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Open Source Affordable Balance Testing based on a Nintendo Wii Balance Board

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***Abstract*— This paper presents an affordable balance testing board based on an algorithm called "the turning point for maintaining balance" for a desktop application that uses a Nintendo Wii balance board to gather accurate measures for further calculations. Two experts tested the accuracy of the application comparatively with a validated and expensive balance testing instrument. Accordingly, the solution gives precise measurements on a person's balance in the form of curve length, area, Center of Pressure (COP), and turning point (TP). This paper shows the development of an open-source application and the corresponding research motivating affordable, functional screening possibilities.**

Keywords—balance testing; Wii balance board; open-source software; center of pressure (COP); force platform

I. INTRODUCTION

Several problems and diseases are influencing our sense of balance. To determine the "postural sway," the horizontal movement around the center of gravity is essential for walking or breathing functions and helps specialists treat patients with eventual balance problems. Careful measurements of balance play an essential role [1] in diagnosing physical diseases (e.g., stroke [2], vision problems[3], hearing [4], rehabilitation [5]). Several new software and hardware solutions have been developed for balance measurement, especially with the recent advancement in computing, e.g., virtual reality games, Kinect-based devices, sensor network-based devices, and even tests based on Wii balance board (WBB) [6, 7].

A way to measure balance is by running tests where the patient stands on a pressure plate that measures the center of pressure (COP) [8]. The COP is the single point location of the ground reaction vector on the force platform [9]. Tests are typically 10-60 seconds long, and the result is a COP-graph, which can be compared to a random walk graph. This data makes it possible to derive parameters such as the curve length, and the distance traveled on the x- and y-axis, and the area of a 95% confidence ellipse. All these parameters are informative about a patient's balance, but the problem is that they all require interpretation that typically needs to be done by specialists.

Aasen et al. [10] introduced an algorithm that uses the COP data to calculate the turning point (TP) for maintaining balance for an objective evaluation. TP is an estimate of the critical time to react and regulate back to maintain balance when the body is unbalanced, in an unstable equilibrium. This is done by utilizing concrete measurements and without the need for subjective assessments by experts.

This paper aims to build an affordable and trustable open-source solution for balance testing utilizing WBB and Aasen's algorithm "The Turning Point for Maintaining Balance" [10]. Such solutions can be the most valuable if they are open-source since technologies improve rapidly, and further development through several additional functions and scaling up would be possible.

In clinical settings, force platform posturography is a commonly used method for balance measuring [11]. Such devices consist of a moveable force plate at the bottom, which moves in sway manners. The estimated cost of measuring balance devices is between $6500 to $100,000 [12]. In many cases, affordable devices would be appreciated for broader balance testing [13, 14]. Measuring balance would be essential to run self-defined tests for various investigations, for sports, for the elderly, or together with investigating the children's functional or cognitive abilities.

Wii balance board is a low-cost and portable device that could help measure COP [15]. Figure 1 shows WBB and an expensive force platform for balance measurement, currently used at the local hospital.

This paper aims to present an open-source program that can gather data from a Wii balance board (WBB), compute calculations on the data, and display the results in an understandable way about a person's postural stability. The solution is intended to be affordable, accessible, usable, and understandable even for non-experts.

Understanding the results by non-experts is critical since several other problems not directly related to vestibular problems may also influence balance. Several teams that investigate, e.g., broader functional difficulties in individuals would gain by having affordable tools that measure balance. Therefore, developing an application that can be used for further investigation of balance when other functional or cognitive impairments are measured would be beneficial. An example is investigating school-aged children's functional ability when special educators investigate vision problems [16].

Fig 1. Wii Balance Board (WBB) on the left and force platform on the right at the Norwegian National Advisory Unit on Vestibular Disorders, Haukeland University Hospital, Bergen, Norway.

While user tests were not possible during the development and Covid19, two experts in research about postures and balance were involved in all iterations during the development and tested the final product in comparison with an expensive instrument at the local hospital.

II. METHODOLOGY

A test for balance measure is a continuous measuring of COP data in a time interval, typically for 10-60 seconds. A test will result in a COP-graph (Image B from Figure 2) which can be compared to a random walk graph. These measurements show curve length, x- and y-curve length, area, and a turning point (TP) for maintaining balance. The Nintendo Wii balance board's (Image A from Figure 2) hardware was used to measure data and generate COP readings. The WBB works like a bathroom scale with four pressure sensors measuring approximately 100Hz [17].

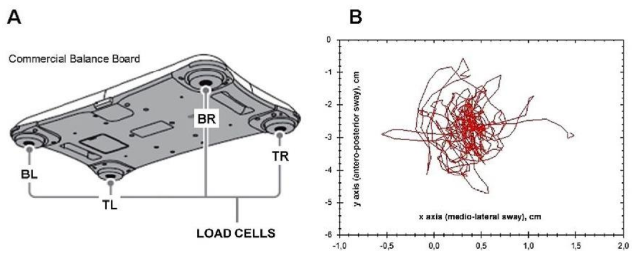

Fig 2. The four sensors of the Wii balance board (A) and the COP graph (B). Image source [17].

