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VISIÓN ELECTRÓNICA

A CASE-STUDY VISION

Processing and analysis of biomedical signals captured from the dominant hand of variables related to carpal tunnel syndrome

Procesamiento y análisis de señales biomédicas capturadas de la mano dominante de variables relacionadas con el síndrome de túnel carpiano

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ABSTRACT

The information presented is part of the results developed from the master's thesis called "Design of a carpal tunnel syndrome prevention system implementing artificial neural networks" in which 5 modules have been generated, of which 2 modules are hardware for the analysis of different types of hand grip and another module is a section on a survey that visualizes the level of difficulty that each patient had for the development of each of the grip exercises that he practiced with the dominant hand, visualizing different behaviors in a population sample of 50 patients with different characteristics.

Data processing was developed for the extraction of the most relevant characteristics taking into account normalized variables of mode, mean, median, maximum values and minimum values with the objective of generating a robust database that could be used for the development of an artificial neural network. In addition, information processing was generated to scale the values. As a result of the experiment, the correlations between the different variables were analyzed, also detailing the sample space and the respective events. For this project, the collaboration of doctor Ricardo Galán from the Military Hospital was counted on, who supported and corroborated the functionality of the prototypes. The impact of this project is fundamental to prevent the new occupational diseases that are emerging, which decimate the productivity and quality of life of workers.

RESUMEN

La información expuesta hace parte de los resultados desarrollados del trabajo de maestría denominado "Diseño de un sistema de prevención del síndrome de túnel carpiano implementando redes neuronales artificiales" en el cual se han generado

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5 módulos, de los cuales 2 módulos son de hardware para el análisis de diferentes tipos de agarre de la mano y otro módulo es una sección sobre una encuesta que visualiza el nivel de dificultad que tuvo cada paciente para el desarrollo de cada uno de los ejercicios de agarre que practicó con la mano dominante, visualizando diferentes comportamientos en una muestra poblacional de 50 pacientes con diferentes características.

Se procedió a desarrollar un procesamiento de datos para la extracción de las características más relevantes teniendo presente variables normalizadas de moda, media, mediana, valores máximos y valores mínimos con el objetivo de generar una base de datos robusta que se pudiera usar para el desarrollo de una red neuronal artificial, además, se generó un procesamiento de la información para escalar los valores. Como resultado del experimento se analizaron las correlaciones entre las diferentes variables, detallando también el espacio muestral y los respectivos eventos. Para este proyecto se contó con la colaboración del médico Ricardo Galán del hospital Militar que apoyó y corroboró la funcionalidad de los prototipos. El impacto de este proyecto es fundamental para prevenir las nuevas enfermedades profesionales que están surgiendo, diezman la productividad y calidad de vida de los trabajadores.

1. Introduction

Carpal tunnel syndrome (CTS) or also known as late median nerve palsy, is a peripheral neuropathy, caused by inflammation and pressure of the median nerve (sensory and motor), inside the tunnel formed by carpal bones and the transverse carpal ligament on the palmar aspect of the wrist [1] [2]. In 1833, Omerand first cites CTS who related it at the time to paresthesias and nocturnal pain, later in 1835 Lobert was considered another precursor for performing a postmortem study and in 1854 Paget reacts with a clinical picture of CTS with repetitive posturing of the radius, finally in 1913 Pierre Marie and Charles Foix describe Pseudoneuroma of the median nerve in autopsies [3] and Learmont performed the first successful release operation in 1930 [4] [5]. The first cases of idiopathic CTS were described by Moersh in 1938 and surgical treatment was first performed by Cannon and Love in 1946 [3]. Subsequently, in 1951 Phalan carried out studies in which he included more than 1200 hands, generating the introduction of pathology in contemporary medicine [6]. In 2003, CTS was considered an occupational disease by the European Union [7].

