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Static postural stability: analysis in time and frequency through the development of a software tool

Estabilidad postural estática: análisis en tiempo y frecuencia a través del desarrollo de una herramienta de software

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Abstract

Posture allows a subject to perform in the environment where they develop in order to act, maintaining an erect position where, using their muscles, they oppose external forces such as gravity. Certain characteristics of a posture indicate the presence of some disorder in a subject, hence the interest in its study. The analysis of postural control in relation to the stability in the standing posture is carried out using balance studies, such as stabilometry; This instrumental evaluation makes it possible to objectively assess postural balance through the study of the center of pressure (CoP) in both the time and frequency domain. There is software, usually accompanied by hardware, that calculates CoP parameters, but provides

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temporal or frequency data, and they are also expensive. The objective of this article is to show the development of a software tool that calculates the relevant parameters for the study of stability, carried out in a free programming language (Python), easy to use, highly useful, free, and will be delivered to personnel in the field doctor for your employment.

Keywords: Balance**,** CoP area calculation, Postural control, Posturography, Software.

Resumen

La postura permite a un sujeto desempeñarse en el medio donde se desenvuelve manteniendo una posición erecta donde, haciendo uso de la musculatura, se opone a fuerzas exteriores como la gravedad. Características determinadas de una postura indican la presencia de algún desorden en un sujeto, de allí el interés en su estudio. El análisis del control postural en relación con la estabilidad en postura de bipedestación se realiza empleando estudios de equilibrio, tal como la estabilometría; esta evaluación instrumental permite valorar objetivamente el equilibrio postural a través del estudio del centro de presión (CoP) tanto en el dominio del tiempo como de la frecuencia. Existe software, por lo general acompañados de hardware, que calculan parámetros del CoP, pero entregan datos temporales o frecuenciales, además son costosos. El objetivo de este artículo es mostrar el desarrollo de una herramienta de software que calcula los parámetros relevantes para el estudio de la estabilidad, realizada en un lenguaje de programación libre (Python), de fácil uso, gran utilidad, gratis y será entregada a personal del ámbito médico para su empleo.

Palabras clave: Balance, Cálculo del área de CoP, Control postural, Posturografía, Software.

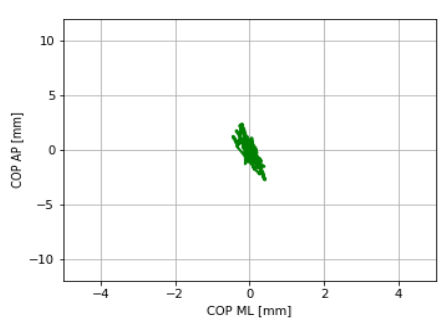
1. Introduction

In human standing the body weight, without pathological conditions, is supported by the feet, in addition this part of the human body is responsible for absorbing the impact in the footsteps, give the thrust to the body to move forward during walking and running, play an essential role to stabilize the body during standing. The entire structure of the foot actively participates in the described tasks, either by supporting the distribution of loads along the sole, providing levers of force or contributing to postural stability. [1].

The ability to integrate sensory, motor and vestibular information within the execution of motor commands to maintain stability and balance is referred to as postural stability [2], [3]. The examination of stability allows the recognition of motor and mental alterations, it has been proven that when organs of vision, vestibular system and/or proprioceptive sensors are affected, the generation of reflexes to maintain stability is altered, making subjects prone to falls and loss of balance [4]-[6]. [4]-[6]. The form of stability analysis is performed by taking into account the behavior of the center of pressure (CoP) on the sole of the foot or on the surface of the polygon of support, either in the time or frequency domain, or by making use of graphs such as the statokinesiogram, the stabilogram, the confidence ellipse or the frequency diagram. It is recalled that the CoP is the vertical ground reaction force reflecting the forces and ankle torques required to maintain the center of gravity within the lift polygon [4], [7], [8]. The polygon or base of support is described as the base of variable shape that is presented in the form of a geometric figure determined by the position of the feet, where an imaginary line that borders the lateral sides of the feet is circumscribed [9], [10], [11]. [9], [10].

