Enviado: 10/05/2022 Recibido: 18/05/2022 Aceptado: 03/07/2022

UNIVERSIDAD DISTRITAL FRANCISCO JOSE DE CALDAS

VISIÓN ELECTRÓNICA

https://doi.org/10.14483/issn.2248-4728

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A RESEARCH VISION

# Simulation of transradial prosthesis using Virtual Reality Environment and electrooculography (EOG) signals for grip therapy

## *Simulación de prótesis transradial haciendo uso de Entorno de Realidad Virtual y señales de electrooculografía (EOG) para terapia de agarre*

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## Abstract

This article shows the development of an application based on a virtual environment for the area of rehabilitation engineering, providing a new form of validation on prosthetic models, allowing its use in people with transradial amputation and requiring grip therapy in their treatment from 3 types of geometric shapes (cylinder, rectangular prism, sphere), as defined in grasping power objects, using electrooculography signals (EOG).

**Keywords:** Anthropometry of the hand, Electrooculography (EOG), Grip therapy, Human prehensile models, Transradial prosthesis, Virtual reality environment.

## Resumen

En el presente artículo se muestra el desarrollo de una aplicación basado en un entorno virtual

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Cite this article as: B. Forero, K. Velásquez, R. Hernández, E. Mejía, “Simulation of transradial prosthesis using Virtual Reality Environment and electrooculography (EOG) signals for grip therapy”, *Visión Electrónica*, vol. 16, no. 2, 2022. https://doi.org/10.14483/22484728.20392

para el área de ingeniería de rehabilitación, proporcionando una nueva forma de validación sobre modelos protésicos, permitiendo su uso en personas con amputación transradial y que requieren terapia de agarre en su tratamiento a partir de 3 tipos de formas geométricas (cilindro, prisma rectangular, esfera), de acuerdo a lo definido en prensión de objetos de poder, haciendo uso de señales de electrooculografía (EOG).

**Palabras clave:** Antropometría de la mano, Electrooculografía (EOG), Terapia de agarre, Modelos prensiles humanos, Prótesis transradial, Entorno de realidad virtual.

## 1. Introduction

Throughout time, human beings have used their lower and upper limbs to perform tasks in their daily lives, from lifting an object, as well as applying a great amount of force in activities that demand greater effort. That said, the population with some type of disability has a high degree of difficulty in carrying out their daily activities. Concerning the above, the World Health Organization (WHO) reported that as of 2011, the population in this condition of disability is around 15% [1], of which Colombia until 2005, recorded that those affected by some permanent limitation represent 6.3% (2,624,898 Colombians) by the census conducted by the DANE [2]. In this, it is stipulated that, among the different types of limitations, those who cannot make use of arms or hands are around 14.6%, being the sixth cause of disability in the country. However, through the Situational Room for Persons with Disabilities (PCD), projections were made on the above figures, in which an additional 2.95% (1,486,213 citizens) were determined until 2019 [3].

Currently, the use of prostheses has been evolving, to such an extent that the impact in Colombia has been sufficient to stipulate the regulation on the design and distribution of these, in which it is necessary to specify the requirements to be taken into account to be used in patients at the clinical level [4], [5], different types of designs have been conceived until today, as is the case of the Macmillan mechanism [6], with the principle of operation from the movement of bars, specifically 6 links, forming a set of three mechanisms of four bars for each finger. Despite the success obtained by the previous study, more and more mechatronic hand prosthesis designs [7], in which different conditions are adjusted both in the measurement and in the bar diagram, to achieve an improvement of the system of human anthropometry.

However, throughout history, mechanisms have emerged that include mechanical systems such as pinions, crank-crank, and racks, among others, which are integrated by the researchers in [8], evaluating 28 mechanisms based on the mechanical parameters of each design. According to the above, the anthropometric conditions of the patient should be estimated [9], [10], seeking that the research design with the proper mathematical support.

On the other hand, the development of such devices has been driven by the control through physiological signals, to provide different functions associated with what the user wants. From this, electroencephalography (EEG), electromyography (EMG), and electrooculography (EOG) are used in the field of rehabilitation engineering, specifically in robot-assisted physiotherapy as exposed in research [11], [12], [13]. In which electronic circuits or sensors such as the Myo ArmBand® or Kinect are used for signal acquisition. For these, specifying the EOG signal and the interaction with the user, the 3-channel protocol [14] is used, for which an electrode is placed on the right eyebrow, a DRL or feedback channel, and a REF or reference channel, which is analogously equivalent to the configuration used in the Electrocardiogram (ECG). In contrast, the 5-channel electrode configuration [15], [16], ($^{V+}$, $^{V-}$, $^{H+}$, $^{H-}$, and GND), in which the authors decompose the captured signal to eliminate the incoming noise and reconstruct the signal, obtaining the waves for each eye movement, is proposed [15], [16].

