° |
| Sample_2 | X° | Y° |
| ... | ... | ... |
| Sample_n | X° | Y° |

a)



b)

Figure 4.12 - Database data structure.

4.2 Android APP

The android application allows to access the data stored in the database and for this the application must be able to access the database and assign the keys stored in the program variables. The APP has two tabs, one that shows the data from the exercise performed at the date/time stored in a list and another tab that shows this data in a chart format. In addition, the user can download the data.

- Getting data from firebase

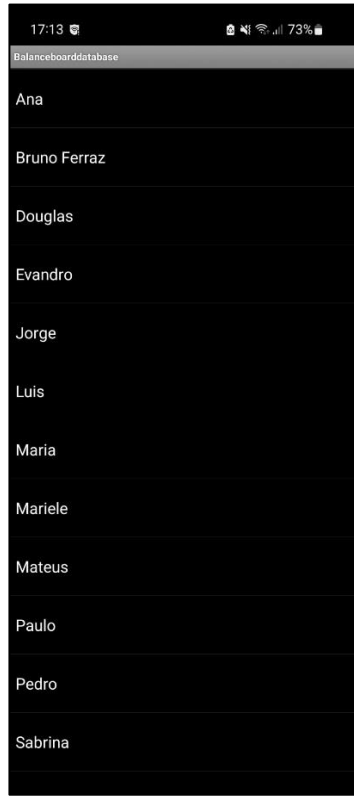
The application takes the `Orient_readings` directory, i.e., takes all the values that are inside it, including all the new ones that are added in real time. And in another function, it splits the subkeys into individual variables to assign to the functions needed for post-processing.

- Data display list

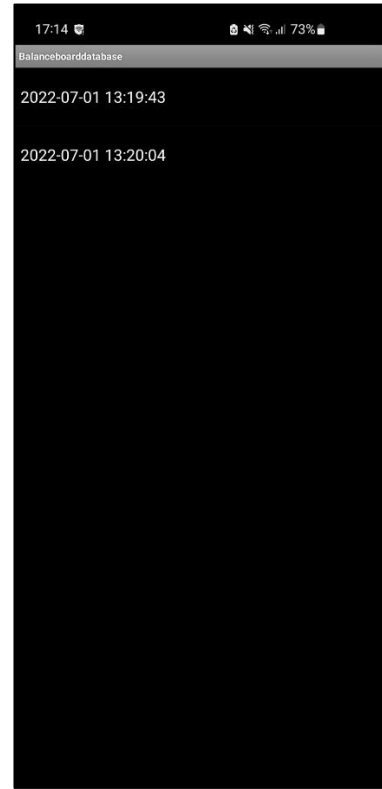
The Data display list interface (Figure 4.13-a)) provides five buttons. Two for navigation between the tabs (**List** button and **Chart** button). One small button in the top right corner to download the selected data. Pressing the **User's name list** provides a list of names of users in the database and lead to the screen in Figure 4.13-b). The **Exercise Data selection** button leads to the screen in Figure 4.13-c). In this screen the user can select the exercise date and time which wants to list its data. The selection leads to the screen shows in Figure 4.13-d), a list of the stored orientation. This data can be saved in the device by pressing the small button that leads to the screen in Figure 4.13-e).



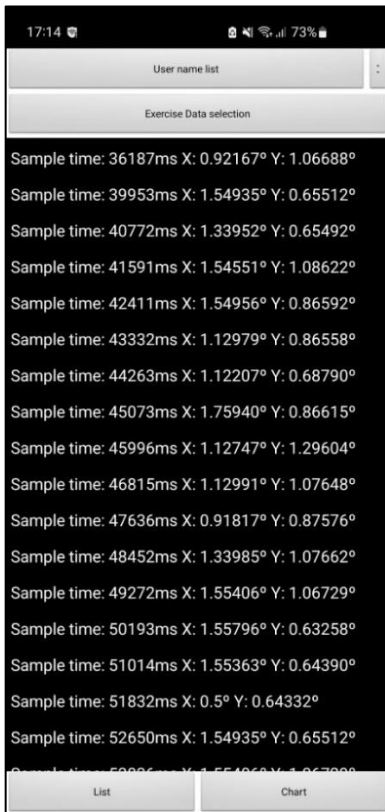
a)



