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Design and Development of a Low-Cost Force Plate with Software Application for Analyzing Balance and Coordination Training for Elderly

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Abstract

The physical fitness of the elderly is more likely to deteriorate by aging. Balance and coordination exercise are important to maintain the strength of the musculoskeletal system, joints and bones as well as to reduce the risk of falling. This paper is systematically designed and development of a low-cost force plate with software application (StandBalance) for analyzing balance and coordination training for elderly. The structure of force plate consists of load cell circuits connected with Node32s board as a part of signal measurement and send wireless data via Bluetooth to analyze with LabView. The software application can real-time record and display numerical data such as the patient's weight and training information which could send feedback to the users and health care providers who can more accurately analyze and more easily search for the patient's information. The software has been designed in 4 operating modes (Balance Screening, Exercise, Games and CoP Modes). The objective of this research study was to test whether the StandBalancecould detect CoPandGRFssignal and display the result whether it was accuracy and repeatability to use for effective. This research was found that the percentage error of static weight measurement is 4.84 which assume it can acceptably measure the GRFs especially when the human body is contact to the developed force plate. Moreover, the absolute error of CoP-accuracy of (Top Left, Top Middle, Top Right, Middle Left, Center, Middle Right, Bottom Left, Bottom Middle, Bottom Right) study areas are 5.14, 4.08, 5.44, 5.02, 5.88, 7.25, 4.49, 5.28, 6.47 mm. respectivelyand the percentage error of CoP-repeatability of study areas are 0.82, 0.74, 1.21, 0.95, 1.34, 0.89, 0.74, 1.13, 1.18 respectively. The absolute erorr of CoP-accuracy are close to 0 mm. and the percentageerror of CoP-repeatability are less than 5 which showhigh accuracy and precision that adequadefor StandBalance to assess balance and train coordination. Therefore, it could ensure that the StandBalancecould detect CoP and GRFs effectively and can use as a device for further clinical implementation with human.

***Keywords:**Low-Cost Force Plate; Software Application; Balance and Coordination Training; Balance and Coordination Analysis; LabVIEW*

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I. Introduction

The physical fitness of elderly is more likely to deteriorate by aging (1). However, the maintenance of balance and body coordination are essential to perform daily activities to specific movements. The lower limbs exercise is important to maintain the strength of the musculoskeletal system, joints and bones as well as to reduce the risk of falling (2). Balance and coordinate exercise like sit, stand and sit to stand training is an exercise prescription in the elderly to improve lower limbs strength and reduce functional limitations (3-4). However, the problem of the lower limb training or coordination exercising in the elderly is lack of the motivation to exercise (5-8). They felt that exercising was a burden and did not know their performance and development from their own exercise. Although there are currently many devices that are designed for lower limbs exercise training, those devices are not designed for the elderly and do not show the biomechanics' feedbacks. Some have high impact and dangers and may lead to injuries (9). Consequently, these can lead to failure to exercise. However, there is one of the devices used to train and analyze the kinetics of body movement is force plate, a device for biomechanical movement evaluation, balance assessments, and kinetic training. A force plate consists of a pair of rigid flat plates with force sensors between them which provide signals to the forces. The load cells give the force applied in the medial-lateral (X-axis), anteroposterior (Y-axis), and vertical (Z-axis) directions, and the force moment consists of the GroudReaction Forces (GRFs; Mx, My, and Mz) (10). The analysis of human movements and balance abilities is assessed through three-dimension which are Center of Pressure (CoP) in anteroposterior direction, mediolateral direction and the force moment like GRFsinCoP. The CoP is a point where the totality of vertical force performs on the ground (11).

Since balance assessment and coordinate training have animportant role in research on fall prevention, rehabilitation of neurological and reduction of injury risk among geriatric people (12). Therefore, training and analyzing balance and coordination with force plate is a good choice for elderly. Many studies showed that laboratory force plate had high reliability and validity. In numerous laboratories and clinics, force plates are presently the gold standard for assessment of balance (13-15). It delivers accurate measures of GRFs and CoP, which is a calculation of the body's center of mass reacted vertically on the floor. The GRFs and CoP is an important data to measure for coordinate movement and balance ability assessment assumed from the distance of CoP sway, CoP data and GRFs data that derived from a laboratory grade force plate considered the gold standard for balance assessment.