On the other hand, regarding grip therapy, being the objective problem faced by the validation of prostheses, different models have been determined concerning the performance that the person exerts in the grasp of an object either by precision or force [17], [18], the first of them, is responsible for the dexterity and accuracy with which the task is performed and cylindrical or prismatic elements are usually used. On the contrary, in the grip by force, greater power is required, which in turn is subdivided into palmar and hook grip.

Thus, it is important to highlight that most of the prosthetic mechanisms are implemented, generally using virtual reality software for the optimization of materials and testing the operation as a whole, thus, virtual environments implemented in Unity 3D® have been developed based on the principle of development in MATLAB® software in which using Simulink and VRML (own software tools), in which it is possible to observe the prosthetic device with different objects to perform the tests related to the contact and interaction of the force taking into account the time, impulse and release on the element, as reported by the authors [19], [20], [21].

Reciprocally, the research presented in [22] is linked to an upper limb exoskeleton in which the patient's physiology is considered, as well as his emotional state, taking into account that frustration and other factors involved in the process of adaptation and management of the prosthesis, affect and are determinants for the functioning on the control of the device.

## 2. Materials and Methods

### 2.1. Design

To determine the prosthetic design, we take into account the obtaining and application of the tests in the virtual environment and the physiological signal based on Electrooculography (EOG), where the methodological development that was adopted is presented in Figure 1, as can be seen, four (4) phases that make up the execution and application of the study are defined.

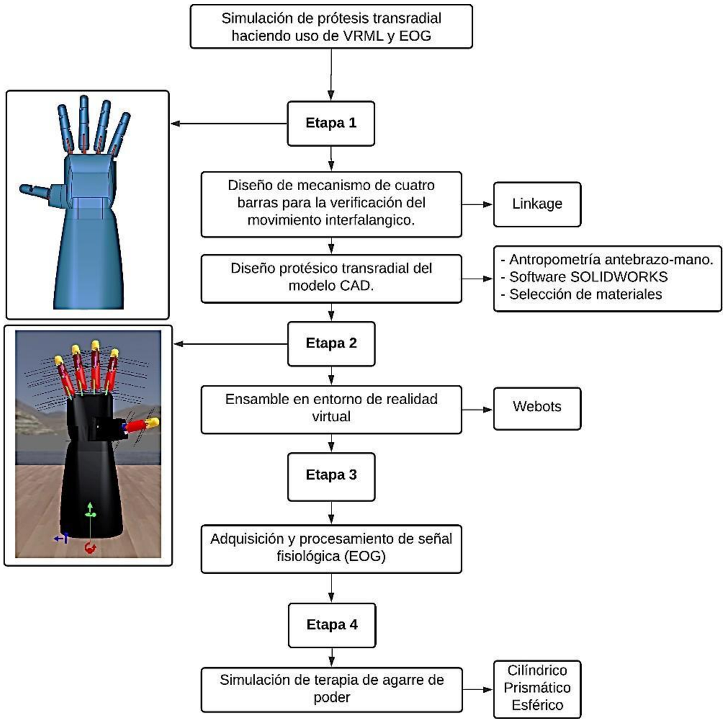


**Figure 1.** Methodological process for the research. Source: own.

***Phase 1:*** Based on the developments presented in the literature for prosthetic mechanisms, it was decided to test and adopt the mechanical system of four (4) bars, which was implemented in the Linkage® software (See Figure 2). In this, the behavior of the phalanges that emulate motors and parts designed according to the anthropometry taken as a reference can be observed. Based on the results obtained, the design, simulation, and numerical methods for the resolution of the prosthetic element are carried out employing SOLIDWORKS® software for 3D modeling (See Figure 3) and MATLAB® for programming the kinematics and its trajectories.

