DEVELOPMENT OF A EXTENSOMETRIC FORCE PLATE FOR THE EVALUATION OF HUMAN BALANCE

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Abstract: This work presents a prototype of a multi axial extensometric force plate used in many biomechanical evaluations, applied mainly to postural and equilibrium disturbances and to human gait analysis. The force plate was made with four load cells developed specifically for the job. With its octagonal geometry it is possible get double the strength with minimum crosstalk between the cells. The load cells were manufactured from stainless steel and the plates from aluminum 5052F. The results of pilot test Software for force plate calibration is also presented, acquisition and analysis of the strength involved during the process, including force and momentum,

Introduction

Of all mammals, it can be said that the only truly biped is the human adult. This characteristic that is regarded by some to be a privilege brings with it certain number of particularities [1]. Ever since human beings adopted such posture they have had to deal with the challenges set down by the force of gravity, in trying to maintain the body in a state of equilibrium over the area covered by ones feet. One thus finds that even when standing still, one does not remain completely motionless -one oscillates [2].

Although it may seem a simple task, posture control is a great challenge for the human body [1]. The posture control system needs to be able to integrate the visual sensory systems, somatosensory and vestibule in a way that it can regulate equilibrium in situations where instability occurs. By its very nature the task of control is highly affected by, environmental conditions as well as by the sensorial information available.

The oscillation found during upright posture, is commonly investigated by the use of a force plate, which is in principal a measuring device on which an individual stands during analysis and permits the quantification of the reaction forces exerted from the ground that act upon the body.

The development of equipment and applications which allow for investigation into postural problems, human stepping action and other kinesiology as well as biomechanics show themselves to be fundamental in the diagnosis and treatment of such conditions, by their capacity to quantify values, in such a way that they can reveal with greater efficiency and reliability the results obtained, in relation to the manner in which these evaluations are thus carried.

Objetives and goals

In the biomechanical field, analysis that is purely visual is frequently criticized [3]. Research into the reliability of analysis of human gait and equilibrium evaluations by observation alone, show that it is only moderately reliable [4].

According to [5] the identification of defects and deficiencies which arise from diverse types of pathology require a careful quantative analysis which involves the use of sophisticated methods in the collection of data for example electromyography, cinematography dynamometry, stabilometry as well as the use of computers for the processing and analysis of results.

The principal goal of this work is to develop a multiaxial force plate (3D), with its elementary sensors as well as the module for the conditioning and digitalization of the signals produced by the sensors as well as the development of an application able to control the processes including data processing.

For this work to be realized the following goals were met:

- Modeling and construction of four multiaxial load cells, capable of releasing forces in two directions, with the minimum of interference between them;
- Planning and development of a mechanical apparatus (force plate) to support a human adult in an upright position, near static or gait. The plate linked up to load cells should be able to supply the measurements of the principal forces involved in the process, such as strength and torque.
- Planning and the construction of a signal conditioner module of eight channels, responsible for the powering, filtering and

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digitalizing of the signals received from the cell load;

- Planning and development of a software which when integrated to the plate and the conditioning module, is able to acquire, plot, store and supply reports about registers of forces and their instances;
- Carry out tests for the evaluation of the prototype in tasks, which explore stability in near static postures among others;

Materials and methods

To measure the force exerted by a body over another, an appropriate gauge is necessary which is known as a force transducer, which supplies an outgoing signal proportionate to the applied force. A force plate for example is basically a system for measuring force or impact that causes deformation on an element sensor. The plate presented in this work is equipped with four octagonal load cells, as shown in Figure 1, based on the model described in [6] and [7], but with some adaptations to improve the performance in our system. In each load cell eight strain gauges are fixed, with two complete Wheat stone bridge circuits, in such a way that one of them supplies the vertical force *Fy* and the other supplies the horizontal forces *Fx* and Fz.

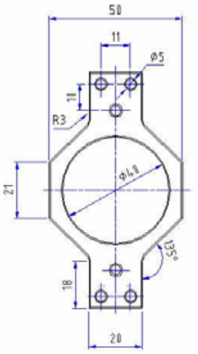


Figure 1: Geometry of Load Cell

Numerical simulations were carried out to check the tension values and deformations along the piece when submitted to maximum force of 1200 Newtons in the axial direction. In this way it was possible to check the efficiency of the chosen geometry, as well as determine the material to be used in its construction.