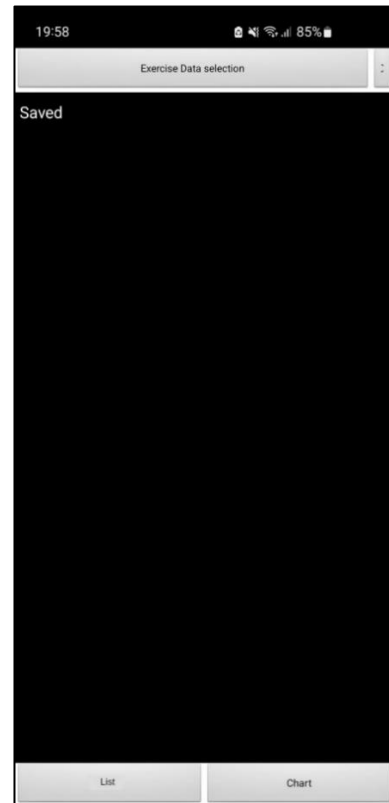
b)



c)



d)



e)

Figure 4.13 - Data display List interface.

- Data display chart

The Data display chart interface (Figure 4.14-a)) provides the same buttons as before to select the user and data exercise. After selecting the user's name and data and time of the exercise, the screen Figure 4.14-b) shows this data in a line chart form. The chart shows the X and Y orientation over time (in milliseconds).



Figure 4.14 - Data display Chart interface.

4.3 Conclusion

This section presents the user interface application developed for the chosen architecture. According to the architecture, two APPs were made, the first one Web based for an ESP32 controller with an IMU sensor and the second for Android devices.

The Web APP features:

- Visual and acoustic feedback;
- Three tabs for different functions;
 - A Chart format interface to display the orientation around X and Y axis along the time;
 - A Radar Map interface to display the current orientation around X and Y axis in a moving target and customizable exercises;
 - A Game interface to provide a customizable and attractive way of doing balance exercises.
- Allow orientation, user's name, data, and time storage in the Firebase database;
- Orientation refresh rate using Web APP of 50Hz;
- Orientation refresh rate for storing data of 3Hz.

The Android APP, by selecting the user's name, data, and time of the stored exercise, displays in a list or chart format the orientation around X and Y axis along the time sampled. Furthermore, this displayed orientation can be downloaded to the device.

5 Evaluation of the developed instrumented balance board

To test the applicability and usability of the developed instrumented balance board and software application, it was set up a study involving ten healthy users with ages between 18 and 60 years that were invited to stand up on the board for 30 seconds. When the user is with the eyes closed, and no acoustic feedback is provided, there is no external reference to help standing on the balance board near an arbitrary angle. So, a particular exercise was set up to be able to do a comparison between when eyes are open or closed with or without the feedback. The exercise consists of keeping the balance board in a horizontal plane (X:0° and Y:0°). This should be repeat with four different conditions, including the use or not of the acoustic feedback and the Radar Map visual feedback provided by the APP.

The exercises sequence was:

- Eyes closed without acoustic feedback;
- Eyes closed with acoustic feedback;
- Eyes open without visual feedback;
- Eyes open with visual feedback.

The user is instructed to stand up on top of the balance board keeping the board in a horizontal plane. The performance of each user is evaluated by calculating the angular displacement of the board according to Equation 5.1. The average angular displacement during the test is then evaluated.

$$AP = \sqrt{X^2 + Y^2} \quad (5.1)$$

The Angular Parameter (AP) is based on the angular orientation of the board along X and Y axis.

After the exercise it was made an individual inquire to qualitatively evaluate the user perspective about the user interface assistance in doing the exercise.

To gather the data, it was implemented a Serial Print function to show the orientation values in the serial monitor of Arduino IDE and process this data in an Excel table.

5.1 Test results

Quantitative data

The results when the users did the exercise with the eyes open with and without the visual feedback (Table 5.1) was analyzed. Despite the percentage comparison seems to deliver a noticeable reduction in the AP ($-30.8 \pm 14.7\%$), in terms of absolute reduction ($-0.6 \pm 0.5^\circ$) is lower than 1 degree, almost achieving 0° reduction. This result shows that in an exercise that the user should try to keep its orientation near the horizontal plane, the visual feedback does not give considerable assistance.

