Development and Selection of Balance Sensing Devices

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Balance is required for many functional activities of daily life. Qualitative or quantitative balance assessment is frequently used in the diagnosis of neuro-muscular diseases, in treatment or therapy monitoring, and for performance assessment in sports training programs. In the last years, various technologies were developed for balance or posture analysis with the main focus on sensors and reliability of the measurements. We discuss the questions related with the development of a balance assessment system, which might facilitate the design or selection of components for balance sensing and training.

Introduction

In human biomechanics, balance is defined as the ability to keep the body's center of mass (COM) within the limits of the base of support [1]. The generic term balance indicates the dynamics of body posture to prevent falling. It is related to the inertial characteristics of body segments and the inertial forces acting on the body. Maintaining balance during a certain body posture depends on the muscle-skeletal characteristics, a rich and fine integration of many sensorimotor processes in our body, functionality of nervous system motor control, the goal one is trying to accomplish, and the surrounding environment. We take for granted good balance when we have no difficulty getting out of bed or rise from a chair without stumbling, or when we walk in stable equilibrium across a gravel driveway. However, with impaired balance many functional activities of daily life that require mobility and fall avoidance are realized with higher perceived effort and are sometimes dangerous. Balance impairment is produced in many neuro-musculoskeletal disorders (e.g., vestibular deficits, cerebellar diseases, stroke, cerebral palsy, scoliosis, Parkinson's disease, peripheral neuropathies, amputation). Various degrees of impaired balance have been described in elderly people [2], [3]. Assessment of balance abilities is important for the diagnosis of potential impairment in postural control [4], evaluation and monitoring of physical exercise training effects [5], identifying fall risk [6], and forecasting mortality risk [7].

Many techniques and methods are presently employed for balance assessment, and different qualitative and quantitative variables are measured for balance and postural analysis. Through qualitative analysis, the mechanical, musculoskeletal and neurophysiological features of posture and balance are described. In many cases, the technology used in this analysis is a stopwatch or a watch. Progress in sensor development and computer performance increased the abilities of many health professionals or sports trainers to make quantitative measurements that have given new insights to understanding the mechanisms of balance and posture changes during activities of daily life, sports performance or in diseases. The objectives of this work were: to identify the balance devices that are commonly used and their main characteristics; to describe our approach in balance device development; and to define framework for tailoring the hardware and software for balance sensing, taking into account situational context and targeted balance improvements.

Balance Tests

Non-Computerized Tests

In the literature, specifically designed tests for balance analysis as well as assessments of balance through posture or gait analysis were described. A systematic review of balance tests in resistance training identified 68 types of balance evaluation [8]. Techniques have been designed to evaluate balance in many situations including:

- unconstrained standing,
- standing unsupported, with feet together,
- open eyes or closed eyes,
- tandem standing and walking,
- walking stance,
- standing on one leg,

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Table 1 – Examples of standardized balance test		
Standardized balance tests mainly without computer technology	**Examples of commercially available *force platforms***	**Examples of commercially available *pressure mats***
360 Degree Turn Test	Kistler	Teckscan
Balance Evaluation System Test (BESTest)	Midot	GAITRite
Berg Balance Scale (BBS)	AMTI Accusway	XSensor
Community Balance and Mobility Scale (CB&M)	Bertec	SAMBalance Lab
Fullerton Advanced Balance Scale (FAB)	TreadMatrix	Swing Catalyst Balance Plate
Functional Ambulation Classification (FAC)	Sensix	Podoprint Namrol
Mini Balance Evaluation Test	Pasco Force Platform	SLIM, Elftman – Podotec
Modified Physical Performance Test	Innervation Performance Force Platform	Win-Pod and Win-Posture from Medicapteur
Postural Assessment Scale for Stroke Patients	Arsalis	Gaitview - allFoots
Push and Release Test	Nintendo Wii	
Retropulsive Pull Test	Vernier Force Platform	
Romberg Test	Fitness Technology	
Sharpened Romberg Test	VertigoMed Balance	
Short Physical Performance Battery (SPPB)	Kistler	
Single Leg Stance Test	Midot	
Step Test	AMTI AccuSway	
Time Up and Go (TUG)	Bertec	
Timed Unipedal Stance Test (Single Leg Support, One Leg Stance Test)		
Tinetti Performance-Oriented Mobility Assessment (POMA)		
Trunk Impairment Scale		
Unified Balance Scale		

- standing on foam,
- step up and over,
- balance in sitting and lying,
- balance during posture change from sitting to standing, and from standing to sitting,
- balance during transfer from bed to chair or from one chair to another chair,
- balance during retrieving objects from floor,
- reaching forward while standing, and
- balance during turning 360 degrees.

Examples of standardized balance tests that can be realized mainly without computerized technology are presented in Table 1. Their description, information on validation, area of assessment, type of training required, cut-off scores, and a bibliography for many of these tests are found in an online Rehabilitation Measures Database. Currently, the Berg Balance Scale, Tinetti Test, and Mini Balance Evaluation System are mostly used for balance evaluation in clinical settings.

