

# Ghersi, I.; Castro Arenas, C. F.; Borsoi, P. D.; Miralles, M. T.

# Force plate calibration and setup for assessments of human balance

Postprint de la colaboración en la obra:

Torres I., Bustamante J., Sierra D. (eds) VII Latin American Congress on Biomedical Engineering CLAIB 2016, Bucaramanga, Santander, Colombia, October 26th-28th, 2016. IFMBE Proceedings, vol 60. Springer, Singapore: 2017.

Este documento está disponible en la Biblioteca Digital de la Universidad Católica Argentina, repositorio institucional desarrollado por la Biblioteca Central "San Benito Abad". Su objetivo es difundir y preservar la producción intelectual de la Institución.

La Biblioteca posee la autorización del autor para su divulgación en línea.

Cómo citar el documento:

Ghersi I., Castro Arenas C.F., Borsoi P.D., Miralles M.T. Force plate calibration and setup for assessments of human balance [en línea]. En: Torres I., Bustamante J., Sierra D. (eds) VII Latin American Congress on Biomedical Engineering CLAIB 2016, Bucaramanga, Santander, Colombia, October 26th-28th, 2016. IFMBE Proceedings, vol 60. Springer, Singapore: 2017. https://doi.org/10.1007/978-981-10-4086-3\_50 Disponible en: http://bibliotecadigital.uca.edu.ar/greenstone/cgi-bin/library.cgi?a=d&c=investigacion&d=force-plate-calibrations-setup [Fecha de consulta: ....]

# Force Plate Calibration and Setup for Assessments of Human Balance

I. Ghersi<sup>1,2</sup>, C. F. Castro Arenas<sup>1,3</sup>, P. D. Borsoi<sup>1</sup>, M. T. Miralles<sup>1,2</sup>

<sup>1</sup> Pontificia Universidad Católica Argentina. Facultad de Ciencias Fisicomatemáticas e Ingeniería. Laboratorio de Biomecánica e Ingeniería para la Salud. Ciudad Autónoma de Buenos Aires, Argentina.

<sup>2</sup>Universidad de Buenos Aires. Facultad de Arquitectura, Diseño y Urbanismo. Centro de Investigación en Diseño Industrial de Productos Complejos. Ciudad Autónoma de Buenos Aires, Argentina.

<sup>3</sup>Universidad de Buenos Aires. Facultad de Arquitectura, Diseño y Urbanismo. Instituto de la espacialidad Humana, Centro Laboratorio de Morfología. Ciudad Autónoma de Buenos Aires, Argentina.

Abstract—Repeatable, quantitative evaluations of human balance rely on thorough characterizations of the devices and sensors used in measurements. Given the growing concern on this field, the research group has developed dedicated devices for the assessment of gait and balance, including a force plate. In this work, a calibration procedure for this force plate is devised and implemented, based on a calibration device which combines versatility, ease of use, and low-cost, and on reference weights. The procedure is detailed, and its results are shown, indicating a positive response for the device, and proving a superior fit compared to the theoretical estimation of its behavior. Based on this improved knowledge on the designed force plate, a dedicated signal-analysis tool is shown, incorporating calibration results and curves. Finally, examples of use of this tool are detailed, with standing balance registers from a control subject, indicating the resulting capabilities of the whole system as a promising tool for the assessment of human balance.

Keywords-Balance, force plate, calibration, curve-fitting.

# I. INTRODUCTION

Gait and balance disorders are a growing concern for healthcare institutions. While many devices and tests have been elaborated over the past decades, the quantification of human balance remains decentralized, with no unified standard or method for the acquisition or analysis of results. As populations grow older [1] the reliable evaluation of risk of falls becomes a necessity. In this context, force plates have been used for research and clinical purposes over the past years [2], while differences between signal processing and mathematical models [3, 4] applied to their signals results in a difficult-to-trace, large number of non-uniform results. As part of a research effort into accurately quantifying gait and balance, the research group has worked in the development of specialized devices for the quantification of motions and ataxias. Among these, a wearable acceleration sensing device was developed [5], as well as a force plate. Given the need to validate results coming from the latter, a low-cost, versatile calibration device and procedure was developed, which is shown in this work. The calibration

procedure is detailed, from its requisites to its implementation, and compared to other research efforts in this field. As a result, the response of the force plate is characterized. Finally, records from a test subject are shown, as obtained through a dedicated application, incorporating the calibration results and specific filters, illustrating the performance capabilities of the system.

