iBEST: intelligent Balance Assessment and Stability Training System using Smartphone

Aung Aung Phyo Wai, Pham Duy Duc, Chan Syin, and Zhang Haihong

***Abstract*—Patients with postural instability could lead to falls and injuries while walking due to balance disorders. So those patients need regular balance training and evaluation to improve and examine balance deficiencies. But many do not notice such balance issues; resulting lack of timely preventive measures. This shows the needs of affordable and accessible solution for balance training and assessment. So iBEST (intelligent Balance assessment and Stability Training) is proposed enabling to train and assess balance conveniently anywhere anytime. Moreover, therapists can remotely evaluate and manage their recovery progress. These benefits can be realized leveraging sensors from smartphone, cloud-based data analytics and web applications. iBEST employs sensorised automated balance assessment in digitizing Berg Balance Scale (BBS) clinical risk assessment tool. The initial feasibility study showed average accuracy of 90.22% using smartphone in classifying the specified BBS test items.**

I. INTRODUCTION

Balance problems can stem from dizziness, weakness in lower extremity, and lack of coordination among different body systems [1]. Elderly are especially prone to physical functional decline that could lead to loss of independence in daily activities. Especially, instability in body balance could lead to falls that account for more than 90% of injuries in community-dwelling elderly [2, 3]. Although various studies report benefits of balance training to prevent fall risks [2, 4], the real issue is how to promote adherence in conducting regular exercises and enable objective evaluation to improve balance [5].

Due to advances in technologies, quantitative evaluation of balance using sensors is feasible now [6]. Several prototypes and products for balance training can be found utilizing sensing technologies such as force plate [7, 8] and accelerometers [9, 10]. In order to enable better patient's engagement, audio feedback is used during training [9, 10]. As a simple solution, Sway (http://swaymedical.com/balance) smartphone application is already available in the market. Most of existing solutions just recognize balance instability conditions using different means and did not incorporate clinical balance assessment scale [11, 12]. So, iBEST uses orientation sensor to detect balance abnormality and enable objective assessment according to clinical balance test procedure. Also, the integration of mobile, cloud and web technology enables iBEST to achieve desirable training, monitoring and interaction between patients and therapists. The use of audio cues guide users what and how to perform exercises besides issuing audio feedback of abnormal conditions to regulate balance with appropriate actions.

The goal of this paper is to evaluate the feasibility of using smartphone for body balance training and assessment by digitizing Berg Balance Scale (BBS) [12]. We first present the iBEST's design and core technologies to evaluate balance. Then, we explain the balance assessment scenario with experiment for initial feasibility study on identifying different BBS items. Finally, we close our discussion with existing limitations, challenges and possible extensions of iBEST in practical settings.

II. BALANCE TRAINING AND ASSESSMENT SYSTEM

The design goal of iBEST is to provide an affordable solution for patients in performing exercise regularly and therapists in measuring balance performance objectively. So iBEST leverages on smartphone as a self-assessment tool for first-hand evaluation to detect balance and sway abnormality.

A. System Design and Architecture

iBEST consists of three components: mobile, cloud and web applications as shown in Fig. 1. The mobile detects balance instability using sensors from smartphone, interacts with audio feedback and manages exercise information. The cloud performs trend analysis from the stored users' profile and data. The web allows therapists to remotely access training information, review individual progress, and manage subjects' exercise schedule accordingly.

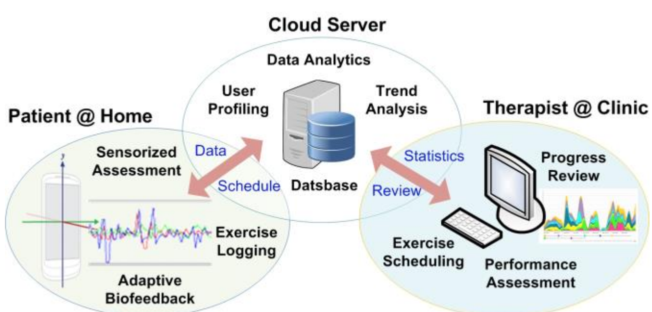

Figure 1. System Design and Architecture of iBEST

B. Operation and Functionalities

iBEST is targeted for any patient with balance disorders to exercise and improve balance using intuitive smartphone based automated assessment. iBEST provides adaptive audio