The load cells as well as the fixing supports were made from stainless steel (AISI 304) and the plate in aluminum 5052F, which allowed us to give both strength and lightness to the prototype. The plates have the following dimension (500x500x15) mm. The choice of materials used in the load cells and the plates, were in agreement with the characteristics of the mechanical properties and the results obtained from the strength simulations carried out on the piece. Figure 2 illustrates the load cell as well as the fixing supports used.

Figure 2: Photo of Load Cell and the Supports.

The principal property characteristics of the stainless steel – AISI 304 and of the aluminum 5052F, used in the making of the prototype are shown in Tables 1 and 2 respectively.

Table 1: Properties of Stainless Steel AISI 304

Property	Symbol	Value
Elasticity module	**E**	$7.31\text{x}10^{10}$ N/m^2
Poisson Coeficiente	ν	0.3333
Specific mass	μ	$2.70\text{x}10^3$ Kg/m
Rupture tension	σe	$8.07\text{x}10^7$ N/m^2

Table 2: Properties of Aluminum 5052F

Property	Symbol	Value
Elasticity module	**E**	$2{,}10\text{x}10^{11}$ N/m^2
Poisson Coeficiente	ν	0.30
Specific mass	μ	$7{,}85\text{x}10^3$ Kg/m
Rupture tension	σe	$2{,}75\text{x}10^7$ N/m^2

Only After finalizing the development of the load cells, supports and contact plates, was it possible to bring together all the composite elements of the platform, thus resulting in the prototype shown in Figure 3.

Figure 3: Photo of Platform Head on.

By adopting the arrangement of the load cells illustrated in Figure 4, it was possible for the mechanism to become sensitive to strength measurements in three orthogonal directions, being that all of the cells measure the vertical force and then in two by two formation measure the forces on the horizontal plane.

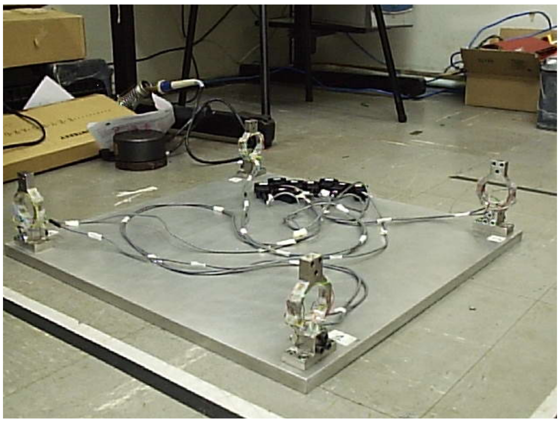


Figure 4: Photo of the Load Cells Final Arrangement

Figure 5 illustrates the arrangement of the load cell as well as the direction of the axis coordinates adopted for making reference to the measurements. The movement direction and the axis coordinates were joined in the following manner.

- Axis X from the front to back direction;
- Axis Y in the vertical direction;
- Axis Z side to side direction;

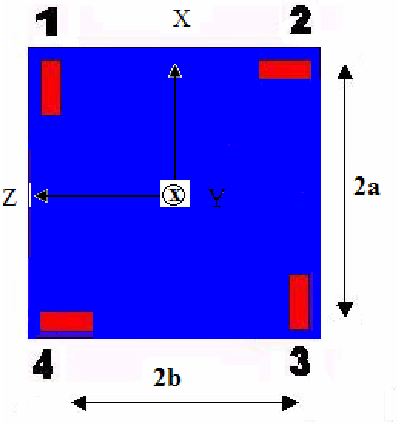


Figure 5: Indicates the Direction of Axis and Cells

To determine the forces involved in the experiments with the prototype, we used Equations (1), (2) e (3) respectively to quantify Fx, Fy e Fz.