There are different factors that can cause carpal tunnel syndrome. For example, some local causes may be cysts in the area. In addition, there are regional causes such as rheumatoid arthritis and systemic causes such as diabetes or hypothyroidism. It is important to note that certain factors such as obesity, pregnancy, menopause and the use of contraceptives may increase the risk of developing CTS, as they may cause an increase in the volume of the synovial sheath within the tunnel [8]. On the other hand, it is also possible to increase the risk by performing physical or occupational work that puts pressure on the carpal tunnel, due to an inadequate load on the upper limbs or specific hand positions during work. Repetitive movements and the constant use of vibrating tools can also be causes of this syndrome. It is essential to take these causes into account to prevent the onset of CTS [7].

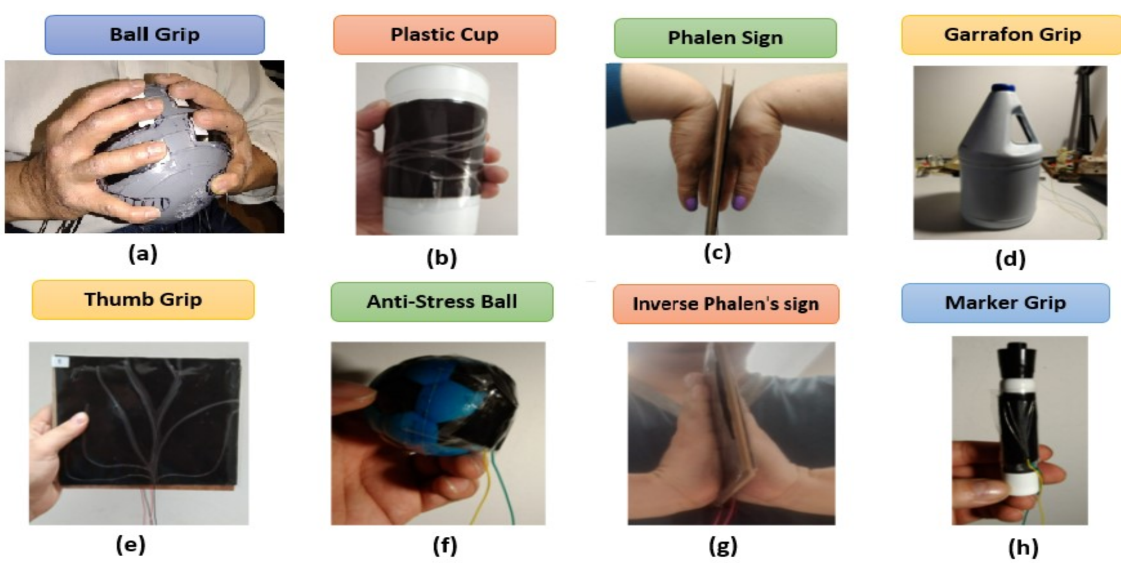
The symptoms of carpal tunnel syndrome vary depending on the degree of disease progression. In the early stages, symptomatology is related to sensory dysfunction, whereas in more advanced stages motor symptoms may appear [9]. In general, people with CTS usually experience loss of the sense of touch, tingling, numbness of the hands and fingers, as well as pain in the shoulder and sometimes in the elbow or wrist at night. They may also have a marked decrease in grip strength in the hand, causing them to drop objects more frequently than normal due to the weakness generated. In some cases, people may have difficulty opening jars or performing activities that require wrist movements, such as brushing teeth or hair [10] [11].

