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Artificial extension for a canine with partial forelimb amputation

G. Garrido - Silva[1*], E. F. Forero-García[1], J. G. Maradey – Lázaro[2], A. D. Rincón-Quintero[3], C. L. Sandoval- Rodríguez [3], O. Lengerke[1]
[1*] Electronic Engineering Program, Universidad Santo Tomás, Colombia
[2] Mechatronic Engineering Program, Universidad Autónoma de Bucaramanga, Colombia
[3] Faculty of Natural Sciences and Engineering, Unidades Tecnológicas de Santander, Colombia

ABSTRACT

When a canine presents a serious case of disease, injury or necrosis, it is imperative to perform an amputation procedure, whatever the affected limb is, since it can minimize the risk of developing pathologies related to tissues, joints and spine, associated with an altered gait and/or unequal distribution of forces in their limbs. Thus, improvement alternatives arise such as prostheses which help to improve the quality of life of canines. The article proposes the development of a functional prototype of prosthesis for canines with partial forelimb amputation through the design and 3D modeling of the prosthesis, together with the selection of the material that adapts to the morphological conditions of the canine. Also, a cushioning system is incorporated to minimize the force of the impact with the ground when performing activities such as jumping, running or walking. Finally, the electronic component is included in the design and the respective electronic and biomechanical tests are carried out to verify its correct operation.

Keywords: Amputation, canine, exoprosthesis

Corresponding Author:

Gianina Garrido Silva
Electronic Engineering Program
Universidad Santo Tomás
Career 9 # 51-11 Chapinero, Bogotá, 680003, Colombia
E-mail: gianinagarrido@usantotomas.edu.co

1. Introduction

There are situations in which damage is generated in one or more of the limbs of a canine, either by injury, disease or atrophy at the muscular, bony or nervous level, so the amputation of this limb is performed in order to avoid the appearance of skin ulcers or excoriations due to the constant dragging or suspension of its limb. However, amputation leads the canine to develop pathologies related to the tissues, joints and spine due to the altered gait and the unequal distribution of weight [1][2][3][4][5].

To avoid these conditions, different types of prostheses have been developed for these animals, which can vary according to their design, material and degrees of freedom they offer. However, there is great difficulty in accessing these devices, either because of the scarcity of companies dedicated to this segment of customers or, alternatively, because of the high cost that sometimes the customer, i.e. the dog owner, cannot afford. The canine patient is an 8 year old dog, who suffers an accident in his left forelimb, for which he underwent an amputation at the carpal joint level. Due to this, the canine must distribute its weight on the remaining limbs and, as a result, suffers from a notable deviation in the hip and spine, in addition to callosities on the stump and decreased muscle tone at the level of the forearm. According to the above, a design and construction of a low-cost prosthesis is proposed as a viable alternative for the recovery of the function of the forelimb of a canine in order to improve its quality of life [6][7][8].

1.1. Highlights of prosthesis

Over the years, the field of prosthetics for canines has had several variations and improvements by its developers, in part thanks to computer-aided design systems, which have been inspired by the advances and materials of human prosthetics. Each design factor is geared toward getting the dog to adapt to the prosthesis in the shortest possible time, with the freedom and support to perform basic processes such as walking. Therefore, it is necessary to know up to date what kind of prostheses have been implemented, in order to base and support the design that will be implemented, and also to establish the differentiating or innovative factor that this project will have. Therefore, a review of articles with similar objectives was carried out, which are presented below [1][2][9]

The first project consulted is called Design and calculation of a canine prosthesis, and corresponds to a degree work of the author Carlos Sabater Fernández, carried out in the city of Valencia in July 2019. This article contains information on the development of a prototype prosthesis of the forelimb of a canine, printed in 3D. The project presents relevant information regarding the type of materials that were implemented which, according to the author, are of three types: a material with the necessary mechanical properties and printable, a material with cushioning characteristics and an anti-slip material for the area that has contact with the floor. The author mentions the materials he mentioned, but beyond that, he mentions a database in which he consulted materials that met those technical characteristics. The database is called CES EDUPACK. The document has detailed information on the design of the prosthesis, the methods of attachment, the characteristics that give it ergonomics, the form of support and the anatomical information that was taken into account along with the biomechanical analyses [5][10][11][12][13]

The second article consulted is called Design of a canine prosthesis for forelimbs, and it is a degree work of the author Miguel Ángel Pardo Jiménez, developed in Spain in 2017. The objective of this project proposes a methodology of great interest for the project in question, given that, in a very similar way, this consists of the design of a canine prosthesis that has the capacity to replace a forelimb. This prosthesis was 3D printed and proposes an innovative design for the height adjustment of the prosthesis, which is a torsionally regulated system. Also, ABS is proposed as the material of choice for printing the parts of the prosthesis, given its high impact resistance [1][8][11][14][15][16][17]