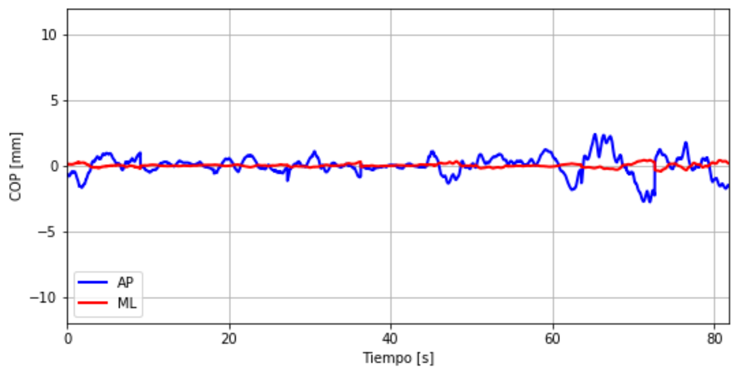
The statokinesiogram allows to judge the variations of the sagittal movements with respect to the frontal movements, by plotting on the abscissa the ML displacement of the CoP and on the ordinate the amplitude of the AP displacement [11], [12], [13]. [11], [12]Figure 1.

Figure 1. Statokinesiogram [4].



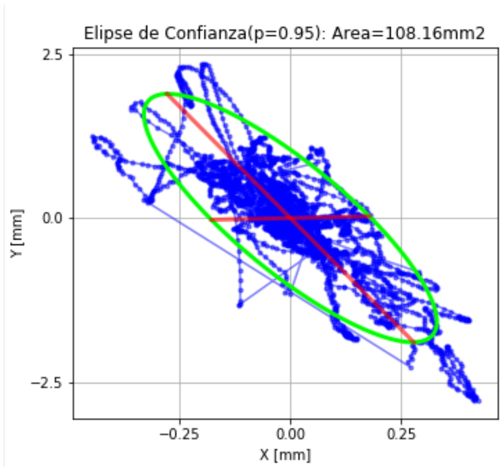
The stabilogram is a diagram over time that records the postural balance of the whole body in an upright position, quantifies the oscillations in the anterior-posterior (AP) and medio-lateral (ML) directions of the CoP. The static analysis is performed in the upright orthostatic position, therefore, without the subject performing movement. [11], [12], Figure 2.

Figure 2. Stabilogram [4].



In the exploration of the confidence ellipse we observe the area of the ellipse that covers the displacement of the CoP, that is, the subject's sway, for this a prediction ellipse is adjusted in such a way that it covers the data of the antero-posterior CoP against medial-lateral CoP; this procedure is performed using principal component statistical analysis, to have 95% probability that a new observation is within the ellipse [11], [12]Figure 3.

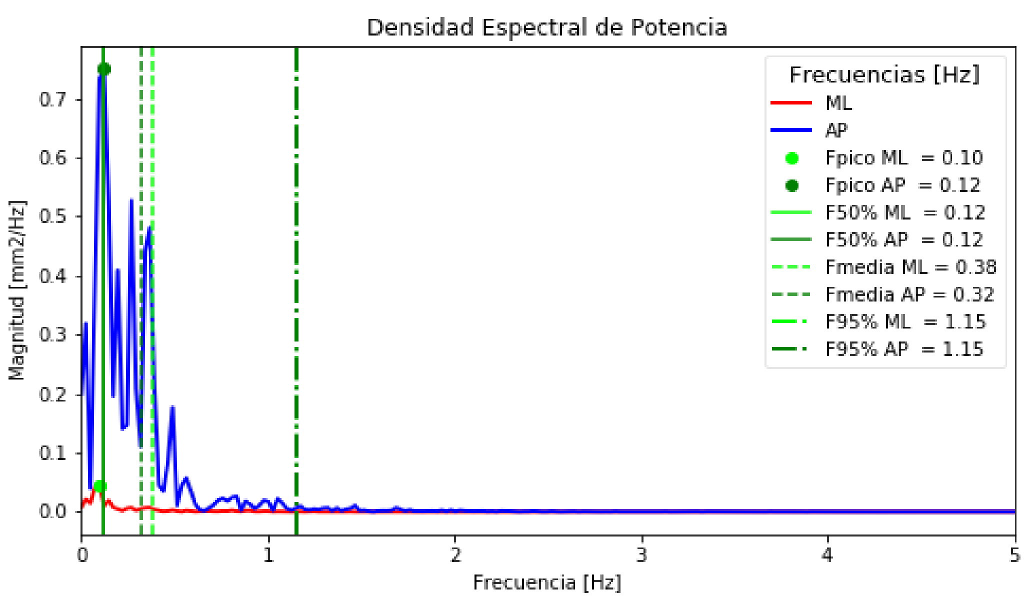
Figure 3. Confidence ellipse [4].