However, laboratory force plate is usually very high-cost, sometimes difficult to operate and their lack of portability limits their use outside laboratories. According laboratory force plate like AMTI, sampling frequency is ranged from 10-2000 Hz. and prices are around $15,000-20,000 US (16). Most of the force plates used in Thailand are imported. Besides the high prices which are increased by transportation and import taxes, technical problems and spare parts are difficulties for laboratories, researchers and health care providers.

In order to solve these problems, we designed and developed a new low-cost force plate with application software (StandBalance) which characterized by low cost, construction simplicity, easiness of maintenance and availability of spare parts in Thailand, yet providing effectivenessof GRFs and CoP datafor balance analyzing and coordinate training for elderly.

II. Design and Development

Designed and Developed Force Plate

Fig1: the developed force plate

In this research, we designed and developed force plate (Fig1). The weight's user capacity of this device is 200 kg. and sampling frequency is ranged from 30-50 Hz, which can be applied as a cost-effective and transportable version of a laboratory grade force plate, with the price $100 US. We used the CoP signal and calculated value from 4 load cells of the corners of force plate to develop this application. The force sensors are attached with the Top Right, Top Left, Bottom Right and Bottom Left corners of the developed force plate. The developed force plate system measures CoP and body swaying in the right side to left side (CoPx) and front to back (CoPy) ways based on vertical force sensors data. The information from the sensors can produce real time CoP data. In addition, the benefit of developed force plate is available signals used with Bluetooth from computers and laptops, and when synced to a device, it is easily to create application in other platforms such as LabVIEW and Blueberry Pi etc. based on CoP data that are derived from it.

The working structure of developed force plate (Fig2) is using a developed force plate as CoP data and weight values transmission reading signal from load cells that measures the force moment and pressure (GRFs and CoP) by Node32s board as a part of signal measurement and report the data by sending wireless data via Bluetooth to LabView computer and using the LabVIEW program which can real-time analyze and display data for balance assessment as well as coordinate training for the elderly. Therefore, the StandBalance can send feedback to the users and health care providers.

The StandBalance is real time recording and can display numerical data such as the patient's weight and training information such as time repetitions, balance screening, total for training, etc. The health care providers, therefore, can more accurately assess and more easily search for the patient's information.

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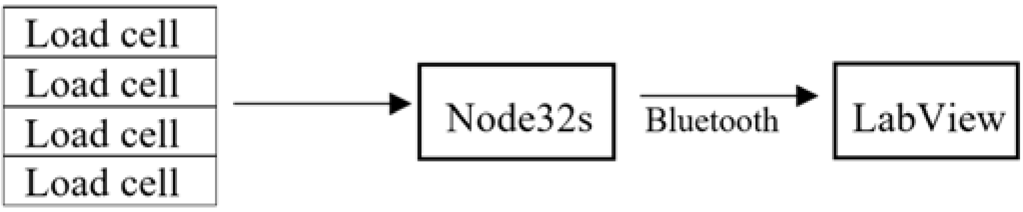
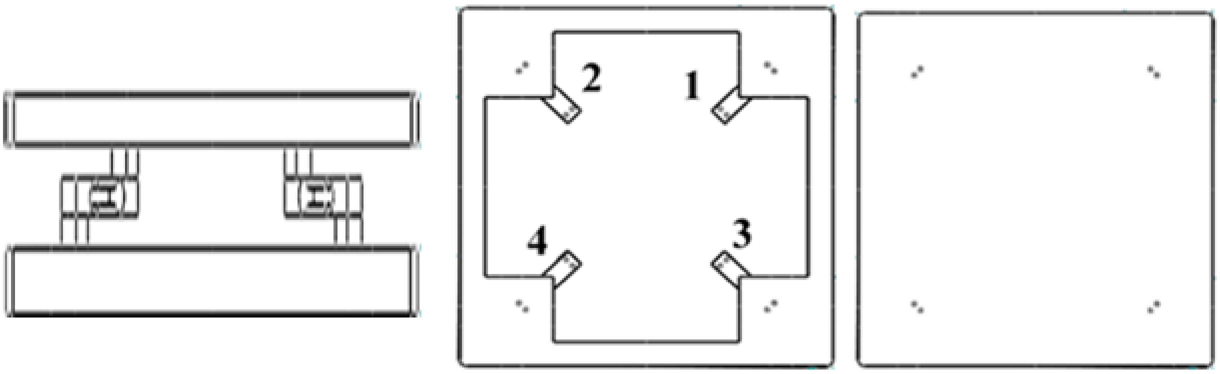