Another of the articles investigated, aims at the Design and development of a prototype of prosthesis in 3D printing applied in veterinary medicine for small species by the author Shamir Mauricio Noblecilla Valdez, developed in the city of Machala in 2017. This article proposes certain aspects to take into account in the present project, such as the types of printing materials used, PLA and nylon, which presented a quite favorable performance when used by the canine and a low cost. Basically, the methodology proposed by the author is: take the measurements of the canine, draw a sketch of the prosthesis, take this drawing to a computational design tool, print the pieces, proceed with their assembly, adjust the padding material and perform the tests on the canine. It is a methodology with very similar aspects to the one proposed for the present project[18].

The author Paula Daniela Romero Salazar, proposes an article with relevant characteristics for the project in question. In this article, entitled One paw, one life: design of prosthesis for canine limbs and identity for its commercialization and developed in Ecuador in 2016, four innovative aspects for the designed prosthesis are exposed, which can be taken into account when elaborating the design of the prosthesis of this project: the first, is that it is adaptable to the four limbs of the dog; the second, is that it works on both flat and uneven floors; the third, is that it is resistant to environmental factors; and the fourth, that the prosthesis can be used without supervision of the owner or veterinary staff. The area in contact with the floor is formed by three nylon wheels, related to the main mechanism. Another relevant factor that can be taken into consideration in relation to the project in question is that the prosthesis can serve as a support when the limb has been amputated or when the puppy still has that limb, but without greater functionality [19].

On the other hand, Fitzpatrick and his team in 2011, performed an intraosseous transcutaneous prosthesis for limb amputation in cases of tumors or malignant neoplasia of the distal zone of the limb in four dogs. This has two subunits, an endoprosthesis that attaches to the limb and an exoprosthesis to support the weight of the dog. First, they designed the Ti6Al4V titanium alloy endoprosthesis specifically for each dog, using computed tomography images from which a dimensional model was reconstructed. Secondly, the exoprosthesis was designed taking into account four models. For the first dog, it was made with a carbon fiber sheet in the shape of a human prosthesis, which included a stainless steel base attached to the exoprosthesis by means of a clamp system. The second dog used a two-piece model with a Delrin or polyacetal shaft, as it is known for high stiffness, low friction and responds very well to fatigue, and Kevlar in rubber, air bubbles and foam beads as a shoe-shaped shock absorber and a semi-built multidirectional counterweight. Similarly, the third dog had variations of the 20º angle of this counterweight and with a deformable polymer part. The fourth dog had a customized model with two metal cylinders centered and, in the most distal part, made of silicone rubber to absorb forces in response to ground contact. Bone integration was favorable, with no infection from the implant, which supported the weight of any species 18 months postoperatively [20].

Because the goal of rehabilitation is to restore functionality as much as possible and preserve the remaining limbs, Mich, & Kaufmann (2018) note that current materials recognized for their high effectiveness in canine limb prostheses are polypropylene and carbon fiber sheet. The latter is optimal for complex, weight-bearing and fatigue-resistant designs. Mich states that there is greater adaptability from the middle of the forearm to the foot, since this distance is short, so large dog breeds have greater difficulty adapting to prostheses compared to small breeds. Also, they consider that the residual limb acts as a lever, so the canine must create and control the movement of the prosthesis with the residue of the limb. Thus, the residual limb must be appropriate for suspension and retention of the prosthesis. In addition, he advises that all considerations for customer satisfaction can be supplemented by a close relationship between the manufacturer, patient and veterinary expert or therapist [21].

2. Methodology of design

The development of the project will be carried out by implementing the methodology proposed by the author Karl Ulrich in his book Product Design and Development, which consists of six phases that will be presented below [8]. Specifically, in each one of them, the project's own activities will be proposed, which will allow the development to be carried out in an organized and sequential manner.

2.1.1. Phase 0: Identification of the patient

In this first stage, the identification of the canine patient is carried out, which corresponds to a medium-sized Creole specimen, who had a partial amputation of his left forelimb due to an accident that destroyed the bones of his carpus and his phalanges. Currently, due to the problems caused by the absence of his limb, he has developed abnormal gait patterns, which led to hip dysplasia.