The ideal solution for a thorough investigation would be to dynamically gather data and display information from an arbitrary Wii board. At the same time, the test is conducted to continuously display important information such as curve length, area, and the TP.

Testing the solution was completed in cooperation with two experts (coauthors) from Haukeland University Hospital against the already existing and used laboratory equipment. The TP parameter was tested by running the same data through Aasen's [10] algorithm on the expensive instrument and via a Wii board.

A. Software Design

The whole system is written in Java programming language and uses JavaFX [Link], BlueCove [Link], and Wii Board libraries on Linux machines. JavaFX provides a simple UI building tool in scene builder and uses Model-view-controller (MVC) architecture. JavaFX was used to customize and design UI to fit the developer's needs, has many UI components, including UI controls, layouts, CSS, plots, and more. BlueCove is a library that provides a necessary implementation of JSR 82 to use Bluetooth in the Java language. With BlueCove, the application will work on multiple Bluetooth drivers and should work across different operating systems, making it very attractive. Wii board [Link] is an open-source library used to interact with the Wii Balance Board.

B. Application Framework

Multiple modules are needed to develop a usable, functioning, and accessible application that could further be used for research. These modules consist of Wii board (gathering of data), logic, and graphical user interface (GUI). The application is developed using JavaFX, and the GUI will function as the main component for the application. The logic component consists primarily of computations and algorithms. The application relies on the Wii board to produce data while a user is undergoing a balance test. Figure 3 shows the three main components of the balance test applications.

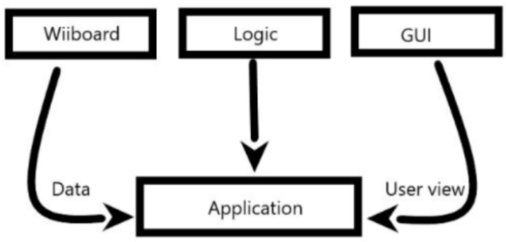

Fig 3. Framework: the three main components of the application.

C. Application Components

Connecting with the WBB, displaying the statistical data, multiple plots, and user management are included in a single user interface (UI). This section of the UI gives the user access to connect to a Wii Balance Board through Bluetooth. Pressing the "connect" button prompts the user to sync the Wii Balance Board with the computer to allow further use of the application as it requires a data source to produce results. Figure 4 displays the UI of the application. It also shows if the Wii Balance

Board is connected or not. The Dashboard menu features four parameters: who is conducting the test, what type of test, duration, and how many times the test will be conducted (e.g., 2x20 seconds). This menu also has a button to start the test that the user wants to complete. There is also a timer counting down the duration to let the user know when the test is conducted. When the countdown number is black, it indicates the remainder of a running test. If it is red, it counts down to the starting of a new test.

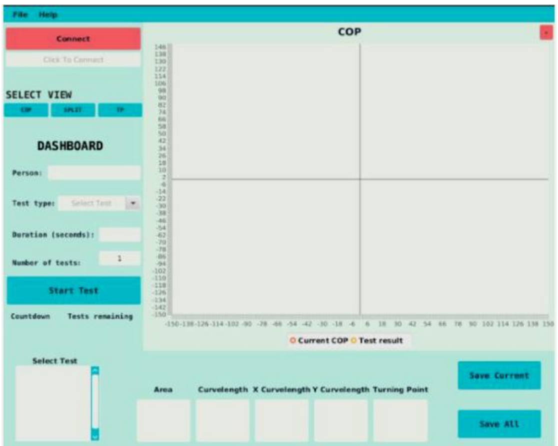

Fig. 4 The UI of the application.

Choosing what plot is displayed can be changed at any given time through the buttons under the “Select view” menu in figure 5.3.2 (COP, X-Y split, TP). These buttons can be used to change plots displayed during a test or after the test has been completed. COP and X-Y split can be seen above in Figure 5, while the different plots regarding TP can be seen in Figure 6.

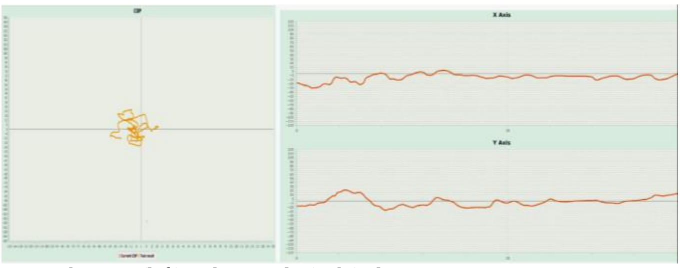

Fig. 5 The COP (left) and X-Y split (right) plots

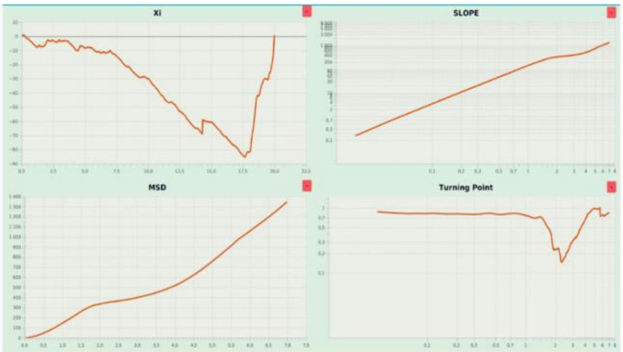

Fig. 6 TP, Slope, MSD, and XI.