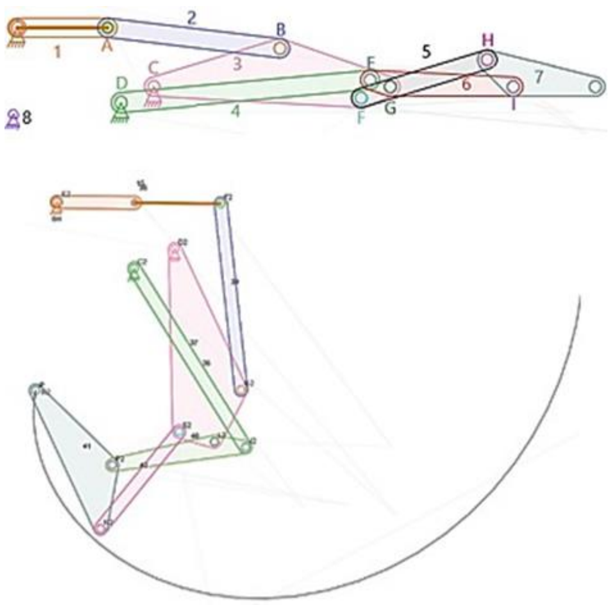


**Figure 2.** The four-bar mechanism for prosthetic design. Source: own.

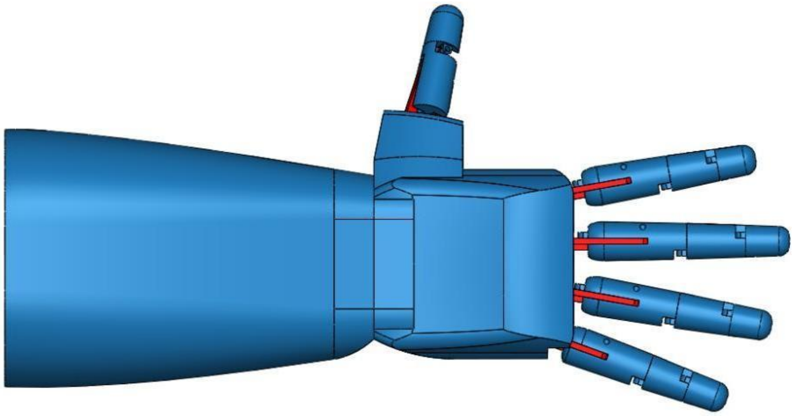


**Figure 3**. CAD design of the prosthetic element. Source: own.

***Phase 2:*** It starts with the development of the assembly using the Webots® program, which is characterized by its virtual environment, from which it is possible to simulate the environment of a grasping therapy together with 3 objects that will be taken into account for the verification of the element, following the prehensile models presented by Cutkosky. [23]

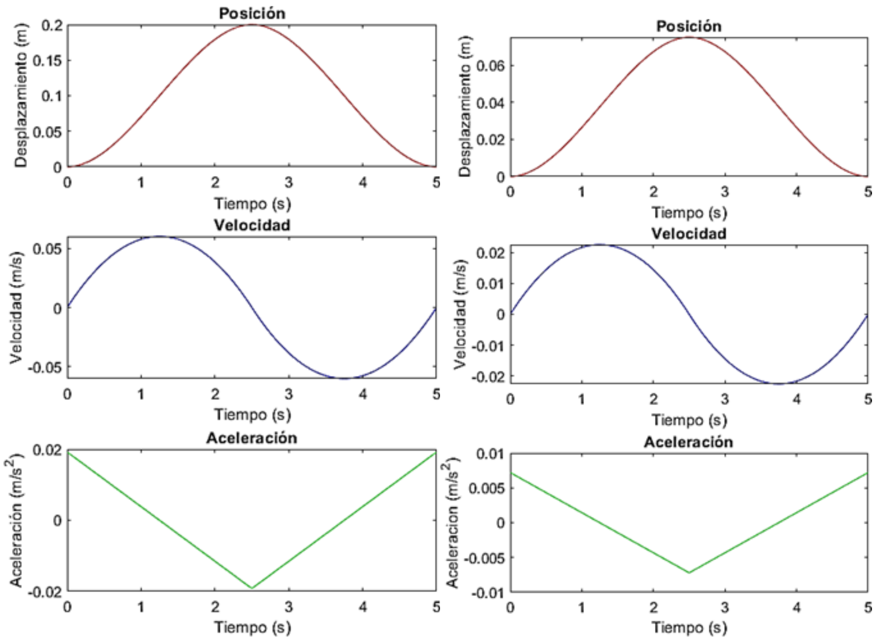
***Phase 3:*** The electronic architecture for the acquisition of the EOG signal is proposed, as well as the obtaining by a microcontroller to perform the respective digital processing, in such a way that the defined eye movements are identified.

***Phase 4:*** Considering the results obtained in the three previous phases, the prosthesis is validated through the virtual environment on which the grip therapy is to be performed, using Webots® software connected to Matlab® for cylindrical, prismatic, and circular objects.

In Phase 1, the selection of the motors for the generation of the flexion-extension movements, as well as the interposition and retroposition of the thumb was considered as a fundamental factor, therefore, the movement they generate, the displacement times, and the dimensions that would have an impact on the size, depending on their location, were stipulated.