The frequency diagram shows the power spectral density (PSD) of the CoP; the PSD is a mathematical function used in the investigation of the distribution of the power of a signal over the different frequencies where it is formed, it establishes the range of frequencies of concentration of the power variations. Human movements present a frequency of occurrence between 0.3 and 3.5 Hz, with an increase in acceleration from the head to the feet; if a movement is in the interval between 0 and 1.5 Hz it is automatic or involuntary, but if it is between 1.5 and 3 Hz it is voluntary and is generated to maintain stability, hence frequencies higher than those described reveal alteration in stability. The DEP allows easy discrimination of variations, which allows the comparison between population groups and the detection of variation in the behavior of the parameter under study [13]Figure 4.

The temporal analysis examines: the average value of the CoP position, the root-mean-square (rms) of the mean CoP position migration, the total CoP migration distance, the mean CoP migration velocity. The frequency parameters describe the total CoP signal frequency intensity, mean frequency, 95% frequency range, center frequency and frequency dispersion. High values in the described parameters make known the presence of postural instability. [5], [14], [15].

Figure 4. Frequency spectral density. [4].



The systems to study stability show some temporal or frequency parameters, but not all of those described, which is necessary to have a complete overview of the behavior of the CoP and thus detect possible pathologies associated with postural instability. Therefore, the objective was to develop an application software that allows to represent the most relevant data of the posturographic measurements, using free software. It should be clarified that software refers to a group of computer programs, with processes and documents that account for a development and its application; when talking about application software, focused developments that allow performing tasks, whether calculations or procedures, are associated, but differ from software because they do not control the computer itself. [16]. Then, the obtained application software is expected to provide useful information on the selection of appropriate CoP measures to effectively discriminate postural stability. In this paper, the obtained tool is disclosed.

2. Methodology

An exploration of the most commonly used methods in clinical and research posturographic examination was carried out, as well as the equations that allow calculating them, finding that the numerical data in the time domain are:

- The average value of the CoP position is averaged for positions in both the medial-lateral and anterior-posterior directions using (1).

$$\bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i \tag{1}$$

- The RMS value of the CoP mean position offset (2)

$$RMS = \sqrt{\frac{1}{N}\sum_{i=1}^{N} x_i^2} \tag{2}$$

- The total travel distance of the CoP (3)

$$Longitud\ de\ desplazamiento = \sum_{i=1}^{N-1} |x_{i+i} - x_i| \tag{3}$$

- The average displacement velocity of the CoP in the two directions (4)

$$velocidad\ media = \frac{1}{T}\sum_{i=1}^{N-1}|x_{i+i} - x_i| \tag{4}$$

The CoP time graphs are:

- Stabilogram. Recording of the successive positions of the CoP coordinates as a function of time, both for medial - lateral (right - left) and anteroposterior (forward - backward) displacement. They are measured in mm.
- Statokinesiogram. It records the medial-lateral temporal displacement against the anterior-posterior of the CoP positions in order to evaluate the variations of the sagittal movements with respect to the frontal movements.
- Confidence ellipse. The construction of the ellipse involved knowledge of the theories on confidence and prediction regions with multivariate cases; for posturography, bivariate can be used and the bivariate confidence region is a confidence ellipse treated as the contour lines of the bell of the bivariate normal population distribution. Two parameters are needed for the calculation: the mean population vector μ (5) and the population covariance matrix, which is estimated with the unbiased sample covariance matrix S (6) [17].

$$\mu = \begin{pmatrix} \mu_x \\ \mu_y \end{pmatrix}$$

$$\bar{X} = \frac{1}{n}\begin{pmatrix} \sum_{i=1}^{n} X_i \\ \sum_{i=1}^{n} Y_i \end{pmatrix} \tag{5}$$

$$S = \begin{pmatrix} S_x^2 & S_{x,y} \\ S_{x,y} & S_y^2 \end{pmatrix} \tag{6}$$

For the case of posturography, the medial-lateral and anterior-posterior directions of movement of the POP are considered with sample mean $\bar{x}$ (7) [17]-[19].