Table 5.1 - Interface test results with the eyes open.

| User | Eyes open no feedback [°] | Eyes open with visual feedback [°] | Absolute difference eyes open [°] | Percentual comparison eyes open |
|---------------------------|---------------------------|------------------------------------|-----------------------------------|---------------------------------|
| User_1 | 2.9 | 2.0 | -0.8 | -28.3% |
| User_2 | 2.5 | 2.0 | -0.5 | -18.2% |
| User_3 | 1.2 | 1.1 | -0.0 | -3.4% |
| User_4 | 2.4 | 2.0 | -0.4 | -17.2% |
| User_5 | 1.3 | 1.0 | -0.3 | -23.9% |
| User_6 | 0.8 | 0.6 | -0.2 | -30.2% |
| User_7 | 4.0 | 1.3 | -2.7 | -66.6% |
| User_8 | 0.4 | 0.9 | -0.5 | -59.6% |
| User_9 | 0.7 | 0.9 | -0.2 | -20.6% |
| User_10 | 1.1 | 0.7 | -0.4 | -39.5% |
| Average | 1.7 | 1.3 | -0.6 | -30.8% |
| Standard Deviation | 1.0 | 0.5 | 0.5 | 14.7% |

The results when the user made the exercise with the eyes closed with and without the acoustic feedback (Table 5.2) was analyzed. It shows a considerable reduction in the AP value in absolute ($-2.6 \pm 1.4^\circ$) and percentual ($-38.3 \pm 17.3\%$) terms for this type of exercise.

Table 5.2 - Interface test results with the eyes closed.

| User | Eyes closed no feedback [°] | Eyes closed with acoustic feedback [°] | Absolute difference eyes closed [°] | Percentual comparison eyes closed |
|---------------------------|-----------------------------|--|-------------------------------------|-----------------------------------|
| User_1 | 5.1 | 4.2 | -0.9 | -17.8% |
| User_2 | 5.7 | 4.2 | -1.6 | -27.1% |
| User_3 | 8.0 | 3.8 | -4.2 | -52.5% |
| User_4 | 8.2 | 6.0 | -2.2 | -27.2% |
| User_5 | 6.8 | 1.6 | -5.2 | -76.7% |
| User_6 | 13.9 | 9.3 | -4.5 | -32.7% |
| User_7 | 7.6 | 6.3 | -1.3 | -16.9% |
| User_8 | 1.6 | 1.2 | -0.3 | -21.7% |
| User_9 | 5.0 | 2.8 | -2.2 | -43.5% |
| User_10 | 4.9 | 1.6 | -3.3 | -66.8% |
| Average | 6.7 | 4.1 | -2.6 | -38.3% |
| Standard Deviation | 2.2 | 1.9 | 1.4 | 17.3% |

In the Figure 5.1 and Figure 5.2 is possible to see that the acoustic feedback gives a better balance assistance for the type of exercise than the visual one.

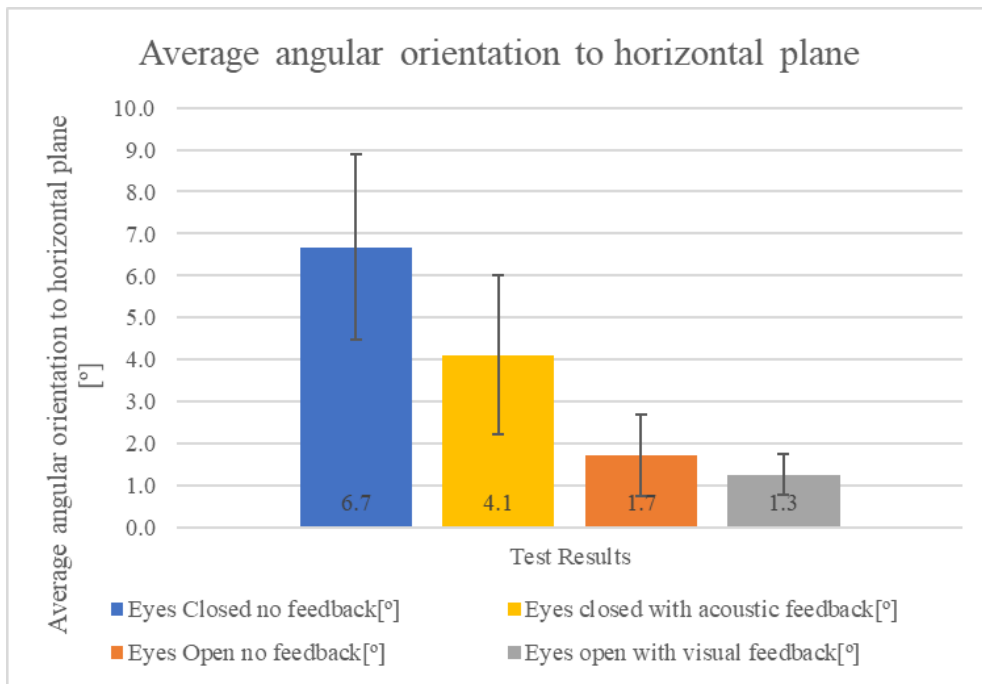


Figure 5.1 - Average distance to the center for exercise.