Based on the above, a linear motor with gear changes of 30:1 from Actuonix (PQ12-P with feedback) was selected, allowing the planning of trajectories for the finger movements according to the drive times of the distal extremities. Thus, a linear displacement of 20 mm is established for the flexion and extension movement (see Figure 4a) being the limit of the characteristics of the sliding bar, for which the position, velocity, and acceleration are determined; in this way the procedure is repeated, as shown in Figure 4b, but with the difference of the established displacement, which corresponds to 7.5 mm, considering that it refers to the additional degree of freedom for the thumb, which allows the retroposition for the grip of an object.

When performing this process on the mechanical drive system, it is important to highlight that for the development of the trajectory planning, it must be considered that at the end of the angular movement, the grip on the type of object of study is being performed, as will be observed in the results section.

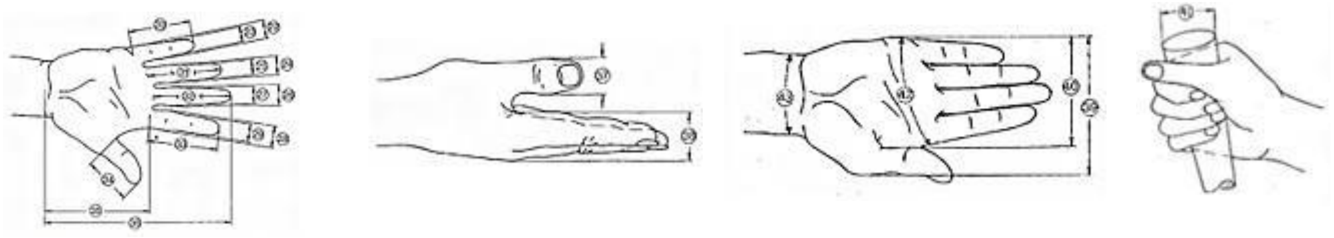


(a) (b)

**Figure 4.** Linear motor actuation signals. a) Linear actuator with 0-20mm range. b) Linear actuator with 0-7.5mm range. Source: own.

## 2.2. Interventions

To determine the mathematical development of the mechanism, we proceed to implement two (2) techniques established in robotics. The first one focuses on the application of the geometric method based on Newton Raphson, to specify the angles and final relations of the movement on the start-end of the implemented geometry. Secondly, there is the planning of trajectories, for the final point of displacement on the two evaluated moments of flexion-extension of the phalanges, providing the achievable limits or work zone of the implemented design. On the other hand, as mentioned in section A, the anthropometric measurements stipulated in the standard are considered: DIN 33402, which specifies the characterization of the measures to be taken into account for the hand, as shown in Figure 5 (a-d). About what was shown in the images, the values taken into account for the CAD model were obtained, as can be seen in Tables 1 and 2, where the dimensions taken in millimeters (mm) are shown. However, some measurements had to be taken from the measurements on a male subject, to ensure a closer approach to the bone structure of the hand, taking as initial measurement parameters the average values determined for the Colombian population [9].



(a) (b) (c) (d)

**Figure 5**. Anthropometric measurements of the hand. a) Top view b) Lateral view c) Bottom view d) Hand grip. [24]

From this, the response of the prosthesis in the virtual environment is taken into account, as well as the behavior presented by the simulation execution time and the time of grasping the object in comparison with the real movement performed on a person under normal conditions. These mathematical methods are necessary to determine the accuracy of the implemented algorithm, taking as variables the test subjects and the tests performed in the validation, as shown in Tables 1 and 2.

## 3. Results

For the evaluation of the prosthetic mechanism, different parameters can be established to achieve the best approach to the amputated limb, therefore, at first, the mathematical support was performed to the bar mechanism, thus achieving the verification of the degrees of freedom for each finger. It should be noted that the purpose of the device as a whole is to guarantee the flexion-extension movements of each phalanx, as well as the interposition-retroposition movement of the thumb.

| **Dedo** | **Índice** | | | **Corazón** | | | **Anular** | | | **Meñique** | | | **Pulgar** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Falange** | Proximal | Medial | Distal | Proximal | Medial | Distal | Proximal | Medial | Distal | Proximal | Medial | Distal | Proximal | Distal |
| **Longitud (mm)** | 48 | 29 | 26 | 50 | 34 | 29 | 40 | 34 | 29 | 26 | 25 | 26 | 38 | 25 |
| **Total (mm)** | 103 | | | 113 | | | 102 | | | 77 | | | 70 | |