The Sibley team [9] classified the dimensions evaluated through balance tests in:

- *Postural component* - relationship between body segment and appropriate orientation with respect to gravity;
- *Static stability* - ability to stand unsupported controlling the center of mass when the base of support does not change;
- *Dynamic stability* - ability to weight shift, controlling the center of mass within the base of support;
- *Reactive control* - corrective movements (e.g., ankle, hip, and stepping strategies) to recover stability following an external perturbation to bring the center of mass within the base of support;
- *Balance within functional tasks* - walking, turning, reaching;
- *Underlying motor systems* - strength, coordination;
- *Underlying sensory systems* - vision, vestibular, sensation; and
- *Underlying cognitive contributions* - attention, fear, confidence.

Therefore, choosing a test and technology for balance assessment depend on situational context (e.g., laboratory research or clinical setting, outdoor or indoor setting) and task demands (e.g., quiet standing, walking, jumping, etc.).

Technology for Balance Analysis

Force Platforms

Force platforms are made of a dimensionally stable board under which sensors are positioned. Information on body balance might be obtained by using various types of force plates. There are force plates that measure ground reaction forces by using 1 to 5 sensors - often presented as *force platforms.* When pressure is applied simultaneously to a force plate in multiple points in a dynamic and detailed pressure map, it is named *pressure mat*. Also, examples of commercially available *force platforms* are listed in Table 1.

Adaptation of the bathroom scale was also presented as an accurate force plate [10]. Examples of commercially available *pressure mats* are listed in Table 1, which give rich information on balance, weight transfer, and gait by sensing distribution of pressure applied to a force plate.

Force platforms might be also classified into two categories:

- a *monoaxial force plate* is equipped with monoaxial load cells (i.e., those based on beam, strain gauge, or one component piezolecetric sensors) that only measure the vertical component of the ground reaction force (Fz); and
- *multiaxial force plates* that are equipped with strain gauges, Hall Effect or piezoelectric sensors that measure the three components of the ground reaction force (Fx, Fy, and Fz) and the three orthogonal moments (Mx, My, and Mz). A wide variety of piezoelectric, strain gauge or Hall Effect sensors for 1 component or 3 component ground reaction force acquisition are commercially available (e.g., Kistler, Vetek, Honeywell, Phidgets, Applied Measurements, SparkFun).

Force platforms are an important tool in balance assessment. The measurement of balance using a force balance might be done: in constrained or unconstrained quiet standing; in challenging postural conditions to evaluate postural performance; or by motor disturbance (mechanical disturbance), sensory stimulation (sensory manipulation) or cognitive disturbance (e.g., virtual stimulation, dual-task) protocols to test for postural strategy. Force plates might be included in motorized equipment that produce platform perturbation (e.g., GeaHD, Biodex Balance System SD). The motorized platform can translate horizontally, displace vertically, and the base can rotate the feet.

The control of whole body posture during upright standing has been modeled as an inverted pendulum oscillating about a fixed position, and balance control was mainly characterized as a process of maximizing the time the body center of pressure (COP) would take to obtain the stability boundaries at any instant [1], [11]. The COP expresses the position of the resultant vertical component of the ground reaction force applied to the body at the force plate. The COP is a two-dimensional position that is dependent on the acceleration of the body and its segments. It represents a weighted average of all the pressures over the surface of the area in contact with the ground. Its units are meters (m).The trajectories of the COP, in both anteroposterior (AP) and mediolateral (ML) directions, are reported in the literature for quantitative descriptions of balance control. Both uni- and multi-axial plates can be used to calculate the ML and AP time series of the COP [1], [12]–[14]. The COP should not be considered the center of mass. The COM is a point equivalent of the total body mass in the global reference system and is the weighted average of the COM of each body segment in a 3D space. The vertical projection of the COM onto the ground is called center of gravity (COG). Although COP displacement can be easily measured with a force plate, the direct measurement of COG is more complicated and typically subject to a larger error. The direct measurement of COG is computed by recording the position of each body segment and estimating each segment mass, using an anthropometric model [11]. More commonly, the displacement of COG is indirectly determined from the COP displacement, and different methods are available [12]. If one foot is on the ground, the *net* COP lies within that foot. If both feet are in contact with the ground, the *net* COP lies somewhere between the two feet, depending on the relative weight taken by each foot. When both feet are in contact, there are separate COPs under each foot. When one force platform is used, only the *net* COP is available [13], [14]. Two force platforms are required to quantify the COP changes within each foot, especially if body weight distribution asymmetry is suspected, as with hemiparetic or amputee patients. It is common in the literature to describe the sum of absolute COP as *sway* path, although sway is more related with COG.