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cues and feedback for interactive exercising, and sensorised Berg Balance Scale (sBBS) for automated assessment. This will improve users' engagement as they will simply go through assessment process using iBEST to test potential balance disorders. Assessment results will be stored in cloud allowing users and therapists to access exercise data and progress. With iBEST, patients can benefit from exercising required balance training at their own home with simple audio guidance and feedbacks. Moreover, the objective assessment using sBBS will allow immediate fall risks evaluation. This will not only save costs and time for patients but also allow them continue training to improve balance stability; able to participate actively in their daily activities.

Figure 2. iBEST Mobile Application Main Screen

B. Balance Assessment Methodology

iBEST utilizes both physical and synthetic sensors from smartphone to determine balance performance different from [9, 10, 13]. Kalman Filter [13] is also used to fuse synthetic orientation obtained from smartphone library and orientation estimates from physical sensors' measurements. This filtering improves the abnormality recognition accuracy by eliminating potential orientation errors. From fused orientation information, five features are derived to detect user's static and dynamic conditions such as sway area per second, mean distance and mean velocity (both in Medial-Lateral and Anterior-Posterior directions). Automated assessment on fall risks can be done through fusing of movement features and orientation deviations using sBBS test criteria according to section III. However, the details of the assessment algorithm are out of scope from this paper.

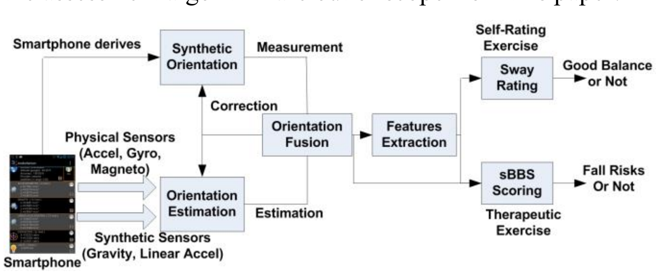

Figure 3. Overview of iBEST Balance Assessment Methodology

III. SENSORISED BERG BALANCE SCALE

The BBS is commonly used to measure balance disorders by assessing the performance of functional tasks from visual inspection [12, 14]. It is a valid clinical instrument used for evaluating the effectiveness of interventions and quantitative descriptions of function [12]. An evaluation on effectiveness of BBS exhibits excellent inter-rater and intra-rater reliability and strong test-retest reliability [15]. Due to BSS's clinical validity, automated balance assessment in iBEST was developed using sensors according to BBS test items.

Instead of manually inspecting balance deficiencies [13], iBEST produces balance assessment scores through sBBS using orientation information. Our solution is meant as first-hand convenient solution to assess balance stability without requiring skilled therapists. As shown in Table I, only 10 levels of BBS minor test levels are omitted in sBBS as those can only be assessed through visual inspection and requiring caregiver or therapist assistance. 5 out of 14 major BBS items are unchanged in sBBS and only 1 level is left out in the remaining items except one major item "Transfer".

TABLE I. SUMMARY OF DIFFERENCES BETWEEN BBS AND SBBS

Major Test items	*Minor BBS Items*	*Minor sBBS Items*	*Omitted Items*
1. Sit to stand	5	4	0. Moderate or maximal assist to stand
2. Standing unsupported	5	4	3. Able to stand 2 minutes with supervison
3. Sitting with back unsupported	5	4	3. Able to sit 2 minutes under supervision
5. Transfer	5	3	0. Two people to assist 1. One person to assist
6. Standing, eyes closed 7. Standing, Feet together	5	4	3. Able to stand 10 seconds or 1 minute with supervison
8. Reaching Forward 8. Picking up object 9. Turn to look behind	5	4	3. Need supervison while performing the desired balance activity

In order to design sBBS, we conducted experiments of 11 static and 9 dynamic (linear and rotational) movement scenarios derived from different scales of 14 items BBS. Then, we used Weka [17] to differentiate different scales from all BBS items. This initial evaluation showed high classification accuracy of 96.7%, 93.19% and 82.86% for static, linear and rotational situations respectively. The grading criteria for fall risks estimation were redefined to match reduced test items of sBBS as summarized in Table II.