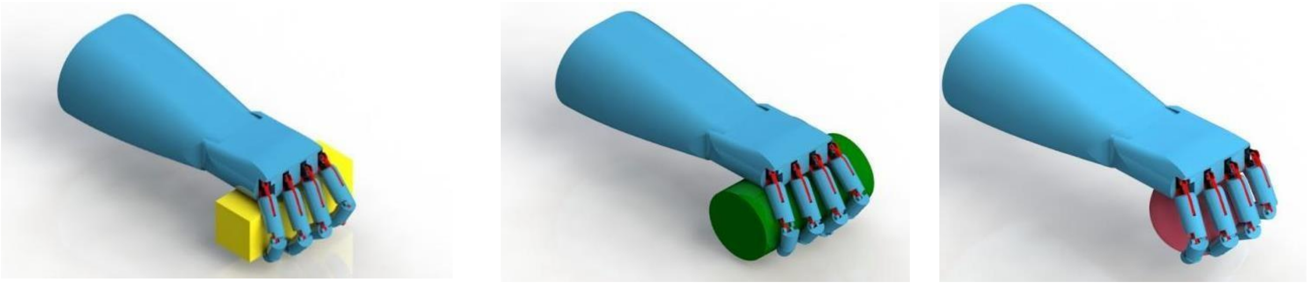
**Table 1.** Anthropometry of the hand. Source: own.

| | | | | |
|---|---|---|---|---|
| **Antebrazo** | Largo | 180 mm | | |
| | Radio de circunferencia | 43 mm | Longitud de la circunferencia | 27 mm |
| **Muñeca** | Radio de circunferencia | 27 mm | Longitud de la circunferencia | 17 mm |

**Table 2**. Anthropometry at the transradial level. Source: own.

After that, the 3D mechanism was made, to proceed to the determination of materials of the components, in which ABS was selected to perform 3D printing of the parts, as well as carbon fiber that accompanies the selected linear motor. As for the validation of the gripping of objects, solid objects similar to those used in real therapy were made, choosing 3 objects to test 3 types of power grips: medium envelope prismatic type, heavy envelope prismatic power of the large diameter, and gripping power with circular compact sphere type object, referring to those movements where more power or force is required to act, according to Cutkosky [23].

As seen in Figures 6a and 6b, it consists of the medium and heavy wrap prismatic grip, respectively, characterized by the claw-like movement between the fingers 1,2, and 3 fundamentally. Similarly, we proceed to the evaluation of the grip for a spherical object (See Figure 6c), which is characterized by the maximum movement of the thumb, adjacent to the middle finger of the hand to secure the circular element without destabilizing it from the central plane of the palm.

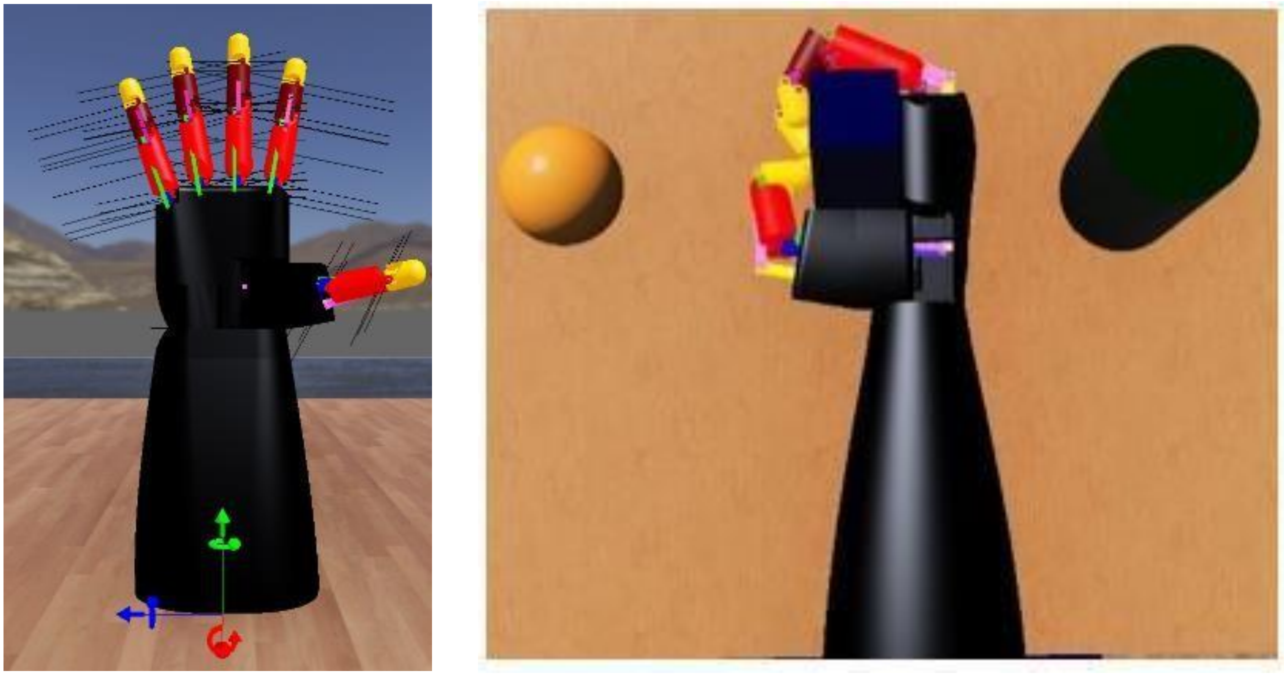


(a) (b) (c)