With reference to the above and taking into account the afore mentioned characteristics, an electronic system for the capture of data was developed in the project of the Universidad Distrital Francisco José de Caldas an electronic capture system with 8 different types of hand grips with the aim of with 8 different types of hand grips with the objective of visualizing the behavior of different patients with and without CTS in patients with CTS and without CTS before each of the tests, in addition to an electromyographic bracelet and a simple survey to 50 patients, in order to a simple survey of 50 patients, to generate the development of a database that would be the core of information to feed the neural network, to subsequently feed the artificial neural network. We proceed to show the different grips developed in figure 1, having first in section a the grip of the plastic ball with the dominant hand, in item b we have the grip of the plastic cup, in part c of the image we have the development of the Phalen's sign, in component d we have the grip and holding of a full liter water bottle, in section e a table with a flat surface is held, but with two velostat sensors, in item f there is the grip of an anti-stress ball, in part g of the figure there is the development of the inverse Phalen's sign and finally in section h there is the grip of the marker, the figure is shown below:

With the grip module developed, we proceeded to measure the different experimental users to capture the grip information of their respective dominant hand as shown in Figure 2.

The information measured by each of the sensors in each of the grip tests, was stored in an espwroom32 and by means of micropython developed five adc that handled a resolution of 12 bits bearing in mind that are from 0V to 3. 3V the analysis voltage window that allowed the capture of information from each of the different sensors (in this part it is clarified that each grip element can have more than one sensor, this will be explained in a summarized way in figure 3), then, the behavior of the signals of a user in each of the developed grips is shown:

Figure 1. **Different types of grips designed, implemented and tested in each of the patients: (a) Plastic Ball Grip: In this grip the strength of the dominant hand is analyzed in the fingers that innervate the median nerve such as the thumb, index, middle and ring finger, along with the palmar area, the non-dominant hand helps to hold the ball, (b) Plastic Cup Grip: in this grip the user holds the cup and develops a sustained force, (c) Phalen's Sign: In this stage the user develops the Phalen's exercise for one minute, (d) Carafe Grip: In this part the user holds a 1 liter carafe filled with water for one minute, (e) Thumb Grip: The user holds with the thumb of the dominant hand the surface board, (f) Anti-stress ball grip: The user squeezes an anti-stress ball for 30 seconds, (g) Reverse Phalen's Sign: The patient develops the activity for one minute, and (h) Marker Grip: The user develops a marker grip.**

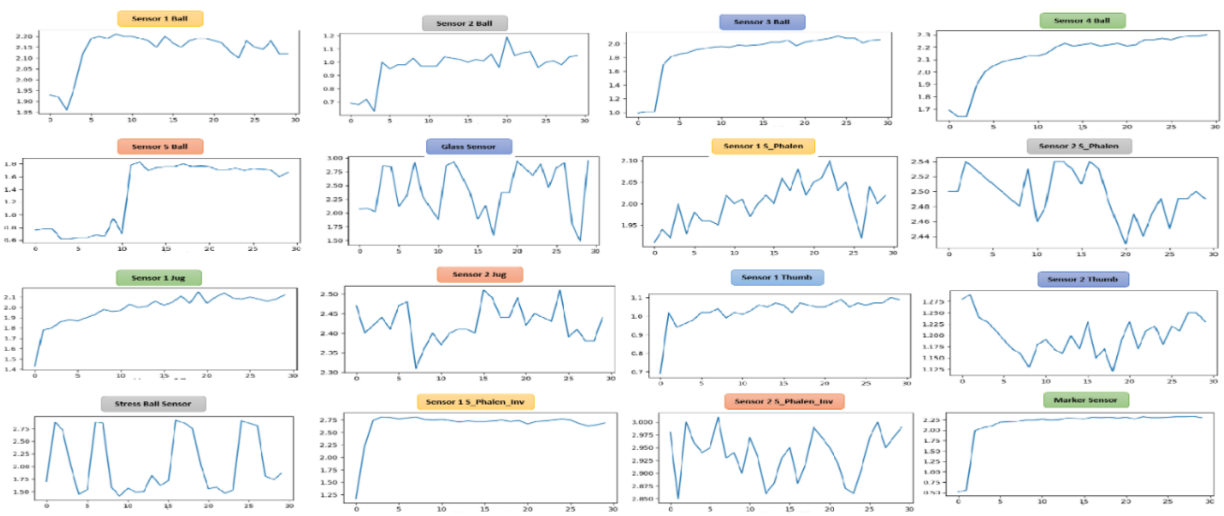


Source: own.