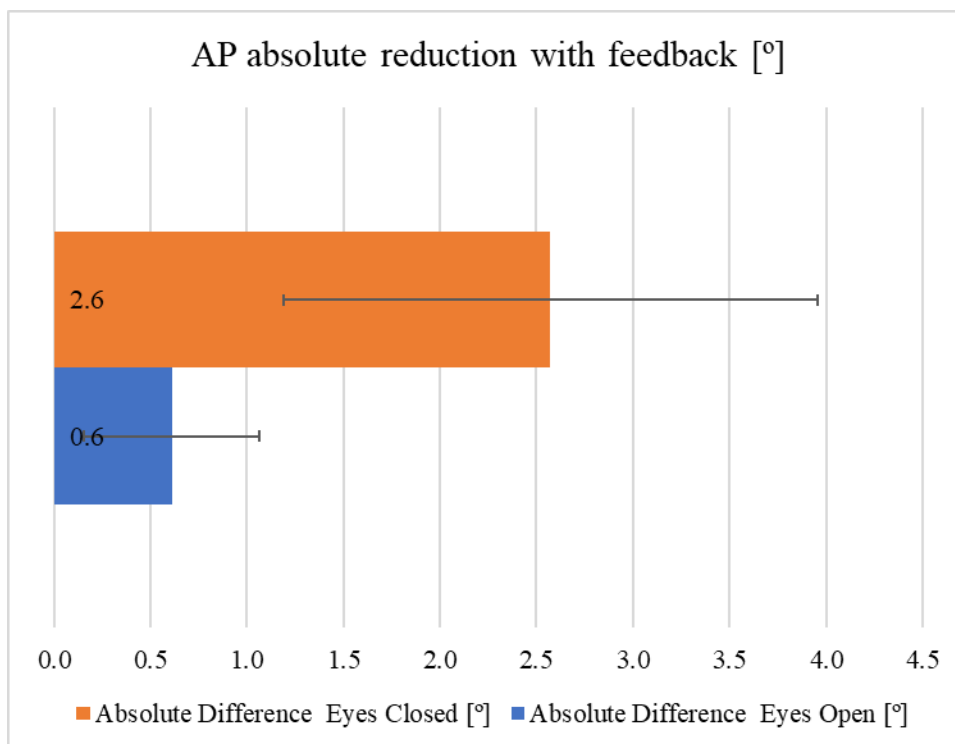


Figure 5.2 - Center absolute distance reduction with feedback [°].

Qualitative data

Four questions (with Yes or No answers) were asked to each user who evaluated the interface, which are:

- Did you have difficulty doing the exercise with your eyes closed?
- Did you have difficulty doing the exercise with your eyes open?
- Do you think that the visual exercise interface assisted in the execution?
- Do you think that the acoustic feedback assisted in the execution with the eyes closed?

The results shown in Figure 5.3 unanimously showed that doing the exercise with the eyes closed without acoustic feedback is difficult (Figure 5.3-a)) and with the eyes open it is not (Figure 5.3-b)). This shows the influence of vision on the sense of balance. And in the results shown in Figure 5.4, 90% agree that acoustic feedback solutions assist in doing the proposed exercise (Figure 5.4-a)), but for the visual feedback only 70% (Figure 5.4-b)). This result corroborates with the quantitative analysis of the exercise since the visual feedback assistance did not reduce the AP considerably.