COP displacement during a standing task can be visualized in two ways: in *statokinesigram* and *stabilogram* plots (Fig. 1). The statokinesigram is the map of COP displacement in the sagittal plane (AL direction) versus the COP displacement in the frontal plane (ML direction). The stabilogram is the time series of the COP displacement in each direction [1], [14]. Fig. 1 illustrates the increase in oscillations of COP (Fig. 1c) and the pressure map for the different ankle strategy (Fig. 1f) employed for balance control with closed eyes.

Wearable Devices

Accelerometers, gyroscopes, magnetometers, inertial measurement units, and electro-goniometers are proposed as reliable and low cost alternatives for recording postural change, movements and body balance [14] both in clinical settings as well as in sports training or research on neuromuscular mechanisms involved in balance control. These devices might be positioned at head level, on the posterior trunk, at pelvis level, on specific joints (e.g., wrist worn device), or on arms and/or legs.

Electromyography (EMG) might also be used to analyze the neuromuscular component of balance. EMG analyses have been used to characterize postural responses following platform-movement disturbances or anticipatory postural adjustments with voluntary movements [15].

Video Capture

High level of accuracy and reliability of the small motions which characterize unperturbed upright stance, balance during gait analysis or sport performance tests might be obtained with video recording (e.g., Vicon MX3, Fastrack), mainly when a 3D motion capture system is used. Three different technologies can be identified. Video capture based on passive marker systems uses reflective markers with a set of

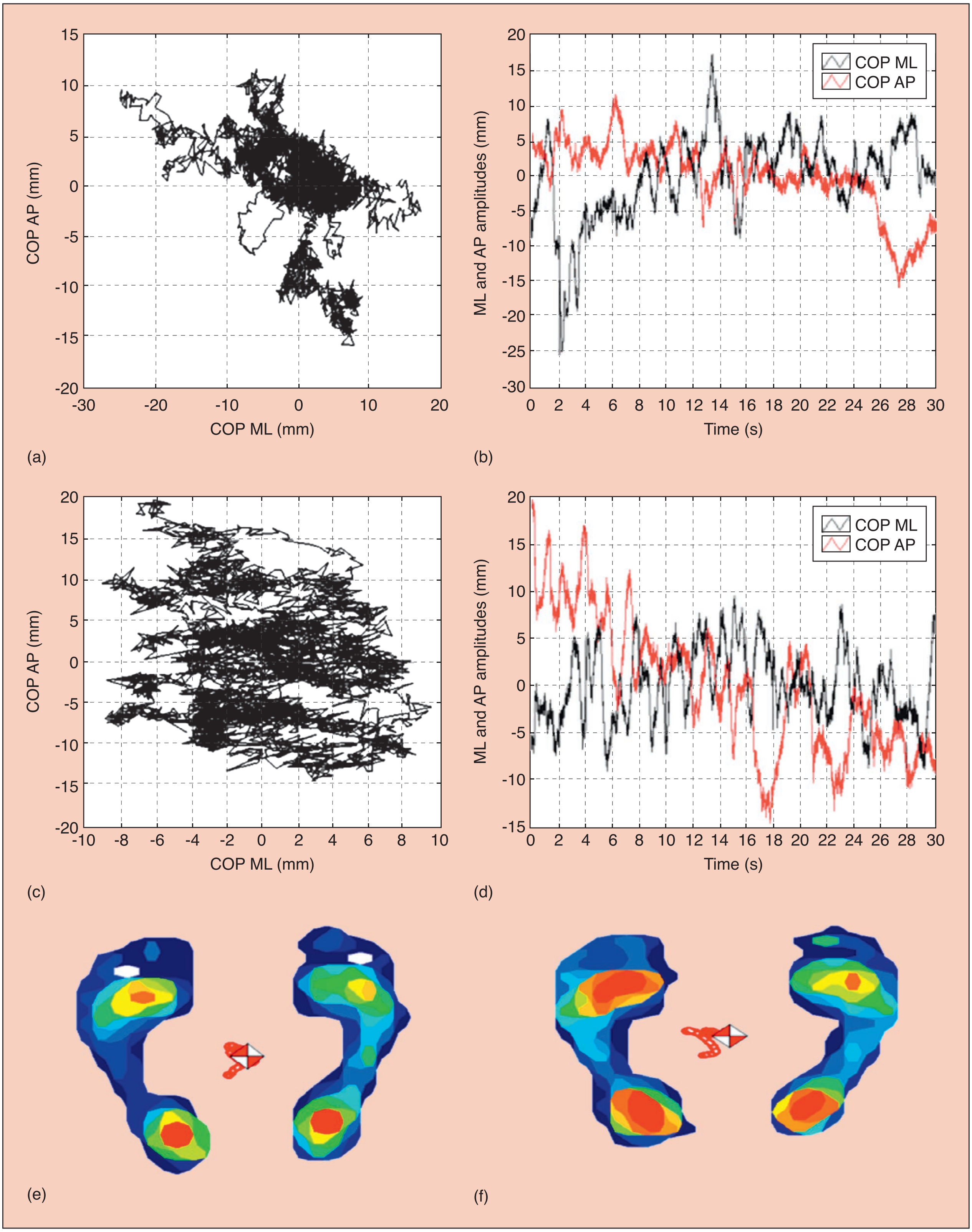

Fig. 1. Technologies for balance analysis: (a) A statokinesigram from an unconstrained standing position. (b) A stabilogram obtained from an unconstrained standing position. (c) A statokinesigram. (d) A stabilogram obtained in standing with closed eyes. (e) A pressure map of both feet during unconstrained standing and (f) with closed eyes, respectively.