Figure 2. Acquiring information from the different test users on each of the different grips tested on each user's dominant hand [Own Source].

Source: own.

Figure 3. Signals acquired by means of the velostat sensors located in each of the devices of gripping module 1. It is highlighted that the signals shown in this illustration are from an experimental user in the test.



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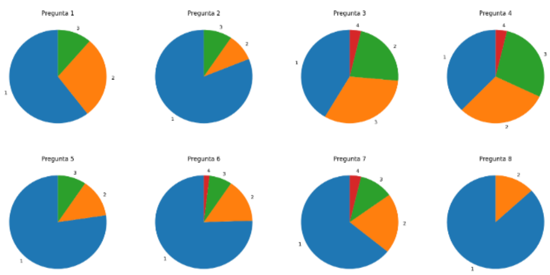
In the second module, an electromyographic bracelet was developed by means of a nanoarduino, an electromyographic sensor, in addition to a bluetooht sensor that allowed a wireless transmission for a greater comfort of the user having in mind the following model and the following signal. (Figure 4).

Finally, in the third module, a survey was developed to visualize the level of difficulty that each person had when developing the first module, bearing in mind the Dash scale of difficulty. Figure 5 shows that the highest level of difficulty experienced in the different grasping exercises of the first module was in the development of the Phalen's sign activity, in the grasping of the decanter, in the development of anti-stress ball pressure and in the development of the Reverse Phalen's sign activity.

Figure 5. It exposes the result of the different questions that were developed in the Dash survey.



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2. Analysis and Results

After generating the capture of all the data, the first thing that was developed was a normalization of the values for the management of the same scale, bearing in mind the following equation:

$$V_n = \frac{V - V_{min}}{V_{max} - V_{min}} \qquad (1)$$

Subsequently, an analysis of the data was generated with the Python pairplot function in order to investigate in an agile way the cross relationship between all the variables that had been obtained to check if they generated a normal distribution, an example of the analysis is shown below (for more information see the master's thesis).

Figure 6. Visualization of the cross-relationship between parameters of the Phalen sign.

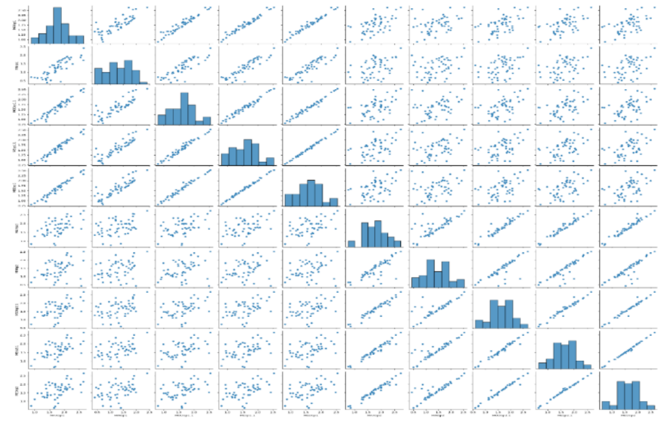

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Figure 6 shows that there are graphs that do not preserve the symmetry or the shape of a normal distribution, so a parametric relationship was advanced in Spearman's correlation coefficient, which is recommended when the values are extreme [12], Kendall's correlation coefficient, which is a nonparametric measure of correlation for ordinal or range variables that takes into consideration ties [13] and Pearson's correlation coefficient, which is a measure of linear dependence between two quantitative random variables [14]. Spearman's distribution equation is:

$$r_s = 1 - \left[6 \sum \frac{d_i^2}{n^3 - 1}\right] \qquad (2)$$

Where d_i is the difference between the ranges between X and Y [15] and n is the number of data. Now we proceed to show Kendall's tau coefficient equation having:

$$\tau = \frac{S_a - S_b}{[n*(n-1)/2]} \qquad (3)$$

Where Tau is the Kendall's statistic value [16]. Finally, the Pearson sample correlation coefficient equation, which was first presented in 1985, is shown.