$$\Sigma Fx = F1x + F3x \tag{1}$$

$$\Sigma Fy = F1y + F2y + F3y + F4y \tag{2}$$

$$\Sigma Fz = F2z + F4z \tag{3}$$

Equations (4), (5) and (6) express the resulting moments on the coordinated axis x, y e z respectively:

$$\Sigma Mx = (F2y + F3y) * b - (F1y + F4y) * b \tag{4}$$

$$\Sigma My = (F2z - F4z) * a + (F3y - F1y) * b \tag{5}$$

$$\Sigma Mz = (F1y + F2y) * a - (F3y + F4y) * a \tag{6}$$

With the strength and momentum components it is possible to estimate the values of the coordinates of the pressure center by using Equations (7) and (8) in the direction X, *Xcop*, and in the direction Z, *Zcop*, respectively. Observing the variations of the pressure center coordinates is an important part in the investigation focused on the stability of a human individual while in a near static upright position.

$$Xcop = \frac{-Fx * h - Mz}{Fy} \tag{7}$$

$$Zcop = \frac{-Fz * h + Mx}{Fy} \tag{8}$$

Figure 6 illustrates the mounted platform prototype, with its connections to the developed eight-channel signal conditioner, as well as the indicating marks of the coordinated axis and the region on the platform where the individual will be accommodated.

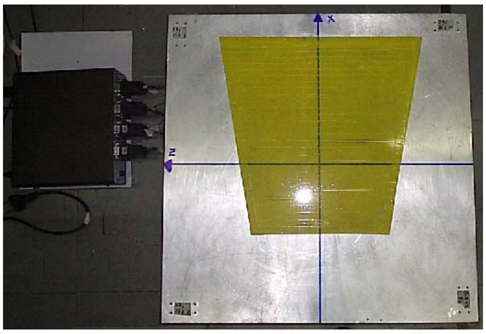


Figure 6: Photo of the Mounted Platform and Axis Indications and the Marked Standing Area.

Results

The prototype's functions were evaluated through pilot experiments using four variations from the different modalities already in existence for the evaluation of human balance. The experiments were based on the Romberg protocol and look to present the localization of the coordinates of the test individuals pressure center, as well as the behavior of these variables over time, with and without the presence of visual stimulus, and still provide indexes for stability obtained in function of the individual's stature and behavior during the evaluations. It must be stated that such experiments did not have the objective of emitting any type of diagnosis in respect to possible disturbances in posture regulation and that this should only be carried out by qualified health professionals

The tests were carried out in four stages each having a 30 and 50 second duration. The individual positions him\herself in the marked area as shown in Figure 7and follows the instructions given during the test.

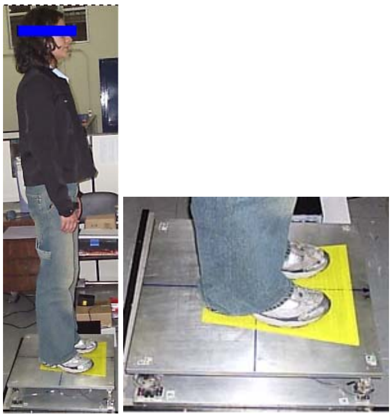


Figure 7: Photo of Volunteer on Platform

At the end of the evaluations, graphs are generated as indicated in Figure 8, where the test individual's pressure center behavior can be verified through the use of sampling.

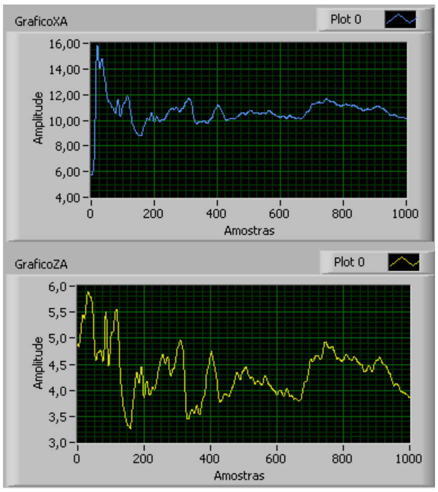
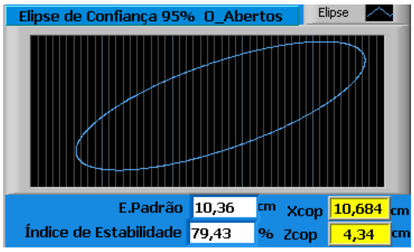