$$\bar{x} = \begin{pmatrix} \bar{x} \\ \bar{y} \end{pmatrix} \quad (7)$$

Since samples are taken n samples are taken, we have (8)

$$(\bar{x} - \mu)^T S^{-1} (\bar{x} - \mu) = \frac{2(n-1)}{n(n-2)} F_{(1-\alpha),2,n-2} \quad (8)$$

Where $F_{2,n-2}$ is the Fisher distribution with 2 y $(n-2)$ degrees of freedom. The left-hand side of (8) can be rewritten to obtain (9).

$$\frac{S_x^2 S_y^2}{S_x^2 S_y^2 - S_{xy}^2}\left[\frac{(\bar{x} - \mu_x)^2}{S_x^2} + \frac{\left(\bar{y} - \mu_y\right)^2}{S_y^2} - \frac{2S_{xy}(\bar{x} - \mu_x)\left(\bar{y} - \mu_y\right)}{S_x^2 S_y^2}\right] = \frac{2(n-1)}{n(n-2)} F_{(1-\alpha),2,n-2} \quad (9)$$

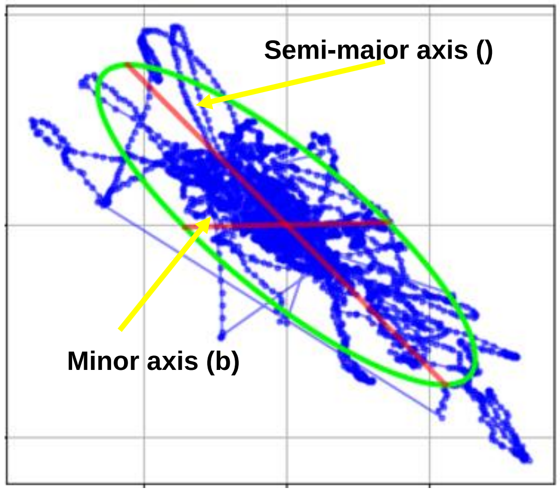
Obtaining a region around μ_x y μ_y with a given probability of $100(1-\propto)\%$ is preset by the value F. The size of the confidence ellipse is bounded as indicated on the right-hand side (9) [17]-[19].

Now, to calculate the area of the ellipse we start from (10).

$$A_E = \pi ab \quad (10)$$

Where a y b refer to the axes of the ellipse, so they must be found. a is the semi-major axis, referring to the distance from the center of the ellipse to the farthest edge of the ellipse, also known as the semi-major axis; and b is the minor radius or semi-minor axis, measured from the center to the nearest point of the edge, Figure 5 [17]-[19].

Figure 5. Semi-axes of the ellipse. Adapted from [4].



One method of obtaining the area is through a regression analysis to find the axis that passes through the point $(\underline{x}, \underline{y})$in such a way that the deviation of the values observed in the regression is minimal; it is clarified that the deviation is located parallel to the abscissa, therefore it is possible to present that it is drawn x versus y or vice versa, hence it is decided to establish a second criterion, the deviation must be perpendicular to the major axis. With these criteria the value of the semi-axes can be obtained using (11) [17]-[19].

$$a = \sqrt{\frac{2(n+1)(n-1)}{n(n-2)} F_{(1-\alpha),2,n-2}.\lambda_1} \approx \sqrt{X_2^2.\lambda_1}$$
$$b = \sqrt{\frac{2(n+1)(n-1)}{n(n-2)} F_{(1-\alpha),2,n-2}.\lambda_2} \approx \sqrt{X_2^2.\lambda_2} \qquad (11)$$

Where λ the eigenvalue of the covariance matrix S. Finally, the area of the ellipse is calculated with (12).

$$A_E = \pi ab \approx \pi X_2^2 \sqrt{\lambda_1.\lambda_2} = \pi X_2^2 \sqrt{\det(S)} \qquad (12)$$

As for the analysis in the frequency domain, we have the calculation and the graph of the power spectral density and the relevant frequency values for the study of the posture of the two medial-lateral and anterior-posterior directions:

- Peak frequency of CoP signal
- Average frequency of CoP
- Frequency of 50% of the CoP signal.
- 95% CoP signal frequency

The power spectral density characteristics were calculated using Welch's method (13), which averages periodograms of a single signal, obtained in consecutive time windows with a percentage of overlap, this allows smoothing the signal spectrum as it decreases the variance between estimations. [13], [20].

$$x_i(n) = x(n + iD) \quad n = 0,1, \dots, N - 1 \qquad (13)$$

The time windows used were Hamming windows, with an overlap of 25%, which allow to have 64 samples, for about 1.28 seconds. [13].