Fig 2: the working structure of developed force plate

First of all, we have designed and developed force plate (Fig3). The developed force plate size is 600*600*130 mm. with top plate (thick 30 mm.) and bottom plate(thick 40 mm.) as show in the lateral view in Fig3 (a). At the top view of the bottom plate as show in Fig 3(b) is the part with Node32s installation connected to 4 load cells (each load cell able to carry a weight of 100 kg.); the number 1 is Top Right load cell, the number 2 is Top Left load cell, the number 3 is Bottom Right load cell and the number 4 is Bottom Left load cell. For the load cellinstallation, it shall be installed making 45-degree angle located in the corners of the bottom plate and cover with the top plate as show in the Fig 3(c). The developed force plate is designed by SOLIDWORKS Program for drawing.



(a) (b) (c)

Fig3: (a) lateral view of the developed plate consists of the bottom plate and the top plate
(b) top view of the bottom plate(c) top view of the top plate

The load cell circuit connection (Fig4) consists of 4 FZ1732 Model YZC1B load cells in the corners which are sensors received the force moment and pressure from object's weight and changes the resistance using together with Wheatstone Bridge circuit and HX711 Amplifier to amplify voltage

signal to be larger to measure (amplifies the signal and converts it to 24bit digital signal) and calculate with Node32s Board processor unit that collect data measured from load cells and send to LabView via Bluetooth.The details of load cell circuit connection are show in table 1.

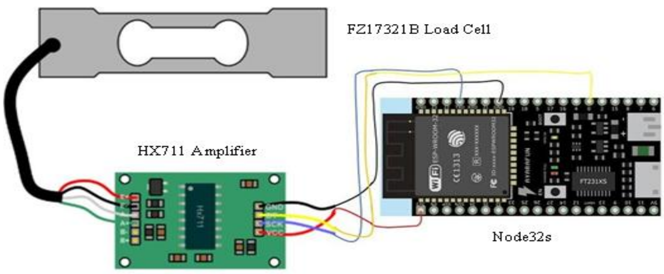


Fig 4:the load cell circuit connection

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Table 1:details of load cell circuit connection

Load cell to amplified HX711 circuit		HX711 Amplifier to Node32s Board	
Red	E+	GND (Black)	GND
Black	E-	DT (Yellow)	Pin 0
White	A-	SCK (Blue)	TXD 001
Green	A+	VCC (Red)	3V3

Designed and Developed Software Application

We also designed and developed the software application for analyzing balance and coordination training for elderly. We wrote the codes to program and to analyze data and then show the results on LabView computer. The first mode is Balance Screening Mode, the second mode is Exercise Mode, the third mode is Game Mode, and the last mode is CoP Data Mode.