Figure 8: Variation of the Xcop and Zcop

The value of Xcop varies around 10 cm and one observes that there exists a front to back movement on the 2cm line, above the average as indicated by the Xcop variable. On the Zcop graph, it is possible to check that there exists a variation of around 4 cm on average, and with a movement on the 0.5 line downwards and upwards. These facts indicate that the test individual had a greater tendency towards a front to back disequilibria.

The results were also obtained by the use of the confidence ellipse method, which through the axis direction longer and shorter, and by their length, indicate which is the predominate direction of the occurred movement, and what the value of the movement on the pressure center around the average point found.

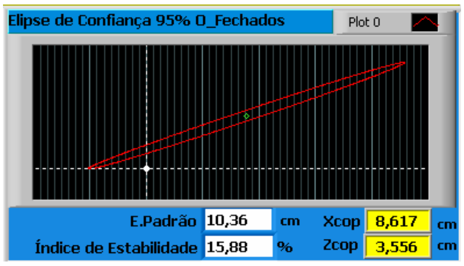
Figure 9 illustrates the results of the troubled stability test while the eyes remain open through the use of the confidence ellipse of 95%. It is possible to see a standard stability index of the test subject, as well as the index of established stability during the evaluation. The index of the standard stability states that the radius and the centimeters of the circular area are the factors, which limit the test subject's stability region. The stability index acquired during the test demonstrates as a percentage the ability of the individual to maintain a stable condition during the equilibrium evaluations.



E.Padrão 10,36 cm
Índice de Estabilidade 79,43 %
Xcop 10,684 cm
Zcop 4,34 cm

Figure 9: Confidence Ellipse 95% generated on the troubled stability test – eyes open

Figure 10 has its confidence ellipse stability test generated in normal stability mode with the eyes closed. One observes that apart from the change in coordinates of the pressure center, the individual's ability in maintaining stability was reduced to 15,88%, which shows that there occurred visual stimulus interference while maintaining stability in the upright near static posture.



E.Padrão 10,36 cm
Índice de Estabilidade 15,88 %
Xcop 8,617 cm
Zcop 3,556 cm

Figure 10: Confidence Ellipse Generated on the Normal Stability Test – Eyes Closed

One is able to see that there occurred a greater tendency of direction toward movement, this occurs, as the length of the longer axis is far superior to that of the shorter axis.

Discussion

The attempt to establish a standard position for test individuals during the realization of human balance tests has been a subject of much research and debate. Efforts are thus directed towards how to eliminate interference from this non-standard posture, in the eventual evaluation and diagnosis of the disturbances to be studied.

The fact of the matter is that each individual experiences different degrees of comfort and\or discomfort when asked to maintain a position, for this reason better positioning of the test individual on the plate during tests is sought, at times restricting the positioning but always trying to align spontaneousness and level of comfort to reach the most efficient evaluation possible. The use of markers on the top of the force plate, as shown in Figure 6, give the operator an Idea of an average area where the best results can be obtained as shown in studies made on this subject, and has shown itself to be a good option in the help to find less interference in the evaluations.

Conclusions

The use of the force plate for postural analysis and evaluations has shown itself to be promising and a necessary tool for an effective investigation by the use of simple tests which are carried out in clinics, but in a majority of cases without any type of effective quantization of the problem.

The search for methods to standardize the patient's posture during the tests reveals itself as being a great ally in minimizing interferences and disagreements during the diagnosis of one pathology over another or even which would be the best form of training and evaluation for human gait.

The results obtained through the use of the prototype in pilot experiments show that the hardware and software developed has the potential to evaluate a diversity of dysfunctions as well as evaluate studies related to posture, gait, and neurological disorders that are prejudicial to the subject's stable state.

It is of importance to state that with the development of this system the project and the construction of the force plate 3D, and through its support elements, such as the software application, it was possible to add national and local know how to this area of development.

Appreciative thanks

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