TABLE II. COMPARISON OF BBS AND SBBS ASSESSMENT CRITERIA

Parameters	*original BBS*	*sensorised BBS*
Total items (Major/Minor)	14/56	14/46
Max: Score	56	46
Grading Criteria	41-56: low fall risk 21-40: med fall risk 0 –20: high fall risk	34-46: low fall risk 17-33:med fall risk 0 –16: high fall risk

IV. Experiment, Analysis and Discussion

We conduct feasibility study experiments with iBEST to differentiate varying levels from different test items in sBBS using the assessment methodology proposed in section 2. We hypothesize that different balance scoring criteria according to BBS test items can be classified from smartphone sensors with sBBS in assessing the potential fall risks.

A. Exercise selection and Experiment Scenario

With iBEST, patients can perform two types of exercises: self-paced balance exercises and sBBS assessment tests. In the first type, user can select desired standing balance exercises like one-leg standing to understand their balance conditions. The scoring is solely on how orientation deviates from normal balance; providing good or bad balance outcomes. The second exercise type is to complete all sBBS test items either self-initiated or assigned by therapists. The assessment is based on comparing current orientation readings with ground truth sBBS profile built previously from training orientation data.

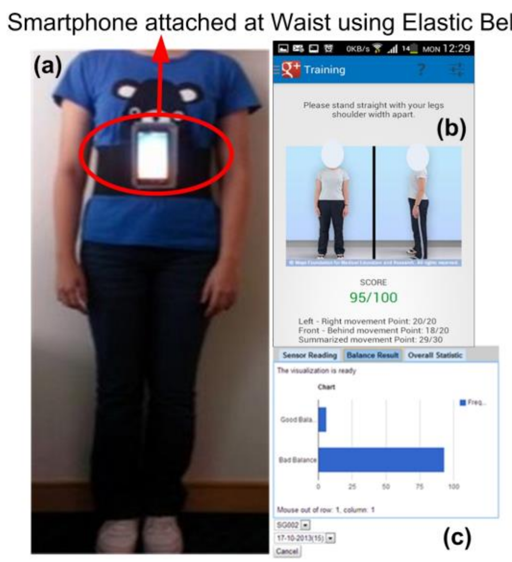

Figure 4. iBEST in balance training; (a) User wearing smart phone. (b) Mobile application with instruction and performance score. (c) web application reviewed by therapists

In order to examine feasibility of automated assessment, all BBS scenarios were evaluated with small sample size (n=5) of young and healthy users. From our validation, placing the smartphone at waist level gives higher correlation with center of mass measurements compared with attaching it at chest position. So the smartphone was attached in all experiments at user's waist as shown in Fig. 4. Before evaluating classification accuracy using sBBS, different physical and synthetic sensing outputs were evaluated to determine the optimal sensing information used in automated balance assessment. In all these experiments, orientation information is sampled at 100 Hz using HTC One X Android smartphone. Automated balance assessment was performed in every 500 ms and appropriate audio cues and feedback were issued throughout the experiment.

B. Results and Analysis

From evaluation of different sensing outputs, 3D orientation derived from physical sensors achieved the best identification performance as shown in Table III. As both static and dynamic conditions are involved in BBS items, orientation showed consistent high accuracy. The physical sensor outputs are only marginally better than orientation in rotational dynamic situations. So filtered orientation outputs are used to derive five balance features in building ground truth balance profile for classification of respective sBBS items for balance assessment.