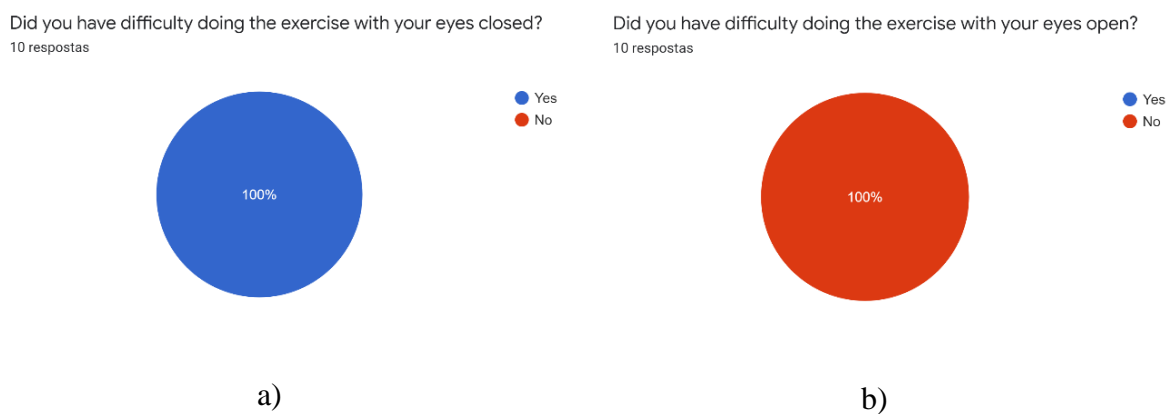


Figure 5.3 - Inquire results about exercise execution without user interface visual feedback.



Figure 5.4 - Inquire results about exercise execution with user interface visual feedback.

5.2 Conclusion

This chapter presented an evaluation of developed instrumented balance board and its results. The evaluation allowed to quantify and qualify the assistance that the interface developed gives to the user in the proposed exercise.

The Radar Map visual feedback did not perform well in this type of exercise since the average reduction obtained is lower than 1 degree. This is an angular displacement that sometimes can be unnoticeable for the user. That reflects the qualitative analyzes in which some users did not feel assisted by the visual feedback interface.

On the other side, the acoustic feedback performed well in this exercise since the average reduction obtained is greater than 1 degree. This assistance is showed in the qualitative analyze, in which 90% of the tested users, who felt difficulty in doing the exercise with the eyes closed, said that the acoustic feedback assisted doing the same exercise with the eyes closed.

Therefore, it is possible to state that for an exercise of keeping the board orientation in the horizontal plane, the acoustic feedback is a solution for assisting users to keep the balance and the board orientation.

6 Conclusions and future works

Conclusions

The developed work fulfilled all the objectives proposed for this work. The dissertation presents available technologies to measure and monitor the orientations of the available balance board. A particular architecture for instrumenting the balance board with wireless data communication and a user interface application were implemented and developed. The application was evaluated to know if the solution assists the user in doing balance exercises.

To do balance exercises there are already some instrumented balance boards, but they don't provide the option of acoustic feedback. This allowed the creation and analysis of a device that is not currently available in the market.

The use of an IMU sensor and the ESP32 microcontroller, which are commercially available devices, for measuring and monitoring the balance board orientation allowed for a compact and simple solution. Furthermore, the device's libraries allow direct retrieval of the orientation values, which simplified the creation of code for reading and processing the collected data. The data is sent via wireless communication (Wi-Fi).

The user interface is implemented using two applications. A Web APP that has interfaces to show real-time orientation in the form of numerical, graphical, and acoustic data. The numerical information is given through a data display, while the graphical information can be in chart format, in which the orientation around the X and Y axis is shown over time, or in the Radar Map, which informs the orientation by positioning the target on a radar map with levels. The acoustic feedback is given through a sound that has its frequency changed according to the orientation the balance board is in.

In addition to this, three exercise options to illustrate the applicability of the developed system have been devised and they are: two of them are integrated into the Radar Map interface, which allows the user to position a target and/or an area to try to stay in. The third option is a game exercise with customized levels of difficulty, where the balance board acts as a joystick to play the game. The Web APP also provides the possibility to store the data on a cloud database, where the user's name and data/time is recorded for further analysis. To use the application the user must access the server's IP via a Web browser. This allows to use the APP from any device (smartphone, tablet, or PC) connected to the same wireless network.

The second user interface application developed runs on Android devices. It provides a way to access the data stored in the cloud database. It is possible to see the user, date and time and view the orientation data in a chart or list format. Furthermore, the displayed data can be download to the device in a standard format (CSV).

With the development concluded, a prototype of the instrumented balance board was tested by ten healthy individuals between the ages of 18 and 60 to evaluate the usability of the interface and the effect on the performance of the proposed exercise. With the analysis made it was possible to conclude that visual feedback by the Radar Map is not so effective for the type of exercise proposed, but the acoustic feedback proved to be a good solution for orientation when the user performed the exercise with the eyes closed. Thus, it can be said that the developed user interface can help in the performance of balance exercises, with potential application in sports and rehabilitation areas.

Future works

The developed work allowed a prove of concept which can be complemented and improved with future works.