Based on these findings, the software to be used was selected, considering that it should be a general purpose language, where diverse application programs can be generated; *open source*, which means free, to be used freely independent of the machine's operating system and with periodic updating; allow a syntax with secondary notation, which improves the readability of the source code and delimits the structure of the program allowing the establishment of code blocks; object-oriented to favor the reusability, maintenance and reliability of the code; with a high number of libraries to favor the performance of numerical calculations. For these reasons, Python was chosen as the programming language.

Tests

For software validation, CoP measurement of eleven subjects was performed using instrumented templates. [21] The temporal and frequency parameters were obtained with Matlab® software, which has functions that allow the calculation of statistical values related to the temporal data and frequency values. Then the data were calculated with the developed software obtaining equal values.

Regarding the confidence ellipse, the data provided by the software developed are within the values found in the literature and refer to the area of the ellipse of people without pathology present. We do not have access to software that performs the calculation of this parameter, since these are subject to stability measurement elements.

3. Results

A software tool for static postural stability analysis, both in time and frequency, was obtained, which allows examining the behavior of the CoP center of pressure in the anterior-posterior and medial-lateral directions from data previously obtained from CoP measurements. The values are displayed both graphically and numerically.

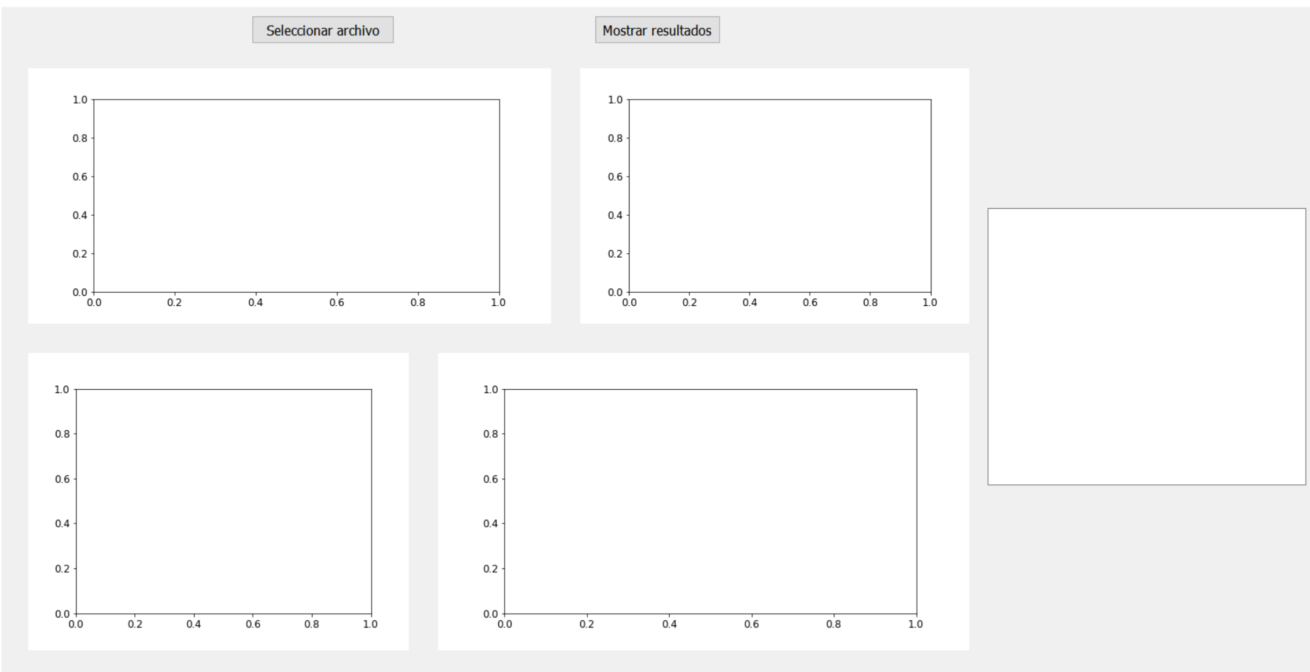
The software performs filtering actions and numerical calculations to obtain the numerical and graphical values of the parameters. First of all, the signal is filtered, since the measured values tend to have a noise signal, known as tendency or fluctuation. This cleaning process is done through a Butterworth type low-pass filter with a cut-off frequency of 10 Hz, since the signals to be analyzed are stationary and are below the cut-off frequency, according to the report of several authors, including Winter in his 2009 book: Biomechanics and motor control of human movement. [22]. The Butterworth filter is widely used because of its simple design, flat frequency response and linear phase response in the pass and stop bands, and it is also easy to implement [23], [24]. This filter is recursive (IIR) and is found within the Python® libraries.