In Figure 6, XI is the time series calculated by integrating the COP points. MSD is the mean squared displacement plot, which shows the patient’s displacement and movement. Further, the application also allows exporting all the data in CSV files.

D. Testing of the application

Concerning the global effort put into combating Covid-19, this research has emphasized OS testing, unit testing, and ensuring the application is functioning at an optimal level. User testing has been strictly limited, even for the team members who were professional in posture testing. However, the continuous comparison with the more expensive instrument helped test the accuracy, calibrate, and develop the application to be more user-friendly.

III. RESULTS

After developing the application and doing extensive testing for functionality, operating systems, computations, and UI, this study simulates the data set provided by Aasen et al. [10]. The shift of the COP points collected at the sole of the feet 20-second duration of body sway with the frequency of 100 HZ resulted in 2000 time-series data points.

Figure 7 illustrates the graphs of $X_i(1)$, representing the COP, and the spread over time measured as mean square displacement (MSD) in mm for increasing window size, in steps of 10 ms, until a window length of 5 s (β=500).

$$< \Delta x_i^2 >_k = \left\{ \frac{\sum_{i=1}^{-k+n} (x_{i+k} - x_I)^2}{(-k+n)} \right\}_{k=1}^{\beta} \tag{1}$$

The SLOPE (2) is then calculated as

$$s_i = \frac{1}{2} \frac{\log\left(< \Delta x_i^2 >_k\right)}{\log(k)} \tag{2}$$

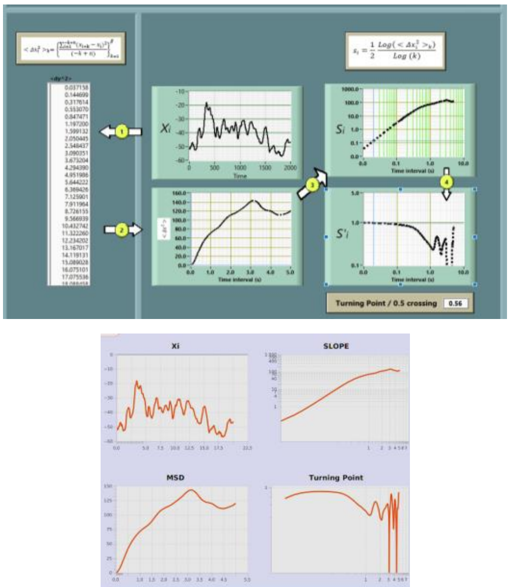

Fig. 7 The comparisons between Aasen’s results calculated on the expensive board (upper) and the UI for the open-access product (down) for the same dataset.

The TP is where the derivative s'_i crosses from higher to lower than 0.5; from persistent to ant-persistent, regulating back to the upright unstable equilibrium. The results from the stepwise calculations of the algorithm presented in Figure 7 shows that the TP algorithm is correctly implemented in the program.

IV. DISCUSSION AND FUTURE WORK

The Wii balance board is more than a decade old and was first released in 2007, and the BlueCove library that connects to the Wii board supports 32-bit systems. Nowadays, most systems and computers run 64 bit and are unable to support this service. Newer operating systems, such as Windows 10, 8, or MAC OS, do not support these older drivers. Therefore, this application needs improvements in Bluetooth connectivity, and it should support new versions of Windows and MAC OS.

The Wii balance board has been reliable in several earlier studies, e.g., for standing balance [7], postural control [18], squatting exercises [19], or help to improve balance and gait in Parkinson's disease patients [20] or knee rehabilitation [21]. However, these tools must be accessible and affordable to make testing available and relevant for clinicians. While these technologies are taken for granted, there are too many versions of them. It can be difficult to compare and choose the correct software, especially if the resources are limited. The open-source make possible that technology should develop further, e.g., by combining other functional screening methods to allow broad screening of school-aged children at schools or to include AI or new methodologies to ensure better results for measuring balance. In addition, publishing the open-source code can invite other students, researchers and professionals for further innovation.

V. CONCLUSIONS

This paper presented a study that developed an application for measuring balance and a UI for visualizing necessary parameters for understanding balance problems for non-experts. The application fulfills the purpose of running a balance test and dynamically testing a person's performance. It is based on a Wii Balance Board and obtains reliable and comparable balance measures. The tests were done by running the same datasets on the Wii Balance Board as on an expensive instrument at the local hospital, and vice versa. It is expected to be used by researchers and physicians in the hospital and allows importing data from otherwhere, e.g., by other experts or patients. In addition, a low-cost and open-source code makes this application available for different settings.

The application is downloadable as an executable *.jar file that supports Java 8 and newer versions. The source code is openly available at GitHub [Link] for further use and development.

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