#### II. FORCE PLATE CALIBRATION

#### A. Background

Force plates rely on multiple load sensors (usually four) to dynamically estimate the weight of a subject ( $W_0$ ), and the relative position of the center of pressure (CoP) in two orthogonal axes (i.e. Anterior Posterior-AP and Medial Lateral-ML). These sensors support a stable, flat surface, capable of holding large weights and sustaining their motions without experiencing deformations during tests. The actual weight of the support surface ( $W_s$ ) is therefore added as an offset value in such a way that, when considered ideally distributed, it is equivalent to placing  $W_s$  at the center of the force plate [6]. When adding the weight of another object or subject, the actual, measured CoP (CoP<sup>M</sup>), will be affected by this force, so that the ratio between the coordinates of the CoP of the object (CoP<sup>R</sup>) and CoP<sup>M</sup> will be, for the AP and ML directions:

$$\mathbf{r}_{\mathrm{C}} = CoP^{R} / \mathrm{C}oP^{M} = (\mathbf{W}_{\mathrm{O}} + \mathbf{W}_{\mathrm{S}}) / \mathbf{W}_{\mathrm{O}}$$
(1)

Therefore, for a fixed  $W_S$  the ratio between real and measured coordinates ( $r_C$ ) becomes a function of body weight. While this background allows estimating CoP coordinates, a validation for the real, precise behavior of force plates is needed, especially for dedicated designs, and for the assessment of the stability of the behavior of any device over time.

# B. Requisites

The basic premise for calibrating a force plate requires the fixed positioning of a number of known weights at known positions on the device, resulting in calibration functions or matrices. For this purpose, specific devices have been developed as part of research solutions [6, 7]. While some of these require versatile, elaborate mechanics and active closed-loop control, others rely mainly on knowledge about the behavior of the force plate to determine an overall response characteristic. A dedicated device, combining characteristics of these, was developed as a low-cost, simple to use reference for the creation of calibration curves and analysis of force plates.

# III. MATERIALS AND METHODS

# A. Force Plate

A dedicated force plate (figure 1), developed by the group, was designed in order to assess static balance and specific gestures over a broad range of subjects (older adults, young athletes, etc.). This device includes four uniaxial load cells (Soehnle SEB4A [8]), with a capacity of 490.3 N in the vertical direction (combined error  $\pm 0.017\%$ ), resulting in a maximum capacity of 1961.2 N for the plate over a flat surface of 0.50 m by 0.50 m. Outputs from the load cells are amplified and acquired at a sampling rate of 60 Hz, through a 12-bit Analog-to-Digital converter, and later accessed by a dedicated application that updates the CoP plot in real time, while saving records on a text file. CoP coordinates, CoP offset values (which are independent of W<sub>0</sub>), raw signals and event indicators are calculated and saved into this file, which is, as a result, available for further analysis. This dedicated force plate was developed by the group as a research effort, in order to promote a higher flexibility and upgraded capabilities for the system, in combination with other devices that have been developed for the study of human balance: its architecture allows incorporating combined trigger functions for these devices, and programmable sample rate, with dedicated filters, analysis tools and user interfaces, and the further possibility to upgrade and embed signal processing algorithms (such as the calibration function) into the device in the future.



Fig. 1 Force plate layout, SEB4A load cell (top-left), and derived signals (right: Center of Pressure Coordinates CoP<sub>AP</sub>, CoP<sub>ML</sub>, and Weight W<sub>o</sub>)

#### B. Calibration device and accessories

The proposed calibration device (figure 2) consists on a spinning surface, weighing  $44.7 \pm 0.7$  N, which smoothly rotates over a strong axis supported by three equidistant bases, guaranteeing the constant distribution of a rotating weight over its full rotation. As a consequence of this setup, and considering that the calibration device adds a specific weight, equivalent weight and radius values have to be calculated, through a similar transformation to the one defined in equation (1), in order to estimate the real CoP coordinates to be fitted in defining the calibration function.

This layout allows tracing curves (i.e. circles, under ideal conditions), following the path of the  $\text{CoP}^{\text{M}}$  in both axes, while weights are rotated. Through the tracing of these shapes, a further understanding concerning the fine, joint response of the load cells, and the CoP coordinates, can be achieved. This layout also allows positioning weights on top of the rotation axis, as well as weights over the rotating surface. In this way, this device can be used under a significant number of combinations, achieving both large distances from the center of the device and sustaining significant weights. An adaptable motor can also be added to the device, in order to provide slow, constant rotations of the equivalent weight.

Grading marks, specific to this device, have been developed with the aid of CAD tools, and fitted to the device and platform, in order to guarantee the fixed placement of the calibrating device, and of each weight, at different distances from the axis of rotation (resolution  $\pm 1.0$  mm). Known weights were combined, resulting in a large number of curves for different equivalent weight values and distances from the center of the device, as shown in figure 2. The force platform was leveled during testing.