1.Balance Screening Mode

The first mode is a clinical Balance Screening Mode that we used Five Times Sit-to-Stand (5TSTS) as a reference which is a balance ability test commonly
used in clinical geriatric. Balance Screening Mode can analyze and screen balance ability of the users.
The advantages of the Balance Screening Mode are to reduce errors of balance assessment and to reduce the burden of health care providers.
The operating window of the Balance Screening Mode (Fig5) consists of instruction for the users "Stand up and sit down as quickly as possible for 5 times, keeping your arms folded across your chest" and "Ready" button. When the program is ready to use, the button will show green light. It also includes a weight (kg.), repetition counts (times), total time of 5TSTS (s) and display boxes. The Balance Screening Mode also shows the Sit button and Stand button. The Sit button will turn green when the users sit and the Stand button will turn green when the users stand. The program will detect the stand motion when the body weights to the developed force plate more than 10 kg, and the program will start recording the time when the users start to stand or the Stand button turns green at the first time. After the users finish the test for five times of sit to stand, it will sound a warning beep and the program will analyze and assess the balance impairment which will show in the Balance Impairment button. If the users can finish the test within 12 seconds, the Balance Impairment button will turn red. The bottom of this window will show the criteria for geriatrics who are aged more than 60 years of which the first criterion is needed for further assessment of fall risk if the users finish the test in 12 seconds but no more 15 seconds. Another criterion will be employed, in the event that the users may have risk to have recurrent falling if the users finish the test more than 15 seconds. The STOP button will be pressed when the test is finished with the result shown on the screen.

Fig 5: the operating window of the Balance Screening Mode

2. Exercise Mode

The second mode is Exercise Mode. This mode shows the numbers (times) of repetitions and total time (s) of training of sit to stand. The Exercise Mode can also show how body sways while exercising as a biofeedback to allow users to develop and adjust their body posture while training. The advantage of the Exercise Mode is that the users will be able to know their development so they have more motivation to exercise.
The operating windows of this mode (Fig6) consist of Ready button which when the program is ready to use, the button will show green light and when

the user is ready to exercise, the Start button will be pressed to start the Exercise Mode. Then the program will record the total time and number of repetitions (Count) of sit to stand. The data such as weight (kg.), repetition counts (times), total time of Sit to Stand (s) will display on the boxes below. This mode also shows the Sit button and Stand button. The Sit button will turn green when the users sit and the Stand button will turn green when the users stand. The program will detect the stand position when the body weight is more than 10 kg.

In the right side of the operating window, there are 4 buttons (Top, Bottom, Right, Left) and the top button will turn green when CoP of the users' goes to the top location of the board, the Bottom button will turn green when CoP of the users' goes to the bottom location of the board, the Left button will turn green when CoP of the users' goes to the left location of the board and the Right button will turn green when CoP of the users' goes to the right location of the board. The buttons always turn together; top and right, top and left, bottom and right, bottom and left buttons. Furthermore, this mode can report the problems of the users when the users have their body excessively swaying, which means the balance impairment and that the buttons will turn red when CoP of the users' sway more than 50%. When these buttons turn red that means users have their body excessively swaying, it shows balance impairment and the elderly should stop exercising. So, this mode can show how body sways as a biofeedback to allow the users to develop and correct their body posture while training. The STOP button will be pressed when finishing the test, and the result will be shown.