further high-resolution, high-speed cameras with incorporated infrared/near infrared strobes. The cameras record the reflection from the markers that are placed on specific anatomic landmarks whose identification is performed thanks to the software. Video capture based on active marker systems uses powered markers sending an infrared signal, which is captured by sensor units. Each active marker has its proper frequency. Active marker systems require small powered boxes to be attached to the subjects' skin [14]. Video capture using a color (RGB) camera and depth sensor like in Kinect (Microsoft motion sensing input device) has the advantage of low cost and unobtrusive measurement of movements. Using an infrared projector and camera and a special microchip, the Kinect system tracks the movements of objects and individuals in three dimensions.

What Makes Sense in Balance Sensing Technology?

Many questions arise when deciding what makes sense in the development or selection of a balance device.

Who Would Use It?

Balance devices might be used by physicians specialized in neurology, physiatry, orthopedics, geriatrics, sport medicine, and rehabilitation medicine, by therapists such as physiotherapists or occupational therapists, by researchers in sports performance, or by patients training in balance exercises at home, at fitness clubs, etc. Therefore, the features and functionality of the balance device should be adequate to end-user needs and expectations.

What Is the Application?

Balance assessment might be done in quiet standing, standing/sitting combined with another activity (i.e., manual reaching, visual orienting, initiating gait, sport exercise). The designer and end-user should prioritize, per task, which devices are optimal for each task, acceptable for the task, or not possible for a task.

What Best Fits the Context?

The first consideration is what best fits the activity, situation, and user needs. Features that are essential to one device may be inessential or even inappropriate for others. Force plates, inertial measurement units, combined with serious games might transform supervised personalized training programs for patients into an interactive, fun and competitive experience with high results. The ability to analyze a person's movements and balance in 3D provides extraordinary reporting features, and the fun and competitive element of the games enhances patient compliance, leading to greater results in the patient's rehabilitation. Therefore, low cost balance devices combined with serious games for balance assessment might be used in clinics, hospitals or research labs in a single training program or a program that lasts multiple weeks. This type of device may engage the subjects in balance monitoring and might extend the treatment or training options.

Is the Device Robust?

Strain gauge technology has advantages with regard to long-term stability [16]. With piezoelectric measurement technology, it is practically impossible to implement a test setup with infinite insulation resistance.

In practice, there is often a drift of about 1-N/min, which is why measurement has to be restricted to a few minutes, subject to the requirements of the measurement task. With strain gauge based sensors, the full Wheatstone bridge circuit can achieve excellent linearity. This avoids having to compensate for additional interference effects such as temperature variations. It also makes strain gauge sensors more suitable for high-precision measurement tasks in partial load areas, such as for reference transducers. When space is tight and installation restricted, the piezoelectric sensor is perfect. With the same measuring range and similar performance characteristics, the piezoelectric transducer is up to thirty times smaller in construction than a comparable strain gauge transducer. Their high natural frequency makes them ideal for dynamic applications but not for long term measurement. When measuring with piezoelectric sensors, there is virtually no displacement, as the quartz already forms the mechatronic component with an electrical output signal. The sensitivity of a piezoelectric sensor does not usually depend on its size or on the volume of quartz but on the material being used and its geometry [16].

What Is the Main Purpose of the Device?

Different hardware and software should be designed or selected when the device is used only for balance or posture diagnostics rather than for better understanding motor control and mechanisms involved in sport performance or for training balance in clinical settings or in various types of sports. Generally, in clinical settings the patients with impaired balance are characterized by more time intervals of neurophysiological control in posture changes. When monitoring balance changes in sports (e.g., vertical jump), higher sampling frequencies are required for force plates than in clinical settings. If in clinical settings frequencies of 100 Hz are adequate to diagnose some balance impairments, research work on sports performance requires force plates with signal frequency acquisition of 500 Hz or 1000 Hz for greater accuracy in balance or posture analysis, especially when impact is involved [17]. If the frequency is low, for example 200 Hz, during the first 50 ms of force application, this corresponds to a force-time curve consisting of only 11 data points. This will not provide ample resolution with which to examine the changing forces in this short period. Also, sensor measuring ranges should be higher when subject tasks might include jumping (e.g., Fx-Fy between 10000-20000N; Fz 20000-40000N).