Secondly, numerical calculations are performed to determine the values of the parameters. In third instance, the determined graphs are made.

In order to make use of the developed application software, the appropriate format of the data of the measured CoP values constituting the random sample must be considered. The input object of the data is always a file with extension *.csv , since all instruments for measuring the CoP allow storing the values in flat files with this type of extension. The file contains an array of numbers forming a matrix of n rows and 2 columns, the columns are the CoP data in anterior-posterior and medial-lateral direction measured in millimeters, the rows are the data recorded in a period of time.

To run the program, an executable file was created, which when opened displays the initial screen of the tool, Figure 6.

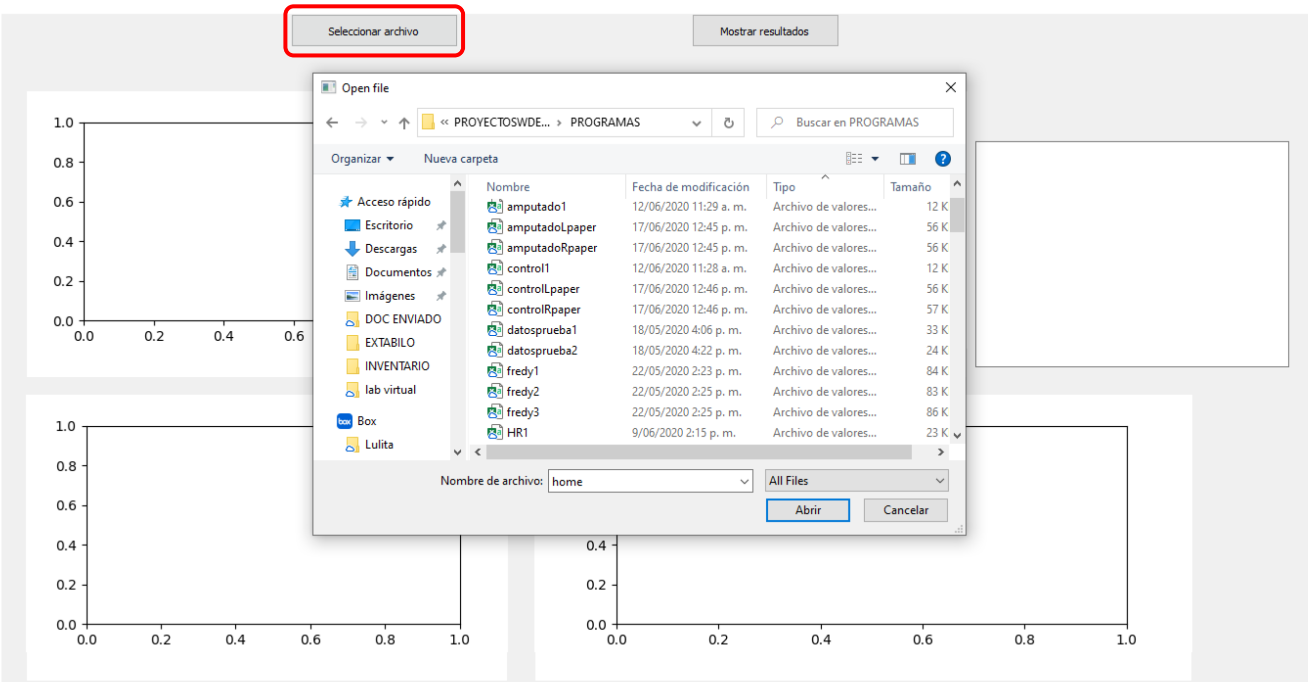
Figure 6. Initial screen of the computational tool. Source: Authors.