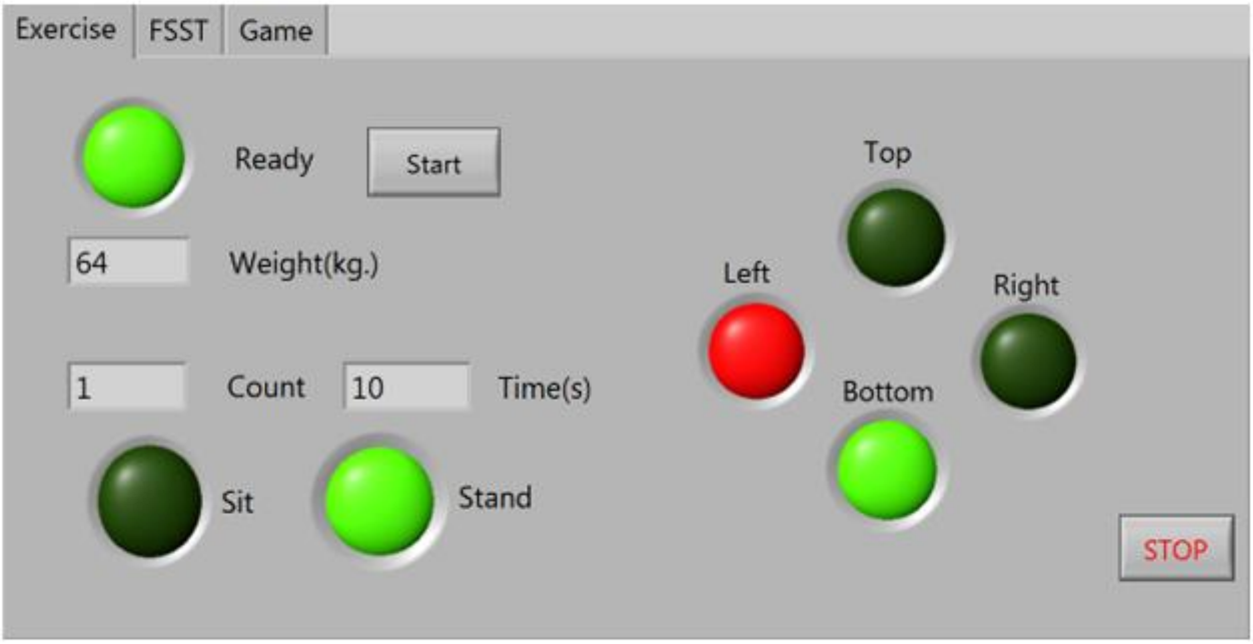

Fig 6: the operating window of the Exercise Mode

3.Game Mode

The third mode is the Game Mode (Fig7). This mode will show orders for the elderly to follow. The orders such as the order to stand, sit, shift body weight to the left or right, will be random, it will show the total time when the game ends. The less time shows the better score of the game. The advantages of this mode are to develop strength, agility, speed and the reaction time of the users. It is also fun and can be used to train the brain functions.

The operation window of the Game Mode consists of a Ready button on the top-left of the window that when the program is ready, it will turn to green light. When the users finish the game, they can press the STOP button. This Game Mode has 4 operating buttons (Sit, Stand, Left, Right) on the center of the windows. Each button will turn green light one by one, so the users have to do one by one respectively. For Example, if the stand button turns green, the users have to stand as fast as they can,

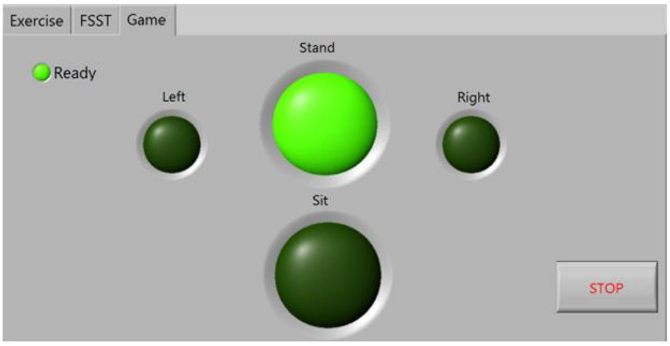

Fig 7: the operating window of the Game Mode

4. CoP Data Mode

The last mode is CoP Data Mode which shows CoP and vertical Ground Reaction Force (vGRFs) which calculates total of the movement weight. Fig 8 (left

and when the program detects that the users have already stood, the program will randomly the next order such as right, so the users have to shift the body weight to the right side as fast as they can etc.

display box) shows the displacement of CoP (X-axis and Y-axis showing the scale range in centimeters and also displaying boxes which report the CoP locationfrom 4loads cells (Top Left, Top Right, Bottom Left,

Bottom Right). Fig 8 (right display box) shows the graph of vGRFs which can show force moment (the acceleration of body weight data). Y-axis will show body weight of the users (kg.) and also has display boxes which show current count and time (ms). This mode is developed for health care providers to use these data to analysemechanical of human movement.