How Accurate Does Sensing Need to Be?

Good assessment of sensor characteristic, hysteresis, calibration, sampling frequency, signal amplification and processing all contribute to good accuracy of the balance device. These questions may help:

- *What functionality and interfaces does it have?*

- *What interaction capabilities do the devices have?*
- *Might the interface cost-effectively be tailored to end-user needs?*
- *Does it need to be used by third parties, through web or mobile app, such as in tele-rehabilitation or on-line training?*
- *The device allows collection of large data, for long interval?*

In our work [18], we design a force platform based on four strain gauge sensors installed under an acrylic plate, where the system is used to measure the ground reaction force applied by a subject during serious game playing in a physiotherapy session. The voltages delivered by the load cells (VL1, VL2, VL3, and VL4) were applied to the differential inputs of a four-channel amplifier module based on INA122 instrumentation amplifier. The single channel conditioning circuit is presented in Fig. 2. The characteristics of INA122 are: typical offset voltage = 150 uV, CMRR = 96 dB, bandwidth (-3 dB) = 5 kHz for G=100, slew rate=0.08 V/us. The amplified values of the load cells signals are filtered using analog active filters or digital filtering as part of the developed software. The analog active filters are a 2nd-order Butterworth low pass filter with 15Hz cut-off frequency that permits to reduce the power network interferences (e.g., 50Hz signals). The conditioning circuit outputs were applied to the analog inputs of a Shimmer3-Proto3 mini extension board that has four analog inputs (AI) AI1, AI12, AI13, AI14 that are associated with a 12 bit ADC. The Shimmer3 module is based on a TI MSP430 microcontroller that is connected to a Bluetooth transceiver used to transmit the acquired data to the computer (i5 mini PC). The sampling frequency was 128S/s. Considering the level of the signals provided by the sensors and the environment of the electromagnetic interference signals, particularly at 50Hz, a set of digital low pass Butterworth and Elliptic filters was designed and implemented.

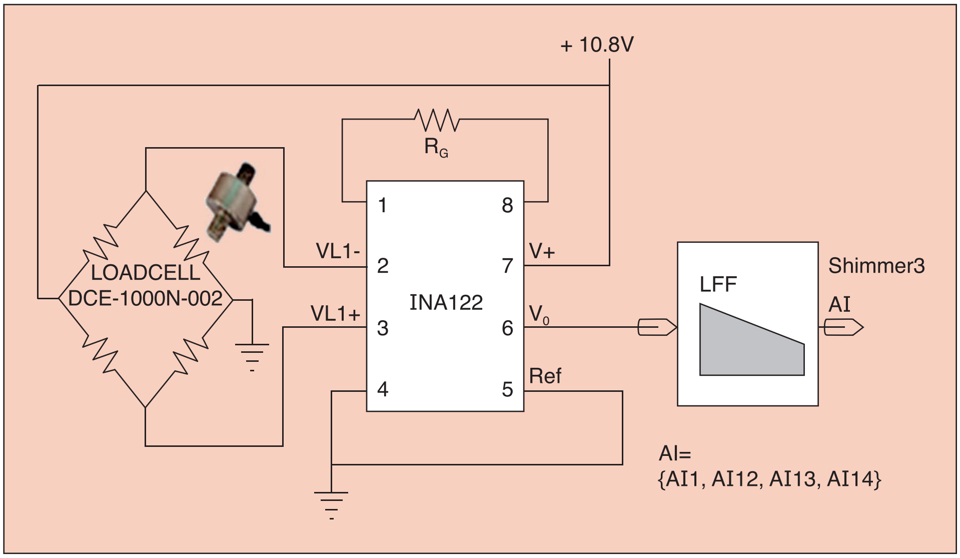

Fig. 2. Load cell channel conditioning circuit. (© 2016 IEEE, *in Proc. Med. Meas. & Appl. Symp.*, used with permission, [18].)

The COP coordinates were calculated taking into account the resulting force moments along the y-y' (AP) and x-x' (ML) axis (Fig. 3).

$$\sum \overrightarrow{M_{Flyy'}} = 0 \tag{1}$$

$$F_3 \cdot \frac{L}{2} + F_4 \cdot \frac{L}{2} - F_2 \cdot \frac{L}{2} - F_1 \cdot \frac{L}{2} + F \cdot X_{COP} = 0 \tag{2}$$

$$\sum \overrightarrow{M_{F|xx'}} = 0 \qquad \sum \overrightarrow{M_{Flxx'}} = 0 \tag{3}$$

$$F_2 \cdot \frac{L}{2} + F_3 \cdot \frac{L}{2} - F_1 \cdot \frac{L}{2} - F_4 \cdot \frac{L}{2} + F \cdot Y_{COP} = 0 \tag{4}$$

$$F = F_1 + F_2 + F_3 + F_4 \tag{5}$$

where F is the ground reaction force measured by each sensor. The values of forces are calculated based on the voltages associated with the load cells' channels and the gain values (G_i) considered for each channel:

$$F_i = M \cdot g \cdot \frac{V_{F1}}{V_{supply}} \cdot \frac{1}{S_{Fi}} \cdot \frac{1}{G_i} \qquad i = 1 \ldots 4 \tag{6}$$

where the gain is imposed to provide high accuracy analog to digital conversion using the maximum number of bits of the 12 bit analog to digital converter.