There are two main options:

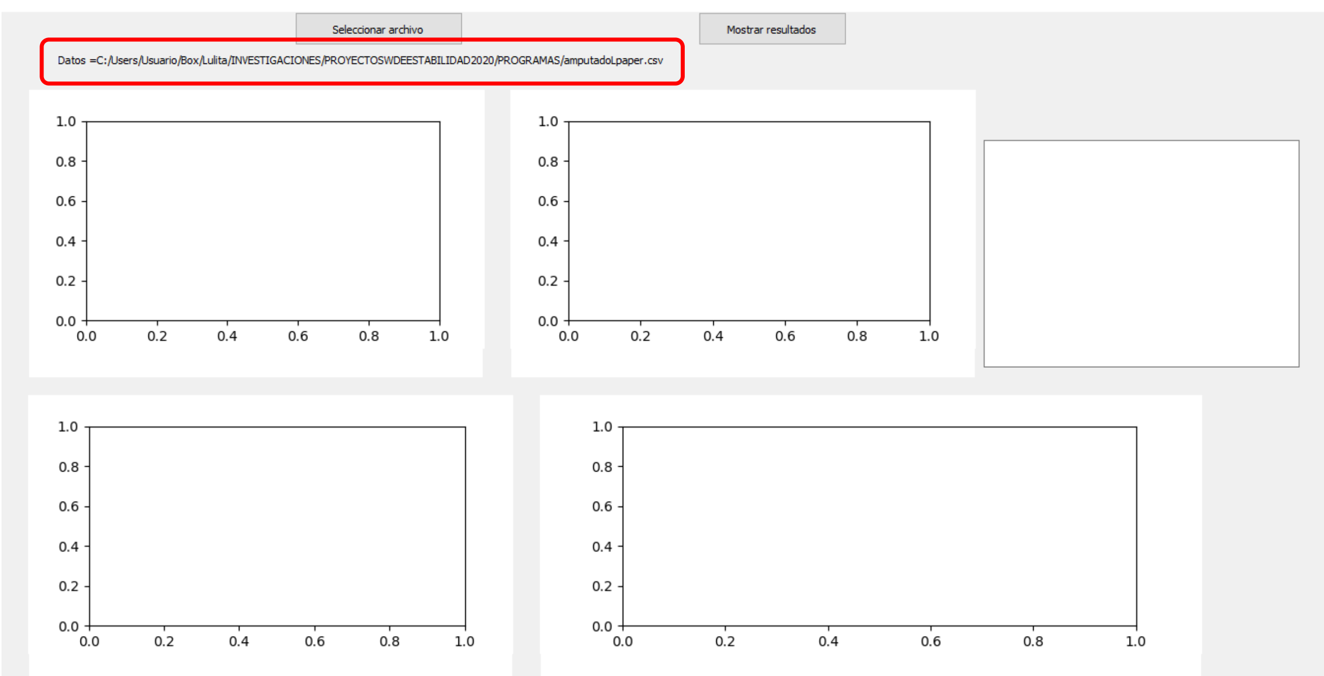
1. Select file. It allows to search the file to be examined in all the folders of the computer, it must be in *.csv extension. This file type was selected because the CoP measurement instruments (instrumented platforms and templates) allow saving the measured data with this extension. If a file with another extension is chosen, the software closes automatically, Figure 7.

Figure 7. Selection of file with *.csv extension. Source: Authors.