**Figure 6.** Power grips. a) Prismatic medium envelope type b) Large diameter heavy envelope prismatic power grip - cylinder type. c) Prehensile power grip with circular compact object - sphere type. Source: own.

Taking into account what was developed, in the second phase nodal trees were established to perform the assembly in the virtual environment, taking as a fixed base what corresponds to the palm and the wrist-forearm, leaving the movement of each phalanx free, as can be seen in Figure 7a. In the latter, the movement configuration associated with the colors assigned to each finger is detailed, as well as the rotation axes for each piece. Subsequently, the complete scenario was generated to test the system, as shown in Figure 7b, where the 3 objects mentioned above are added. From this, it was possible to visualize the desired movement, however, it became evident that the determining factor in this type of simulation is related to the physical conditions.

By not considering the conditions of centers of rotation, density, and masses, among other factors, the simulation remains static, hence the importance of knowing this type of mathematical conditions before the complete assembly, to obtain results that allow the verification of the proposed system.



(a) (b)

**Figure 7.** Simulation of objects in the virtual reality environment. Source: own.

About Phase 3 and what was collected through the literature, it was possible to implement the electronic circuit for the acquisition of the EOG signal, as shown in Figure 8. Therefore, by duplicating the system it is possible to use a configuration of 5 electrodes for the acquisition of the signals for the vertical and horizontal axis. The developed circuit is mainly conformed by an impedance coupling generated between the potential difference between the positive and negative electrode, followed by the instrumentation amplifier, then the filtering is applied for signal amplification and noise reduction to reach the output stage in which the desired result is observed, according to the representative curve of the signal, following its amplitude (50uV to 3500uV) and frequency (DC to 100Hz) [25].

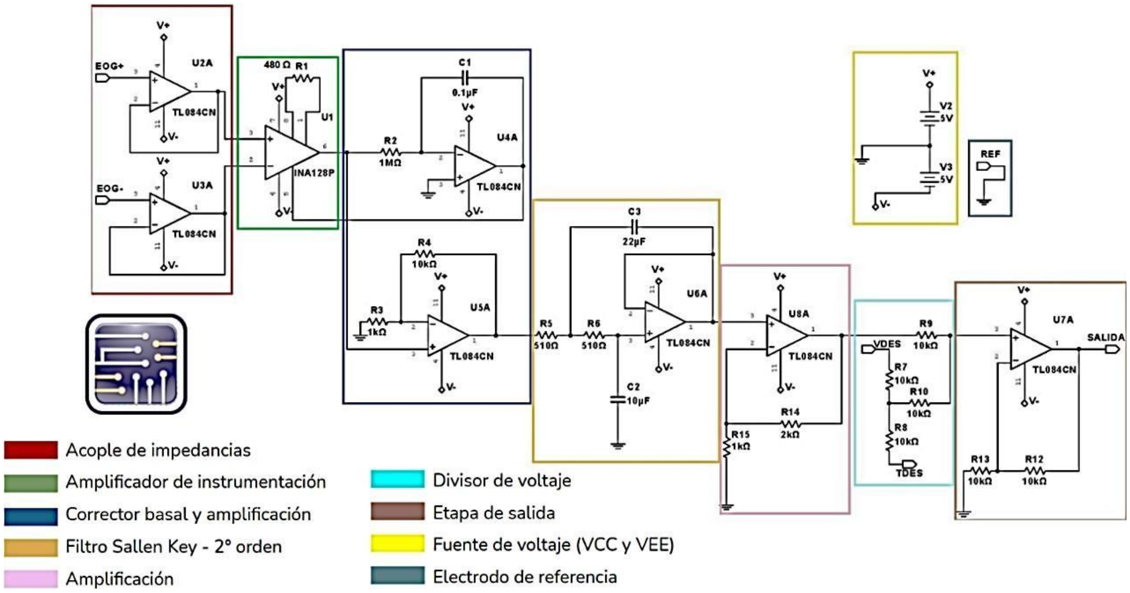


**Figure 8**. Electronic circuit implemented for electrooculography (EOG) detection. Source: own.

For the validation of the acquired signals, a graphic matrix was generated (Figure 9) to observe the deviation of the signal as it moves, having as main axes the final directions and a central point to which the eyes return at the end of the displacement, to compare whether the acquired signal corresponds to the movement performed. It is of utmost importance to consider the distance at which the screen where the panel is displayed is located, since this may vary the angles and derivations of the signal according to the location of the pupil. Additionally, it should be considered that double blinking is observed, as well as the movement when the user closes his eyes.