The COP coordinates are calculated based on following relations:

$$X_{COP} = \frac{F_1 + F_2 - F_3 - F_4}{F_1 + F_2 + F_3 + F_4} \cdot \frac{L}{2} \tag{7}$$

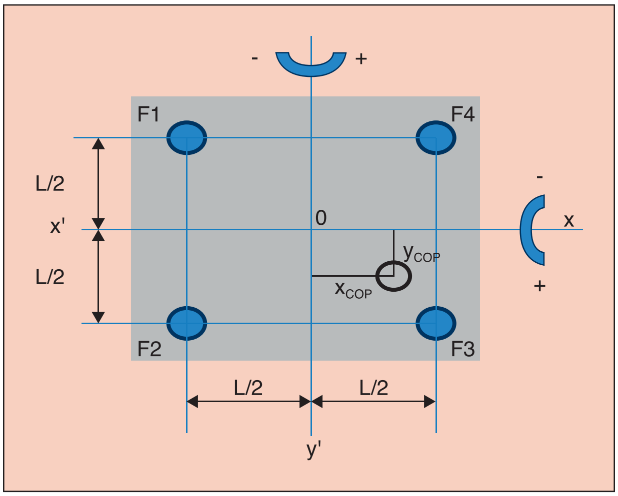

Fig. 3. Position of sensors and axis representation for COP assessment. (© 2016 IEEE, *in Proc. Med. Meas. & Appl. Symp.*, used with permission, [18].)

Fig. 4. K-Theragame virtual graphical user interface. (© 2016 IEEE, *in Proc. Med. Meas. & Appl. Symp.*, used with permission, [18].)

$$Y_{COP} = \frac{F_1 + F_4 - F_2 - F_3}{F_1 + F_2 + F_3 + F_4} \cdot \frac{L}{2} \tag{8}$$

where L for the force plate developed in our lab is 40 cm.

Our developed system for balance analysis integrates signals from the force platform with signals from Kinect sensors in a mini PC through Bluetooth communication. The Kinect sensors provide information on user's joints co-ordinates. The developed system calculates the correlation between COP coordinates and upper limb position and velocity. The information provided by Kinect and the force platform is primarily processed at the mini PC level and delivered through Wi-Fi Internet connection to a server where it is uploaded to a database using SQL. Visualization of the stored data can be made also on a laptop or tablet, based on data visualization client applications developed for the physiotherapist use.

Operation of the System

The balance system might aggregate the data to identify trends, or provide analytics or meaning to current readings? What buttons do what? How is the system operated?

The Kinect device allows natural user interface for interaction between the user and virtual reality-based movements. Measurements based on Kinect technology might give rich information on movements of various body segments and should be more adequate on evaluating balance in upper body segments when training balance, particularly in home rehabilitation settings. In our lab, a serious game was developed using Microsoft Kinect SDK and the Unity 3D 4.0 Game engine, the main scripts being developed using C#. Through the motion of his body, the user controls an avatar. The game's main activity is to pick the vegetables from virtual shelves and put them in a pan (Fig. 4). The lateral shelves are divided in three intervals of height and were chosen so that the user must perform 60, 90, and 120 degrees amplitude movements in each shoulder joint with his arm outstretched. The frontal shelves are divided in four intervals of height and were chosen so the user must perform 60, 90, 120, and 150 degrees amplitude movements in the shoulder joint with the arm outstretched. According to the patient rehabilitation needs and limitations, the physiotherapist might establish an appropriate configuration of the game, selecting angles within the 60 to 150 degree interval.

An example of shoulder joint angle variation during arm movements with a Theragame training session is represented in Fig. 5. The motion amplitude expressed by angle values is translated in the game scenario by depositing vegetables only on the shelves that correspond to the required angles for the