$$\tau XY = \frac{\sum(X-\vec{X})(Y-\vec{Y})}{[\sum(X-\vec{X})^2 \sum(Y-\vec{Y}^2)]^{1/2}} = \frac{S_{XY}}{\sqrt{S_{XX}S_{YY}}} \quad (4)$$

The vectors $\vec{X}$ and $\vec{Y}$ indicate the sample means of X and Y, and S_{xx}, S_{yy} and S_{xy} correspond to the corrected sums of squares for X, Y and the cross product of XX [14]. With the above in mind, an analysis graph was generated for the parameters of each stage with the following code:

```
corr_df = corrSPE1.corr(method = 'spearman')
plt.figure(figsize=(30,20))
sns.heatmap(corr_df, annot = True)
plt.show()
```

This was used to develop a global analysis graph of all the variables taken into account. (Figure 7).

The following results were obtained in Table 1:

Figure 7. **Correlation of all prevention system parameters**

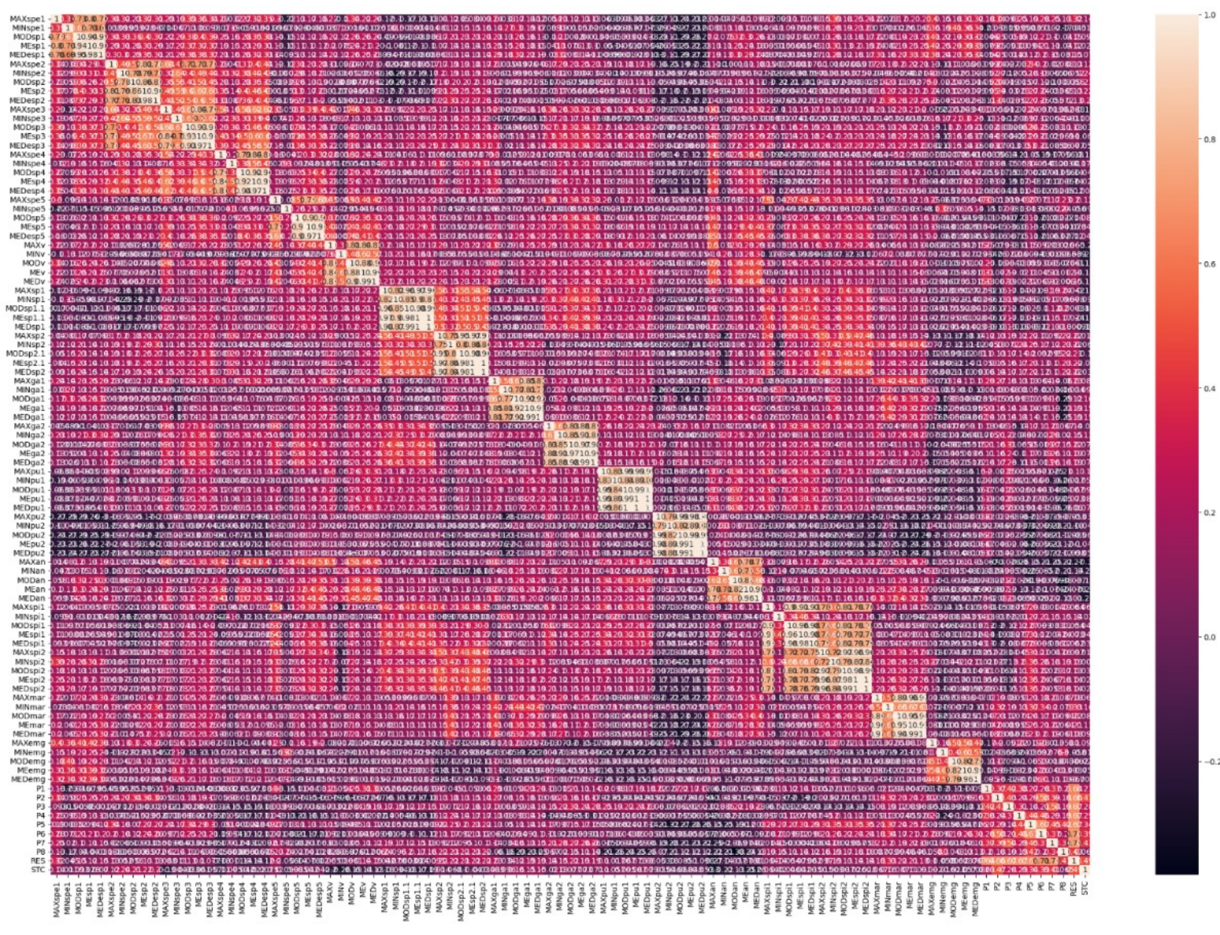

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Table 1. Correlations of the parameters extracted from the different sensors to the different questions asked in the survey.

CORRELATIONS PARAMETERS SENSOR 1 TO QUESTION 1					
CORRELACION	MAX	MIN	MOD	MED	MEDIAN
Spearman	0.27	-0.14	0.0099	0.0009	-0.0021
Pearson	0.18	-0.23	-0.046	-0.079	-0.054
Kendall	0.23	-0.11	0.014	0.0029	0.00098
CORRELATIONS PARAMETERS SENSOR 2 TO QUESTION 1					
CORRELACION	MAX	MIN	MOD	MED	MEDIAN
Spearman	-0.11	-0.17	-0.051	-0.11	-0.098
Pearson	-0.099	-0.052	-0.052	-0.095	-0.11
Kendall	-0.088	-0.14	-0.039	-0.084	-0.073
CORRELATIONS PARAMETERS SENSOR 3 TO QUESTION 1					
CORRELACION	MAX	MIN	MOD	MED	MEDIAN
Spearman	0.069	-0.16	-0.025	-0.054	-0.065
Pearson	0.13	-0.13	-0.032	-0.044	-0.083
Kendall	0.055	-0.13	-0.022	-0.045	-0.053