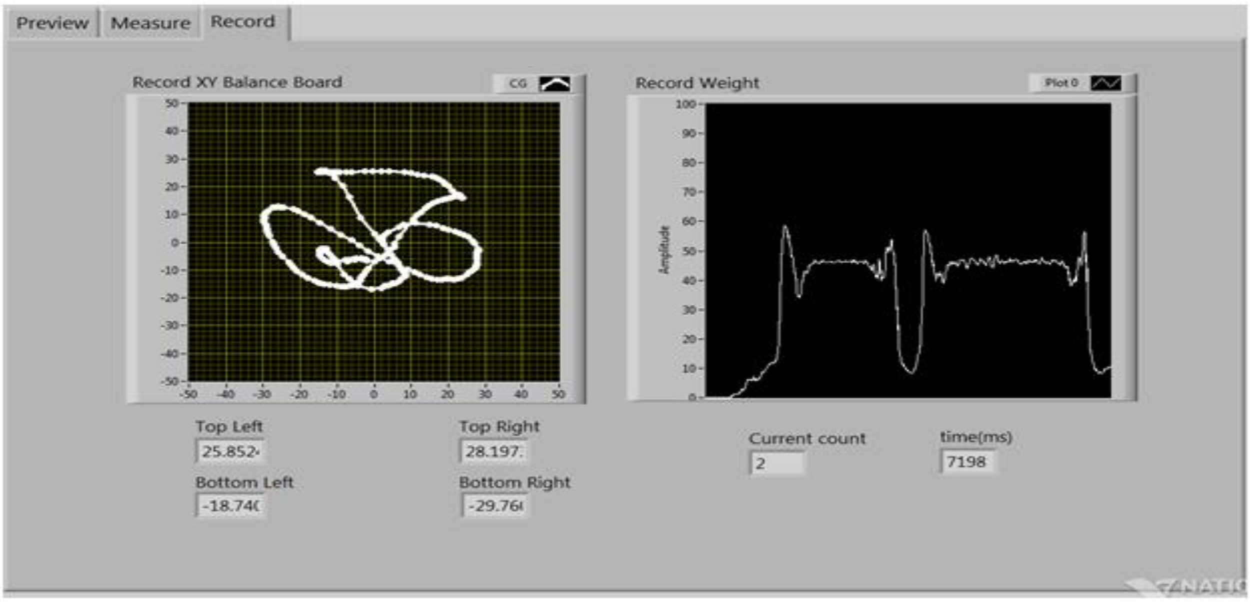

Fig 8: the operating window of the (left display box) CoP Mode with (left display box) vGRFs Data

The StandBalanceinteracts with the users in the same manner as an expensive laboratory force plate but added training and balance assessment software programs. The StandBalance allows for simplified access to the users' input data, distribution and processing of ready to use data on computers and reporting back to the users. The researchers aim that StandBalance will easy to use and help the elderly to pay more attention in exercising to reduce the burdens of healthcare providers.

III. Methods

1. Static Weight Calibration ofStandBalance

We conducted a weight measuring test from the corners of 4 load cells to test the functionality of the Node32s board. The test was performed by placing 3.6 kg standard Kettlebell (weighed with standard weight machine before the test) on a developed force plate and using Node32s board with Arduino program to read measured 14 weight values and we will measure static calibration by finding percentage error to measure the accuracy of weight measurement of StandBalance by following equation (1) as below.

%Error of Static Weight $=\frac{1}{n} * \sum\left(\frac{|(x-X)|}{X}\right) * 100$ **(1)**

x = weight value that can measure
X = the actual weight value of the object

2. CoP-Accuracy of StandBalance

We examined accuracy and precision of the application by measuring of CoP whether it was accurately and repeatability for detecting and showing, the 9 study areas including Top Left, Top Middle, Top Right, Middle Left, Center, Middle Right, Bottom Left, Bottom Middle, Bottom Right. If CoP in these areas is accuracy and precision, it means that the StandBalance can be exercised for analysis and training. The objective of this research is to test whether the application employed with developed force plate can detect CoP signal and display the result accurately and repeatability for safe and effective.