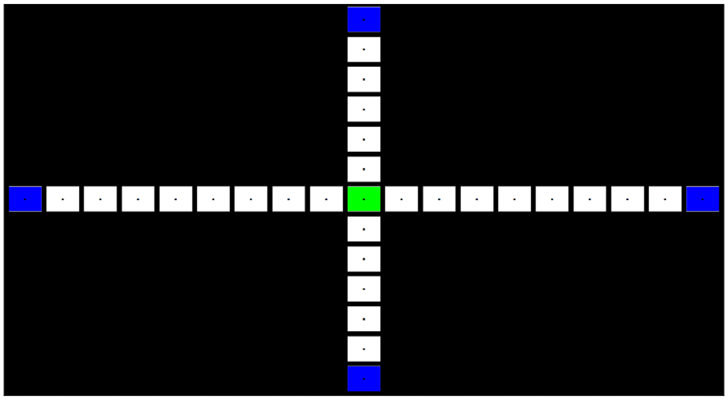


**Figure 9**. Visualization panel for therapy. Source: own.

Finally, the signal is visualized digitally, as illustrated in Figure 10a, in which the verification of the user's request with what is obtained by the circuit is carried out; such data allow leaving evidence of the assertive behavior of the developed circuit allowing the future implementation of an algorithm that is responsible for the characterization of such signals. Currently, phase 4 is being implemented in which the signal obtained will be connected to the virtual reality environment, and additionally, there is a database (Figure 10b) to proceed in future research to use such data for the characterization and creation of algorithms by artificial intelligence that are responsible for validating the physiological signal with greater precision.