TABLE III. Comparison of BBS and sBBS Balance Assessment

Sensing Parameters	***Static (%)***	***Dynamic (%)***	
		Linear	***Rotational***
Physical sensor (Mean of Accel, Gyro & Magneto)	73.12	75.36	**84.07**
Gravity	93.28	84.15	70.13
Linear Acceleration	57.46	57.71	70.28
Orientation	**96.70**	**93.19**	82.86

From our validation experiment, the average accuracy of 90.22 % was achieved to classify different scales (minor: 0 to 3) of BBS items (major: 1 to 14) [12]. The lowest accuracy of 85.26 % for BBS.8 "Reaching Forward" is due to the involvement of upper body movements as orientation sensing is only limited at waist. The following Fig. 6 shows the average classification accuracy of all BBS items.

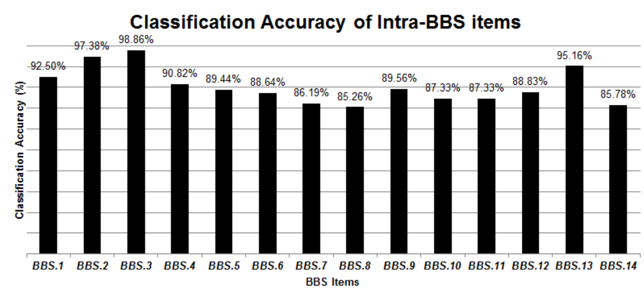

Figure 5. Average classification accuracy of rating scales for BBS items

C. Discussion and Future Works

The goal of iBEST is to provide affordable training and assessment system using smartphone. This paper examines the feasibility of balance assessment according to BBS using smartphone sensors. We presented iBEST's system design, features and methodology for balance assessment with sBBS. So users can conduct balance training comfortably at home while allowing therapists to remotely manage their progress. The in-situ balance assessment allows users timely recognition of potential fall risks. Instead of conducting exercises at clinic, patients could perform scheduled body balance training conveniently at their home. Besides being convenient, patients can save costs and time while continuing proper training regimen constantly tracked by therapists. The exercise profile and automated analysis of balance scores by user can further be reviewed and evaluated by therapists. As for clinics, iBEST helps in saving resources; both equipment and manpower while providing essential therapy services to more patients. Based on the progress and performance of the subjects, therapists can revise appropriate training schedule and exercises to individual subjects.

Realistically, iBEST is only meant as a self-training and timely assessment solution for subjects with minor balance problems who can conduct required training independently. It is not targeted to replace requirement of therapists in initial rehabilitation and assessment in regaining necessary physical strength. iBEST helps patients who underwent training at clinical in order to continue the prescribed exercises at their home. Regarding to validity of iBEST, the current feasibility study is limited only to evaluation of proposed automated assessment methodology, sBBS with healthy subjects. The evaluation did not compare test outcomes with clinical any of ground truth recording solutions such as force plate or optical motion tracking. Furthermore, the number of subject size is small and there is still room for improving features extraction and balance assessment methodologies.

Future works include evaluation of iBEST with elderly subjects by comparing with ground truth evaluation system including manual BBS rating by therapists to examine the efficacy and performance of iBEST. As current sBBS only include subset of tests items from BBS (46 out of 56 total test items), it is important to validate how this automated assessment is valuable to clinical practice. Besides simple audio cues and feedbacks, it is another area to explore on utilizing gamification concept for better user engagement and exercise adherence [5]. Besides assessing physical aspects of balance, it is important to incorporate evaluation of postural control by subjects who are performing balance exercises in different scenarios [18].

V. Conclusion

The improper and unstable body balance could lead to serious injuries like falls ending to hospitalization and disability. Requirements to conduct regular balance exercises at clinic also lead to costly, inconvenience and inefficient resource usage. iBEST leverages on automated balance assessment approach, sBBS using smartphone sensors. So iBEST provides a body balance coaching system to sense balance states and to manage the training process while providing automated fall risks assessment. iBEST is helping users in conducting balance exercises conveniently to identify balance disorders in timely manner. This will benefit to both patients and therapists as well as clinics in terms of continue regular training, progress review and reduction of resources. In summary, improving postural stability through iBEST will prevent potential fall risks allowing subjects to having more autonomy in everyday activities.

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