Fig. 2 The calibration device is positioned over the plotted surface of the platform. Rotation of combined weights allows tracing calibration patterns.

#### C. Calibration curve estimation, analysis and system setup

Table 1 specifies the traces and static measurements involved in the calibration procedure. The relationship between measured and reference  $W_0$  values, as well as the value of  $W_s$  (offset), were estimated by placing static weights on the plate. Measurements from a single-sensor force plate (Vernier FP-BTA, resolution  $\pm$  0.3N) were used as reference in determining this response. In order to define the calibration functions, force plate measurements were performed with the calibration device for up to five distances from its axis and different weights. Slow rotations were repeated three times in each case, and signals were filtered with a Hamming window digital filter ( $F_{cutoff}$ =1.0 Hz), for analysis. Based on these traces, ellipses were fitted with a modified least-squares method [9] solving equation 2:

$$\left(\frac{CoP^{M}{}_{AP}-Z_{AP}}{S_{AP}}\right)^{2} + \left(\frac{CoP^{M}{}_{ML}-Z_{ML}}{S_{ML}}\right)^{2} = 1$$
(2)

where parameters  $Z_{AP}$  and  $Z_{ML}$  are the central coordinates of the ellipse (center of the calibration device), and  $S_{AP}$  and  $S_{ML}$  are the respective axis values of the fitted shapes. This model assumes no significant rotation for the ellipses. Results from this method allowed inferring ratios between  $CoP^R$  and  $CoP^M$  as functions of  $W_0$ , and therefore calibration curves of  $r_C$  in both axes. These were compared to the ideal curve (equation 1) resulting from the calculated  $W_S$ value. Error curves, eccentricity and linearity were characterized, and the derived functions were implemented on a dedicated analysis tool.

Table 1: Traces and measurements used for calibration, both with the calibration device (rotation) and with static weights on the force plate

Weight rotation over axis							Static weight on		
Equivalent	Calibration Traces: Equivalent Radius (mm) *						force plate surface		
Weight (N)							Weight ( $W_0 \pm 0.6$ ) N		
$73.0\pm0.7$	36.4	45.6	54.7	6	53.8	72.9	26.6	47.8	56.5
$101.3\pm0.7$	55.8	66.9	78.1	8	39.2	100.4	96.2	145.2	196.3
$141.5\pm0.7$	68.4	75.3	82.1	88.9		95.8	291.5	388.3	486.8
$184.5\pm0.9$	52.1	57.4	62.6	67.8		73.0	*Propagated uncer-		
$246.8\pm0.5$	14.4	18.3	22.2	2	26.1	30.0	tainty specific to		ic to
$294.6\pm1.1$	15.3		18.6	2		1.9	each value		

# IV. RESULTS

#### A. Calibration results

The relationship between averaged static measures of  $W_0$  by the device (measurement time:  $t_m>30$  s), and the acquired reference values, proved to be linear (offset  $W_s = 262.1$  N) with a coefficient of determination  $R^2=1.0$  for a linear fit.

Rotation of the equivalent weights from Table 1 resulted in adequate traces by the force plate (example in Figure 2). Relative error between traces and fitted ellipses was plotted as a function of rotation angle, showing no significant trends compared to noise levels, reinforcing the assumption of elliptic traces with dominant AP and ML axes. Given the multiple traces acquired for each weight, a measure of linearity (optimal value: 1.000) was tested for changes in  $S_{AP}$ and  $S_{ML}$ , in relation to the corresponding relative increases in equivalent radius. This resulted in values of (0.999 ± 0.009) for the AP axis and (0.994 ± 0.009) for the ML axis.

Considering the theoretical background from section II.A,  $r_C$  values for CoP coordinates in the AP and ML directions (estimated as the ratio between each equivalent radius and corresponding  $S_{AP}$  or  $S_{ML}$  values), were fitted as potential functions in  $W_0$ . Results were weighted by a factor of  $1/(M \Delta r_C)^2$ , where M is the number of traces plotted for each weight (3 or 5, see Table 1) and  $\Delta r_C$  is the propagated uncertainty of each  $r_C$  value (prioritizing results with a higher degree of confidence). As a result, the calibration curves and equations shown in Figure 3 were obtained. Combined with the previously calculated CoP offset values, these functions characterize the spatial response of the force plate.

Similarity between AP and ML curves proved to be significant, with a low eccentricity ( $e = 0.095 \pm 0.044$ ) for the fitted ellipses. Results show, however, a difference between real and theoretical calibration curves, and this finding is most probably due to device-specific factors, such as differential traction between load cells when fixed to the support surface, as well as tolerances in dimensions and amplification stages between cells. This response has proved to be consistent and stable between calibration procedures.



Fig. 3 Acquired and theoretical calibration curves of the force plate.