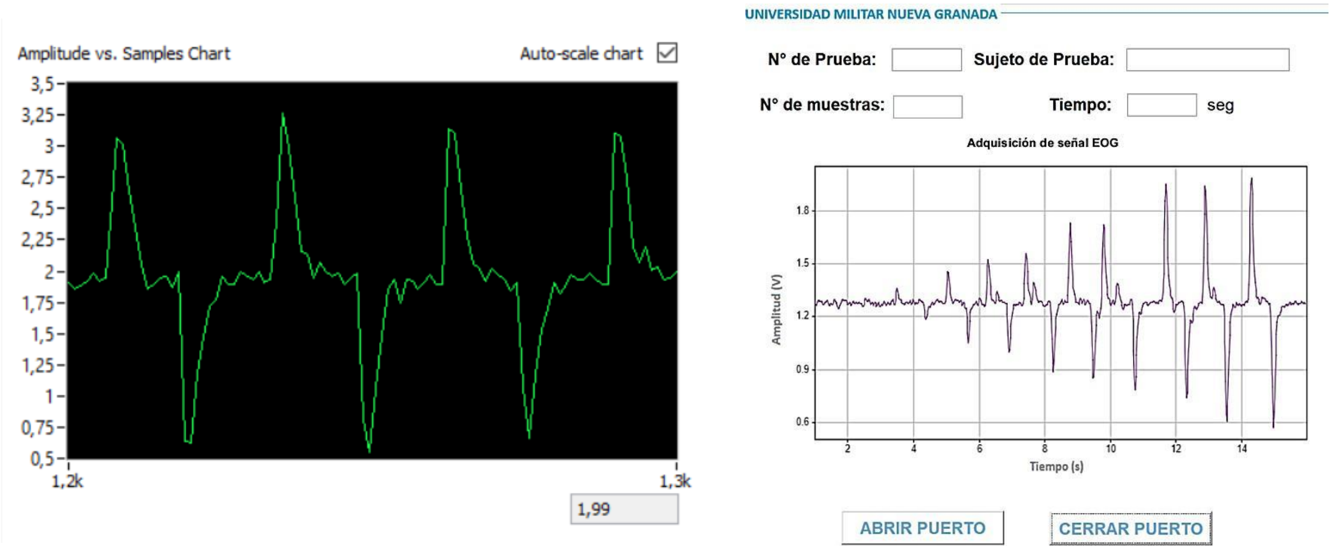


**Figure 10.** a) Signal visualization using DAQ-MX b) Panel for EOG database creation. Source: own.

Taking into account what has been exposed in the previous section, it is necessary to compare what has been obtained with the literature review. Starting from this premise, the first object to highlight is the factor determined in the mechanism of the degrees of freedom (G.D.L) offered by the different prosthetic models, as mentioned by the author [26] in his research, which determines 5 articular movements on the phalanges of the hand, while the model proposed in this research has 3 in each finger, adding an extra movement of the thumb. If we continue reviewing this factor with different authors, we observe a tendency to advance the functionality offered by these prosthetic elements, to such a degree that, although the functional anatomy in normal conditions only has 26 G.D.L., there are already prosthetic mechanisms that have 28 or more movements.[8] Therefore, the importance of conditioning the mechanism to add more movements are supported, without the need to add actuators that make the model more robust and distant from the anatomy of the amputated limb.

Linked to what is determined in the mechanism segment, the development of prostheses in which gears or bars are mainly used is observed, as evidenced in the research [24] in which they perform the reduction of actuators using the configuration between different types of mechanical mechanisms that are activated in a chain, starting from the mathematical reasoning between gears, which require greater precision in their manufacture, generating a greater amount of cost for the final product, which is why contrary to what is stated by the author, it is possible to achieve the desired movement of the joints using joints and rods, which in economic terms only requires 3D printing of the rods with ABS material.

Regarding the analysis performed on the virtual environment, we proceeded to compile the information that was determined for the approach on the different software that provides the required features, thus, the author [24] makes use of the environment coupled in MatLab®. On the other hand, in the document published [25] by the author to obtain her professional degree, the use of the Coppelia Robotics® program is evidenced, which was updated from its most known version V-REP, which has several connection modules for this type of applications and to this day is one of the most used in the field. In this way and taking into account Table 3, the simulation was obtained in the Webots® Environment, due to previous knowledge of the programming language, as well as the importance of an open source license and great compatibility in case of requiring tools of other types of environments.

| **PARAMETER** | **MATLAB 3D WORLD EDITOR** | **ROS** | **WEBOTS** | **COPPELIA ROBOTICS** |
|---|---|---|---|---|
| Support format | WRL, X3D, X3DV | WRL, X3D, X3DV | WRL, X3D,WBT | OBJ, STL, DXF, 3DS, Collada, URDF |
| External APIs | C, C++, Python, ROS | Gazebo, OpenCV, MoveIt, Coppelia R. | C, C ++, Python, Java, Matlab, ROS | C / C ++, Python, Java, Urbi, Matlab / Octave |
| Language of main program | C, Java | Python, C++ and Lisp | C++ | LUA |
| License | Pay | Open | Open | Pay and open |
| Documentation | Media | Media | Media | High |

Table 3. Comparison of virtual reality environments. Source: own.

## 4. Conclusions

Considering what has been exposed throughout the document and following the defined stages, it was possible to first establish the anthropometric measurements for a male subject, allowing the implementation of the mechanical design based on the movement of bars, with the use of linear displacement actuators. Subsequently, the implementation of the said prosthetic element was achieved, utilizing a virtual reality environment, in which it was possible to perform the mechanical actuation employing a programming algorithm, to carry out 3 types of prehensile models (medium envelope prismatic type, large diameter heavy envelope prismatic power and prehensile power with sphere type circular compact object), using 3 test objects (sphere, cylindrical and prismatic). At this point, the importance of the physical implications of the center of rotation, mass, and density for the system became evident, since, without defining the mentioned parameters, the simulation generates errors, preventing communication with the physiological signal (EOG).

Based on the latter, the electronic circuit of the electrooculography signal (EOG) was stipulated, with its respective formal digital acquisition, allowing the development of an interface designed for the future application of a database and collection on test subjects for the physiological signal. On the other hand, it is worth mentioning that improvements are planned on the prosthetic model in terms of aesthetics, to prevent the union between the hand and forearm a widening which is not generated in the transradial member in normal conditions, improving the quality of life of the person. As well as to determine a different coupling on the additional movement of the thumb, reducing its size and increasing its performance when grasping objects. Thus, the research is currently in its final phase, stipulating the foundations for future research linked to the use of EOG and Virtual Reality, as robust and innovative solutions that impact the area of Rehabilitation Engineering.

## Acknowledgments

The authors would like to thank the Universidad Militar Nueva Granada and the Vicerrectoría de Investigaciones who financed the present project with code IMP-ING-3503 entitled "Control System for a robotic platform for people with motor disabilities through electrooculography and deep learning", from which the present work is derived. Oscar Rubiano, whose contributions contributed to the search for solutions to the problems presented, is also acknowledged.

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