CORRELATIONS PARAMETERS SENSOR 4 TO QUESTION 1					
CORRELACION	MAX	MIN	MOD	MED	MEDIAN
Spearman	-0.011	-0.052	-0.058	-0.098	-0.12
Pearson	-0.0083	-0.023	-0.055	-0.073	-0.084
Kendall	-0.012	-0.04	-0.049	-0.078	-0.095
CORRELATIONS PARAMETERS SENSOR 5 TO QUESTION 1					
CORRELACION	MAX	MIN	MOD	MED	MEDIAN
Spearman	0.29	-0.2	-0.11	0.05	0.0031
Pearson	0.33	-0.15	-0.11	0.044	-0.031
Kendall	0.24	-0.17	-0,089	0.035	0.00098
CORRELATIONS PARAMETERS SENSOR 11 TO QUESTION 1					
CORRELACION	MAX	MIN	MOD	MED	MEDIAN
Spearman	-0.086	-0.25	-0.12	-0.007	-0.021
Pearson	-0.079	-0.26	-0.16	-0.072	-0.067
Kendall	-0.068	-0.2	-0.095	-0.0051	-0.014
CORRELATIONS PARAMETERS SENSOR 12 TO QUESTION 3					
CORRELACION	MAX	MIN	MOD	MED	MEDIAN
Spearman	0.16	0.19	0.14	0.18	0.15
Pearson	0.17	0.19	0.12	0.17	0.15
Kendall	0.13	0.14	0.10	0.14	0.12
CORRELATIONS PARAMETERS SENSOR 13 TO QUESTION 3					
CORRELACION	MAX	MIN	MOD	MED	MEDIAN
Spearman	0.23	0.059	0.16	0.18	0.19
Pearson	0.19	0.072	0.17	0.16	0.17
Kendall	0.18	0.042	0.12	0.14	0.14
CORRELATIONS PARAMETERS SENSOR 14 TO QUESTION 4					
CORRELACION	MAX	MIN	MOD	MED	MEDIAN
Spearman	0.12	0.033	0.074	0.11	0.094
Pearson	0.13	0.08	0.059	0.14	0.14
Kendall	0.097	0.017	0.059	0.083	0.061
CORRELATIONS PARAMETERS SENSOR 15 TO QUESTION 4					
CORRELACION	MAX	MIN	MOD	MED	MEDIAN
Spearman	0.13	0.11	0.14	0.14	0.12
Pearson	0.17	0.097	0.15	0.17	0.15
Kendall	-0.1	-0.03	-0.06	-0.073	-0.1
CORRELATIONS PARAMETERS SENSOR 12 TO QUESTION 5					
CORRELACION	MAX	MIN	MOD	MED	MEDIAN
Spearman	0.084	-0.011	0.043	0.052	0.051
Pearson	0.058	0.0066	0.024	0.027	0.014
Kendall	0.062	-0.0047	0.032	0.041	0.04