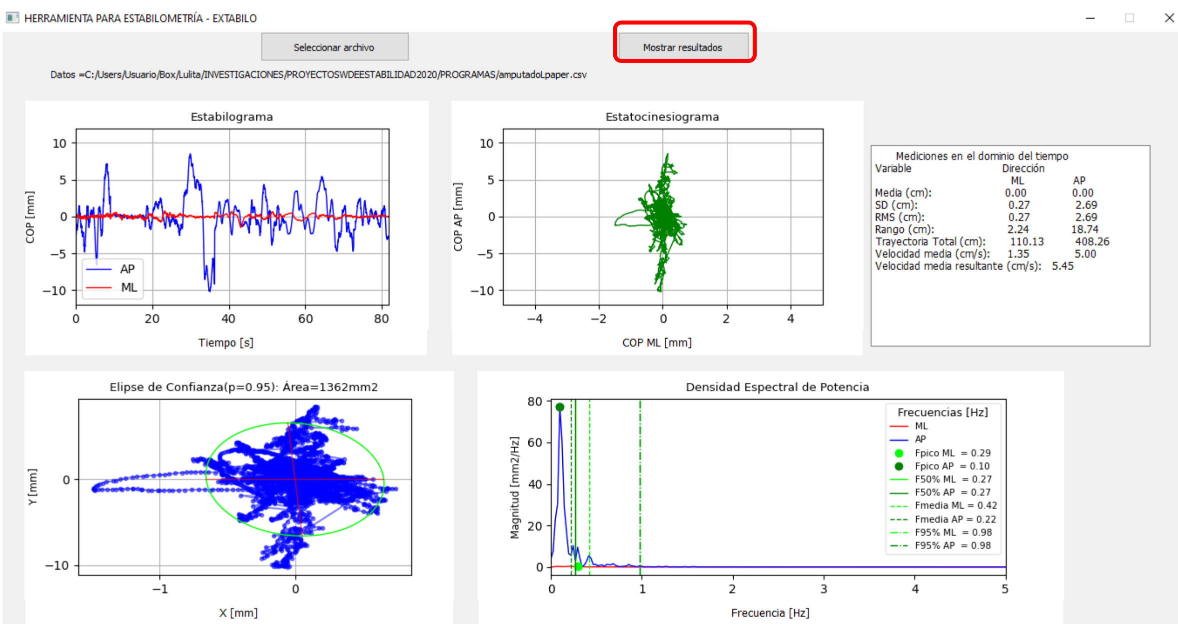
Once the file to be plotted is selected, the interface displays the path to the selected file, figure 8.

Figure 8. The path to the selected file is shown. Source: Authors.



2. Show results. Plots and calculates the data concerning stability, Figure 9. The relevant graphs are generated in the study of postural stability, as well as the relevant parameters of the COP in the time domain, among which are: the mean value of the COP, the standard deviation, the mean square value, the range, the trajectory traveled, the average speed, all the above data are calculated for each of the two possible directions of movement of the COP, which are anterior-posterior (AP) and medial-lateral (ML). Additionally, the value of the average velocity resulting from the whole COP is obtained.

Figure 9. Final result in the visualization of stability parameters. Source: Authors.



4. Conclusions

Technology plays an increasingly important role in the medical field, both in the diagnosis and treatment of diseases. The massive use of software tools in medicine is a fact, allowing the collection of large amounts of patient information to be easily processed and stored. In the case of physical rehabilitation or physiotherapy where balance and posture disorders are analyzed, CoP analysis systems are required; the existing ones in the market are of high cost, some exhibit temporal analysis, others frequential, but not both.

Due to the lack of technological resources to visualize posturographic data both in the time domain and in the frequency domain of the CoP behavior, with this first version of the developed software we have a computational tool, of free access that was developed with Python® and performs the exploration of the CoP temporally and frequentially. It will be of help to the medical personnel since they will be able to observe the behavior of the center of pressure, through the data of the calculated parameters, making possible the detection of pathologies and alterations. The study of postural behavior patterns in groups of different conditions will be possible using the obtained computational tool, since the temporal and frequency parameters are visualized in an easy and understandable way. The software makes it possible to analyze the involvement of a pathology in stability, as well as the incidence of various factors that alter stability, by performing postural assessments with standard spatiotemporal and frequential metrics of the pressure at the center of the foot (CoP) recorded during static standing posture.

In addition, the postural analysis software can support teaching processes aimed at medical professionals who wish to be trained in the diagnosis of postural and balance disorders, since it allows to show the performance of the temporal and frequency parameters of the CoP associated with a postural impairment syndrome. The analyses can be performed without having a subject present, only with CoP measurement recording data to verify the position of the podal center of pressure, the oscillation surface, the variation of the velocity and the frequency data.

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