Regarding the developed architecture:

- Develop an architecture where the data storage is done by the user's device instead of the ESP controller;
- Explore the use of a smartphone as an alternative to the IMU and ESP controller.

Regarding the interfaces developed:

- Develop a way to change the Wi-Fi credentials without reprogramming the controller;
- Developing new games using the balance board as a joystick to turn more attractive the practice of balance exercises.

In relation to the interface evaluation:

- Conduct more tests to evaluate the influence of the experience obtained in performing the proposed exercise and verify if the use of visual and acoustic feedback still helps significantly;
- Test the acoustic feedback with people with vision problems and balance problems.

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Appendix A: Concept design flowchart

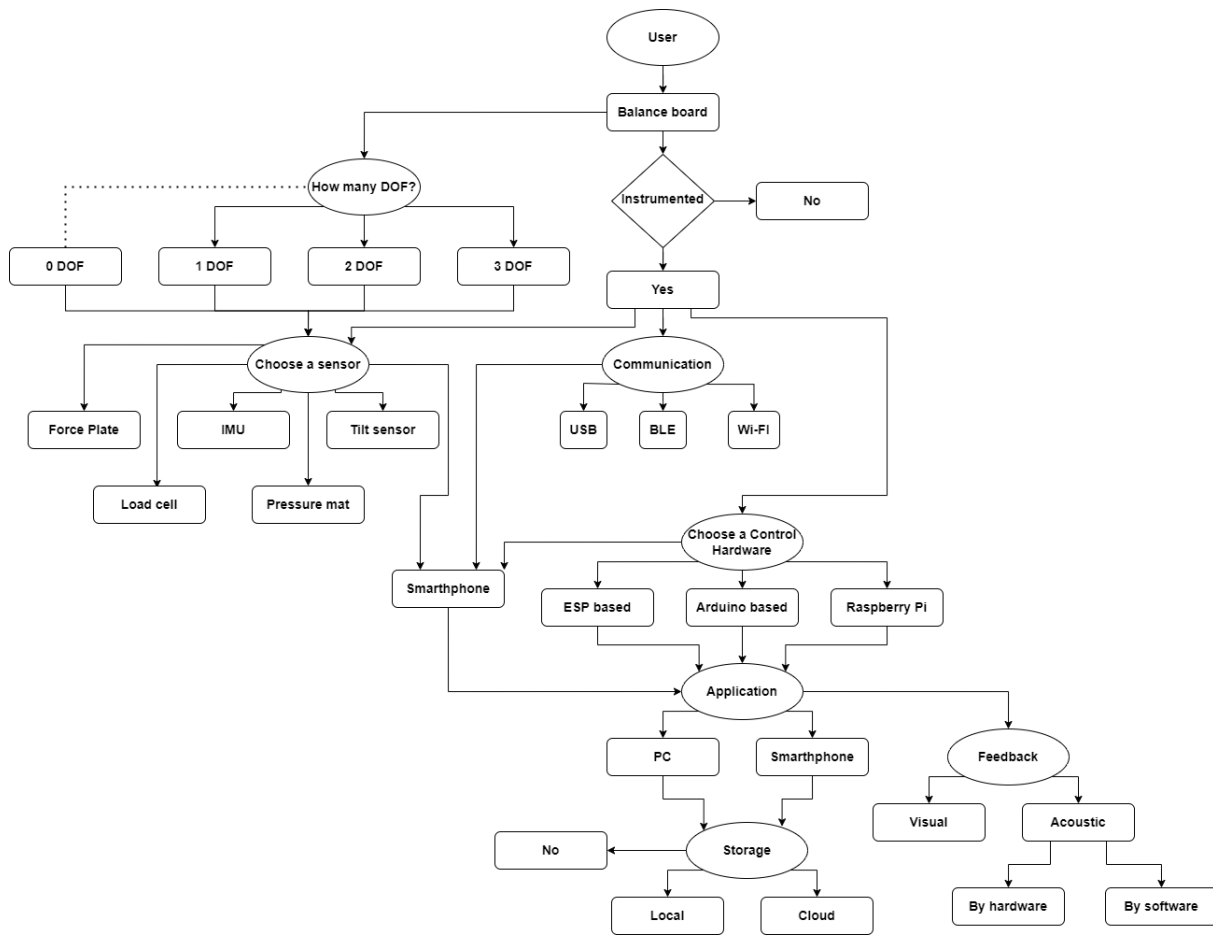


Figure A.1 - Concept design flowchart.