# B. Force Plate Analysis Tool

Acquired calibration functions were incorporated into a dedicated analysis tool developed in Matlab, resulting, as a whole, in the completion of a comprehensive system for the assessment of human balance. Figure 4 shows results from tests on a young adult, a professional ballet dancer (19 years old), while performing standing balance assessments without feet separation, both with open and closed eyes, as shown by the dedicated interface. This subject gave specific informed consent before testing, and performed these tests while standing on the platform with no shoes on.

The application allows selecting portions of the acquired signals, and choosing specific filters for standing balance analysis. Furthermore, it automatically calculates biomechanical values associated to gestures (sway-path length, deviation and range in both axes, areas covered by the gesture, etc.), and saves test results. CoP plots are prominently shown by the interface, allowing for comparisons between segments of different tests, as shown in Figure 4. For this subject, results showed a 12.6 % larger sway path for a test with closed eyes ( $t_m = 60$  s), as opposed to the same test when performed with the subject's eyes opened.



Fig. 4 Section of the developed interface for balance assessments. Standing balance CoP registers ( $t_m$ =60 s) from a subject with open (blue) and closed (black) eyes are filtered, displayed, and compared on the table (left: eyes open, right: eyes closed), showing significant differences between cases.

#### V. CONCLUSIONS

The devised calibration mechanism proved useful for gaining a deeper insight into the behavior of the designed force plate. Calibration results opened the way for validating its derived registers, and resulted in a superior fit for the device, compared to the theoretical calibration curve. As a result, a comprehensive, programmable system was set up, able to generate biomechanical evaluations associated to static human balance, as well as for dynamic gestures within the range and capabilities of this device. Further work includes the periodic reiteration of the calibration procedure, and the integration of the force plate with other devices developed by the group (wearable accelerometers and gyroscopes), so as to obtain synchronized data during gait and balance assessments.

#### ACKNOWLEDGMENT

This work was supported in part by Universidad de Buenos Aires, Programación Científica 2013-2016, Proyecto Interdisciplinario PIUBAMAS 2062120100011BA: "Evaluación del riesgo de caídas en adultos mayores y en pacientes geriátricos".

This work was supported in part by Pontificia Universidad Católica Argentina, Facultad de Ciencias Fisicomatemáticas e Ingeniería: "Modelos biomecánicos y desarrollos de dispositivos para la cuantificación del movimiento humano en individuos normales y/o disfuncionales".

Authors would like to thank Gonzalo Fernández for his insight and assistance during the setup of the device.

# CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

# References

- United Nations DoEaSA (2013) World Population Ageing. New York. ST/ESA/SER.A/348
- Duarte M, Freitas SMS (2010) Revision of Posturography based on force plate for balance evaluation, *Rev Bras Fisioter*, 2010 May-Jun; Vol. 14(3), pp. 183-92, ISSN 1413-3555
- Paillard T and Noé F (2015) Techniques and Methods for Testing the Postural Function in Healthy and Pathological Subjects *Biomed Res Int.* 2015; 2015:891390. doi: 10.1155/2015/891390.
- Han J, Moussavi Z, Sztrum T, Goodman V (2005) Application of nonlinear dynamics to human postural control system, *Conf Proc IEEE Eng Med Biol Soc.* 2005; 7, pp. 6885-8.
- Miralles M, Vecchio R et al (2012) Estudios de equilibrio en pacientes con riesgo de caída a partir de datos de acelerometría en tres ejes, *Proc. XIV JIIC*, Paraná, Argentina. http://bioingenieria.edu.ar/grupos/geic/biblioteca/j2012/Docume ntos/Trabajos/T12TCAr14.pdf

- Baratto M, Cervera C, Jacono M (2004) Analysis of adequacy of a force platform for stabilometric clinical investigations, *IMEKO, IEEE, SICE 2nd International Symposium on Measurement, Analysis and Modelling of Human Functions, June 14-16, 2004*, Italy. http://ada-posturologie.fr/home-a.htm
- Blanchard Sanhueza G (2010) Test system for clinical force platforms, *Conf Proc IEEE Eng Med Biol Soc* 2010; 2010:5772-5. doi: 10.1109/IEMBS.2010.5627840.
- 8. Soehnle SEB4A. See http://www.soehnle-professional.com/
- Ghersi I, Miralles MT, Mariño M (2014) Augmented-Reality and Alternative-Input System based on Simultaneous Head Position and Pose Estimation, *IFMBE Proceedings*, Vol 49, pp 222:225.

Corresponding author: Institute: Street: City: Country: e-mail: Ignacio Ghersi LaBIS-FI-UCA 1500 Moreau de Justo Ave. Buenos Aires Argentina igghersi@gmail.com