We placed a 1.5-kilogram weight dumbbell in study areas and tested by putting the weight randomly to eachstudy area whether the StandBalance could detect and display CoP in eachareas and measure error distances.The measurement was measured for 14 times. The obtained absolute error value was calculated following the equation (2) to find absolute error displacement of accuracy (mm.). If theStandBalance has the absoluteerror accuracy close to 0 mm., it is assumed highly accurate.

Error of CoP-Accuracy = $\sqrt{(x-\bar{x})^2(y+\bar{y})^2}$ **(2)**

x = actual location in the x axis
y = actual location in the y-axis
$\bar{x}$ = mean of location detectable in the x-axis
$\bar{y}$ = mean of location detectable in the y-axis

3. CoP- Repeatability of StandBalance

We placed a 1.5-kilogram weight dumbbell in study areas and tested by putting the weight at the same locations whether the StandBalance could detect and display CoP in eacharea similarly or equivalently when it used repeatedly. We tested each area for 14 times, collected data and calculated percentage error of CoP-repeatability following the equation (3) and (4) to analyze the precision and if the percentage error of repeatability is less than 5 is assumed high precision.

SD = $\frac{\sqrt{n\Sigma x^2-(\Sigma x)^2}}{n(n-1)}$ **(3)**

%Error of CoP- Repeatability = $\frac{SD}{\bar{x}} * 100$ **(4)**

IV. Results and Discission

1. Static Weight Calibration of StandBalance

According to Newton's third law the GRFs is the forces exerted by the ground on an object in contact with it. The GRFs corresponds with the object's weight (17). The GRFs are one of the most often analysed biomechanical measures and help characterize human movements. Measuring GRFs plays an important role in the areas of sports performance analysis, rehabilitation, ergonomics and clinical research(17).

Based on the calculation, it was found that the percentage error of static weight measurement is 4.84 which the mean of total measured weight is 3.43kg. from the Kettlebell actual weight 3.6 kg. and the mean of Top Left, Top Right, Bottom Left, Bottom Right load cellsare 0.60, 0.92, 1.18 and 0.73 kg. respectivelyas shown in Table 2.

TheStandbalance has percentage error of statice weight measurement aproximately5 which showit can acceptably measure the GRFs especially when

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the object or body is contact to the developed force plate. However, in the future, we would like to test the GRFs from human acceleration forces to ensure that the StandBalance can detect the GRFs data effective.

n = 14	Top Left-load cell(kg.)	Top Right -load cell(kg.)	Bottom Left-load cell(kg.)	Bottom Right-load cell(kg.)	Total Weight (kg.)
??	0.60	0.92	1.18	0.73	3.43

Table 2: the mean of weight valuesfrom 4 load cells

2. Cop-Accuracy of StandBalance

We examined CoP accuracy and repeatability of the StandBalance and it tested in the 9 study areas (TopLeft, Top Middle, Top Right, Middle Left, Center, Middle Right, Bottom Left, Bottom Middle, Bottom Right) (Fig9) for 14 times in each study areas. The obtained absolute error of CoP-acuracy value (mm.)and the percentage error of CoP-repeatability was calculated from the equation to find in aspect of accuracy and precision whether the StandBalance could detect and display CoP in target locations andin each time of use repeatedly.

Table 3: the absolute error of CoP-accuracy, the percentageerror of CoP-repeatability

Locations (n=14)	Absolute Error of CoP-Accuracy (mm.)	Percentage Error of CoP- Repeatability
Top Left	5.14	0.82
Top Middle	4.08	0.74
Top Right	5.44	1.21
Middle Left	5.02	0.95
Center	5.88	1.34
Middle Right	7.25	0.89
Bottom Left	4.49	0.74
Bottom Middle	5.28	1.13
Bottom Right	6.47	1.18

It was found that the absolute error of CoP-acuracyof (Top Left, Top Middle, Top Right, Middle Left, Center, Middle Right, Bottom Left, Bottom Middle, Bottom Right) study areas (Fig9) are 5.14, 4.08, 5.44, 5.02, 5.88, 7.25, 4.49, 5.28, 6.47 mm. respectivelyas shown in Table 3.