CORRELATIONS PARAMETERS SENSOR 13 TO QUESTION 5					
CORRELACION	MAX	MIN	MOD	MED	MEDIAN
Spearman	-0.24	-0.34	-0.29	-0.29	-0.28
Pearson	-0.21	-0.32	-0.27	-0.26	-0.26
Kendall	-0.2	-0.28	-0.23	-0.23	-0.23
CORRELATIONS PARAMETERS SENSOR 16 TO QUESTION 6					
CORRELACION	MAX	MIN	MOD	MED	MEDIAN
Spearman	-0.012	0.0046	0.0016	-0.013	-0,012
Pearson	0.28	0.092	0.19	0.26	0.31
Kendall	-0.0091	0.0023	-0.001	-0.018	-0.018
CORRELATIONS PARAMETERS SENSOR 12 TO QUESTION 7					
CORRELACION	MAX	MIN	MOD	MED	MEDIAN
Spearman	-0.038	0.14	-0.046	-0.0043	-0.024
Pearson	-0.014	0.15	-0.033	-0.0042	-0.036
Kendall	-0.034	0.11	-0.045	-0.0099	-0.027
CORRELATIONS PARAMETERS SENSOR 13 TO QUESTION 7					
CORRELACION	MAX	MIN	MOD	MED	MEDIAN
Spearman	-0.0028	0.2	0.025	0.076	0.063
Pearson	0.0047	0.18	0.029	0.067	0.053
Kendall	-0.004	0.16	0.02	0.061	0.05
CORRELATIONS PARAMETERS SENSOR 17 TO QUESTION 8					
CORRELACION	MAX	MIN	MOD	MED	MEDIAN
Spearman	0.069	0.065	0.069	0.045	0.041
Pearson	0.087	0.079	0.094	0.064	0.061
Kendall	0.069	0.065	0.069	0.045	0.041

Source: own.

3. Conclusions

It was observed that the correlation between the different variables is at a moderate and tenuous level that allows the generation of different stochastic analyses for the implementation of different computational algorithms that implement artificial intelligence or optimization algorithms.

Data filtering is essential to eliminate possible noises, and a correct normalization of the data allows a simpler handling of the database logic and the correct extraction of the information to be visualized.

For this case an analysis of the different sensors used in each of the stages was developed, annexing an additional analysis of the survey developed to visualize the relationship that existed between the different variables and the subjective sensation of developing the tests, a correlation between the different variables and the subjective sensation of developing the tests was observed.

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