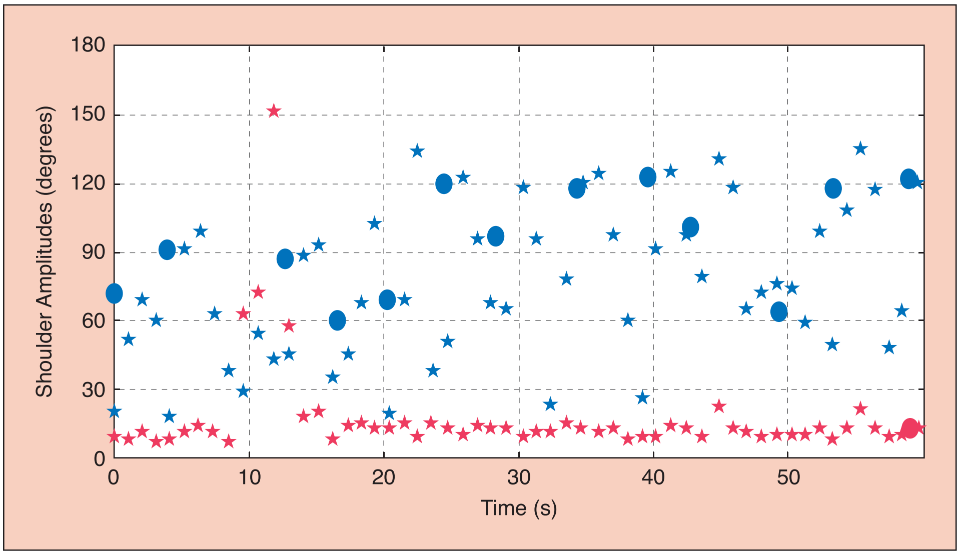

Fig. 5. Arm amplitude movements. Small red stars are angles of the right hand (unused hand during game) and blue stars are the amplitude of the left hand movement during game playing. Blue circles are the amplitude of left hand when an object is picked. (© 2016 IEEE, *in Proc. Med. Meas. & Appl. Symp.*, used with permission, [18].)

imposed upper limb exercises (e.g., 60°, 90° selection means no vegetables on the third and fourth level shelves). The data measured by the Kinect sensors and force plate during the game is stored in the database. The data include the velocities and angles reached during the game.

We measured the variation of the radius of the area covering COP trajectory points during left, right, or left-right arm training with the serious game and changes in pattern of COP trajectories during playing with both arms in comparison with playing with one arm, indicating different balance control. The variables used in the *global analysis of COP* displacement are:

- standard deviation,
- root mean square (rms),
- range of COP displacement,
- sway path,
- resultant sway path,
- area (95% of the COP data inside),
- mean spread or velocity,
- resultant mean velocity,
- power spectral density,
- peak (F_{peak}),
- mean (F_{mean}),
- median (F50) frequency, and
- the frequency band that contains up to 80% of the spectrum (F80) (Table 1).

Structural COP variables are derived from analysis of nonlinear dynamics. Various methods were proposed for stochastic analysis, identification of rambling and trembling subsystems, fractal analysis, sample entropy, approximate entropy, Lyapunov exponent, sway density curve, empirical mode decomposition, the entropic half-life, and rotary spectra approach to derive the structural COP variable [1], [14]. Table 2 gives the common variables used in the global analysis of COP displacement.

More research is required to test their reliability and validate their relevance for clinical applications or to increase performance in sports. The Baratto team [19] examined 38 posturographic measures that resulted from COP time series analysis. They concluded that only two measures derived from global analysis of COP (total sway path and frequency band) and two measures derived from structural analysis by decomposition of COP signal and the sway-density plot are valuable to discriminate three different groups of individuals: normal, Parkinson's patients and osteoporotic patients.

Does the Real-Time Data Acquired by a Balance Device Provide Context-Aware Services?

Augmenting the data with third-party data is often used to provide context on how the data relates to the user: whether it relates to them as a person or to their environment. Understanding what motivates the end users is an important step in designing products and services. The service should also be designed to adapt gracefully if the user refuses or revokes permission, or if the third-party datasets are temporarily unavailable. Intuitable interfaces should be developed for users to control the systems themselves. Moreover, some degree of automation is also needed that might be implemented by building an interface that allows end-users to configure functionality that would run automatically in the future. However, introducing automation to perform actions in the future is a work with high degree of uncertainty because people often have difficulty describing their own current needs, particularly predicting their future needs. Even more challenging to users is the need to anticipate all of the changing conditions to which the system might respond. One technical blogger [20] suggested that we should

> *… stop thinking about products' end-users and start thinking about the system's end-designers. Because that is what we are all becoming as we choose and use network components.*

This meant that using and specially configuring a device for balance sensing might be more like programming than based on perceived needs and experience. The developers and end-user should find the right balance of user control and autonomous system actions.