3. CoP-Repeatability of StandBalance

We also found the percentage error of CoP-repeatability of (Top Left, Top Middle, Top Right, Middle Left, Center, Middle Right, Bottom Left, Bottom Middle, Bottom Right) study areas (Fig9) are 0.82, 0.74, 1.21, 0.95, 1.34, 0.89, 0.74, 1.13, 1.18 respectively as show in Table 3.

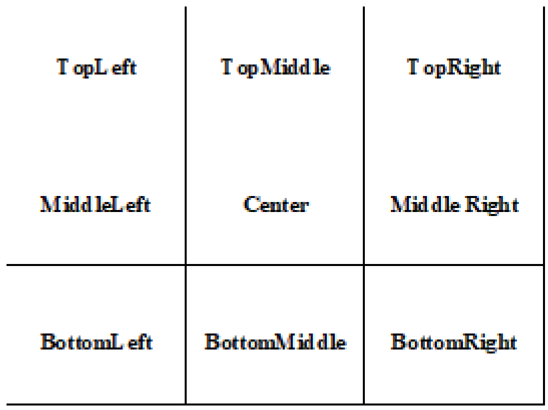

Fig9: the study areas of CoP-accuracy and CoP-repeatability

The absolute error of CoP-accuracy in each study areas are very close to 0 mm.which show high accuracy and the percentage error of Cop-repeatability are less than 5which show highprecision. Therefore, it could ensure that the StandBalance could detect and display CoP accuratelyand preciselyfor balance assessment and coordination training for further clinical implementation with humans.

Additionally, the Game and Exercise Mode should be added with more variety games and exercise program that should be improved in aspect of the graphics and sounds to be more beautiful and interesting which can encourage the elderly to exercise. However, we plan to develop the StandBalance by creating and designing more interesting coordination games as well as some researches who have created balance intervention games using CoP from a customized software application. This approach also allows the creation of games that are customized to meet the needs of specific subjects, such as patients that have problems with cognitive function. The games have been quite wide-ranging, but generally require the subjects to shift their CoP to move in a virtual environment. Some examples include catching fruits from the tree, moving a football around barriers towards a goal and dancing along the music (18-21). Nowadays, the use of the force plate as a balance assessment and training tool is growing rapidly. Use of the force plate for assessment and training purposes is likely to continue to grow in the years to come. Greater emphasis must still be placed on implementing randomized control designs with larger sample populations to answer questions of interest. There must also be a greater emphasis placed on determining how specific neural and musculoskeletal adaptations occur in response to CoP training, and how those changes compared to other commonly utilized balance training interventions.

However, the limitation of StandBalance is thesampling frequency is quite low which ranged from 30-50 Hz. compares to laboratory force plate like AMTI which sampling frequency is ranged from 10-2000 Hz. This suggests that a sampling rate as low as 10 to 100 Hz. may be adequate data to describe these accurately (22). Though, the StandBalanceis notas accurate as a standard force plate, however, the purposes of StandBalanceare to be a coordination training device that easy to understand and suitable training programs as well as to balance screening among geriatric people with cheap price to make it accessible to the elderly. The StandBalabce are mainly to solve health problems among the elderlyin the country. Therefore, for these purposes the researchersare not require high sampling frequency, 30-50 Hz. is enough for balance screening and coordinate training in elderly which is different from the research purposes in the laboratory and other training programs like jumping or running that requiresvery high sampling rates.

V. CONCLUSION

We designed and developed a new force plate with application software (StandBalance) for training and biomechanical data purposes. The developed force plate is characterized by low-cost, construction simplicity, easiness of use and maintenance and local availability of spare parts and also providing effectiveness of CoP and GRFs data. Therefore, it could ensure that the StandBalance can use as a medical device for further clinical implementation with human.

The goals of StandBalanceare to enable the elderly in Thailand could access inexpensive medical devicethat help them to improve balance, coordination and strength of the musculoskeletal system andto reduce the burden of health care providers.

In the future, the researchers also plan to have it tested with elderly to ensure that the StandBalance will be really practical.

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