Table 2 – Usual variables in the global analysis of COP displacement	
Variable	**Description**
Standard deviation (SD) and root mean square (rms)	RMS is defined as the square root of the mean of the squares of a sample. If the COP signal has zero mean, rms and SD provide the same results. SD and rms offer good reliability in discriminating between young and older subjects and those with pathologies.
Range of COP displacement	The distance between the maximum and minimum COP displacement for each direction – the greater the values, the worse the postural stability.
Sway path	Also named path length quantifies the magnitude of the two-dimensional displacement based on the total distance of COP trajectory. The smaller sway path, the better the postural stability.
Area (90% or 95% of the COP data inside)	Ellipse area/surface quantifies 90 or 95% of the total area covered in the ML and AP direction using an ellipse to fit the data. The smaller the surface, the better balance and posture control. The use of prediction ellipses should be preferred over confidence ellipses.
Mean speed or velocity	Is calculated by dividing the COP excursion by the trial time. The smaller the velocity, the better the postural control. COP velocity is considered as the most sensitive parameter when comparing individuals from different age groups and with different pathologies.
Frequency bands distribution	Three frequency bands are usually considered: low frequencies (0-0.02/0.5 Hz) which mostly account for visuo-vestibular regulation, medium frequencies (0.2/0.5 – 2 Hz) for cerebellar participation, and high frequencies for proprioceptive participation (>2Hz).
Power spectral density	Total power frequency is considered an energy expenditure index.
Median (F50) frequency and the frequency band that contains up to 80% of the spectrum (F80)	Mean, median, centroid, and 80-95% power frequency. Higher frequencies of postural sway are indicative of faster postural and balance control. Higher mean and median frequency might be an index of ankle stiffness. Changes in postural control system are better characterized by F80.

Cost of the Devices

And *what is the cost of the device*? The price of a Swing Catalyst Force platform and pressure mat that give accurate and rich information for sports performance evaluation (e.g., during golf swing) is $19, 995. If is necessary to evaluate the COP for each leg, at least two force plates should be purchased. For sport performance evaluation, many force plates are often required. With a price around $100, Nintendo Wii Balance received the 2015 Guinness World Record for the best-selling personal weighing device. Users can select an area for personal improvement, and Wii Fit Plus will suggest a number of diverse activities for them. Laurent Fisher, Managing Director of Marketing and PR of Nintendo Europe said, *The launch of Wii Fit with the Wii Balance Board revolutionized the way people got active at home, making it fun and easy to exercise in the comfort of their own living room*. In the last few years, cumulative evidence was published on the importance of Wii Balance for balance training in clinical settings [21].

Maintaining the System

The buyers should also ask how the device is maintained, what guarantee is provided, how to upgrade the system, and if will be difficult to add new features to devices that are already out in the field?

Connectivity

An important question currently is if the device allows connection with other hardware or software. Making the system to do meaningful and valuable things for users means forming the right connections and helping devices and applications coordinate in the right ways. It is important to check if the device will work with preexisting devices. This depends on what hardware the end-users have, may have, and be familiar with using. Also, it is important to consider what connectivity and power issues are important.

The availability and reliability of the network connection is also key for development or selection of the balance assessment system. The proliferation of different standards means that getting devices to work together is hard. Many devices are locked away in proprietary ecosystems, because frequently that is the easiest way to get them to work.

In information technology, interoperability refers to *the ability to transfer and render useful data and other information across systems, applications and components* [22]. Palfrey and Gasser extend their theory of interoperability beyond technology to consider data, human and institutional layers. They define *interoperability on the data layers as the ability of devices to understand each other when messages are passed between them*. *Interoperability in the human layer* means that the people involved in the exchange of information can understand and act effectively on the information [22]. For instance, the information received from personal health records (e.g., from a wearable device) into electronic health records should be relevant and operable for a neurologist or other health professionals working with that patient. *The institutional layer* is considered the extent to which societal systems can engage effectively around the system [22]. Interoperability is great for users. It broadens the choice of products, letting them mix and tailor the products and services from multiple vendors to suit their own needs. But businesses often think that their interests are best served by keeping their technology proprietary and non-interoperable. The lack of interoperability with other devices and systems is seriously limiting its potential value and usability. Users will expect devices to work together, but right now many do not.

User Experience

In design and development of a balance measurement system, it is also important to understand the experience that the end-user will have with the cross-platform for balance sensing. Cross-platform systems develop software for or run software on more than one type of hardware [23]. In cross-platform, the flow of data and interactions is realized in a coherent sequence across devices. The user should feel as if they are interacting with the service through the devices not with a bunch of separate devices. Data and content must be synchronized, and cross-device interactions must be clearly signposted.

The connected devices or cross-platform for balance sensing must allow inter-usability. It is important to evaluate the user experience across multiple devices – coined by Charles Denis and Laurent Karsenty in 2004 as "inter-usability" [24].

The balance device should have a universal design. Universal design is a term coined by architect Ronald Mace [25] to describe the concept of designing all products and the built environment to be aesthetic and usable, to the greatest extent possible, by everyone, regardless of their age, ability, or status in life. Similar to *design for all*, rather than designing for certain disabilities, the approach aims to create a design solution that works for everybody, whether disabled or not. He introduces seven principles of universal design: equitable use; flexibility in use; simple and intuitive use; perceptible information; tolerance for error; use of designed product with low physical effort; and appropriate size and space for approach and use.

In conclusion, the researchers, developers and buyers of balance assessment devices need to strike the right balance.

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