2.1.2. Phase 1: Concept development

In this phase, different design ideas for the prosthesis are proposed by means of freehand sketches or using drawing programs such as Sketchboard. For the selection of the best design, a selection matrix is prepared, which evaluates each of the concepts taking into account a set of previously designated criteria. The fulfillment of these criteria, for each option, will be defined by a numerical value on a scale of 1 to 5, being 1 qualified as bad and 5 as excellent, additionally the criteria will have a percentage assigned, which measures the degree of importance in the design. Finally, the respective weighted average is made for each option and the one with the highest score is chosen. Next, each of the design alternatives for the prosthesis model will be presented:

Design 1: presents a support that allows it to fulfill the same function of the lost limb of the animal. It can be seen that there is a hollow space covering the limb up to before the elbow joint, which allows more space for the coupling of the electronic system. Likewise, an articulation is made by means of a support between the limb and the leg, allowing greater mobility to the animal. The prosthesis is held attached to the limb and also held firm by the use of a pair of brackets on each side. The prosthesis is attached to the limb by means of two pieces, which are adjusted using a Velcro strap.

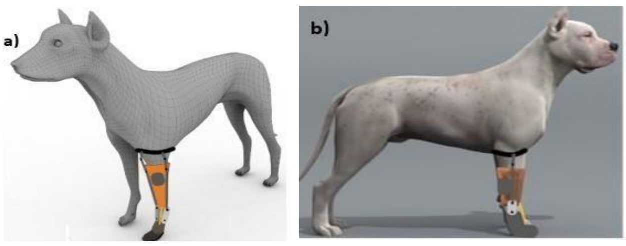

Figure 1. Sketches of the first design alternative for the prosthesis

Design 2: This design shows a support similar to those used for crutches, i.e. in the shape of a plug. This support will be totally rigid. The coupling with the dog's residual limb is made by means of a cup, which is secured to the limb by means of Velcro straps, preventing the patient from having to undergo surgery again.

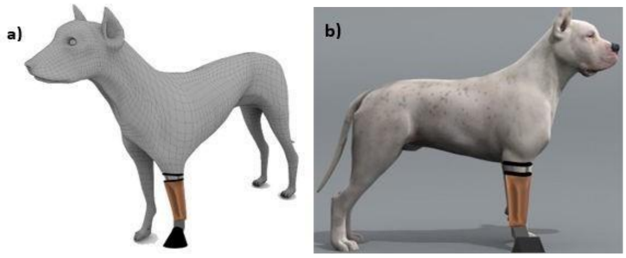

Figure 2. Sketches of the second design alternative for the prosthesis

Design 3: This alternative shows a prosthesis whose support system emulates the foot prosthesis used by athletes. The dog's limb will be inserted in a hollow cylindrical space, where the electronic system will be attached to its external face. As with the previous design, the prosthesis will be anchored to the limb by means of a Velcro strap. Additionally, there will be a section that emulates the elbow joint and allows better and greater displacement of the limb.

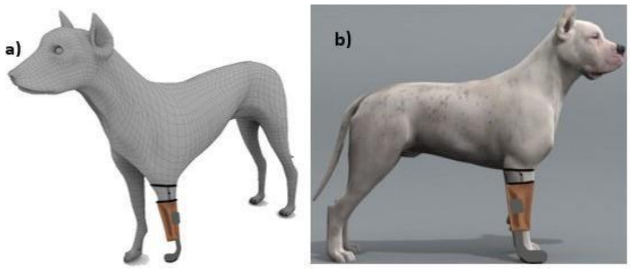

Figure 3. Sketches of the third design alternative for the prosthesis

An Affordance matrix was used to select the most appropriate design, taking into account the following selection criteria:

- Complexity of the design: when dealing with the issue of the complexity of the design, we analyze how difficult it can be to model and build such a design, taking into account the limitations we have such as space, materials and time. This criterion will have a value of 10%.
- Usefulness of the support system: refers to how good the support system of the design will be to allow the dog to perform the different daily activities, such as walking, running, jumping or lying down. This criterion will have a value of 20%.
- Ergonomics of the support system: when talking about the ergonomics of the support system, it refers to the adaptation of the characteristics of the system with the user, allowing the free development of its activities. This criterion will have a value of 30%
- Freedom of the shoulder - elbow segment: since the amputation is located in a distal segment of the upper limb, it is necessary to take into account how the system adapts to the entire limb, allowing the mobility of the rest of the limb. This criterion will have a value of 15%.
- Design innovation: this criterion refers to how innovative the design idea is, taking into account existing products on the market and other information collected during the technological watch. This criterion will have a value of 25%.

Table 1. Affordance matrix. Criteria, alternative and results

Alternatives	Criteria					Results
	Complexity	Utility Support System	Ergonomics Support System	Freedom segment Shoulder-elbow	Innovation	
Design 1	0.2	0.8	1.5	0.75	1	4.3
Design 2	0.4	0.6	0.9	0.3	0.75	2.9
Design 3	0.3	0.8	1.2	0.75	0.75	3.8

According to the data obtained in the matrix, the design chosen was number 1 with a score of 4.3.

2.1.3. Phase 2: System level design

The product architecture is developed taking into account the product schematic.

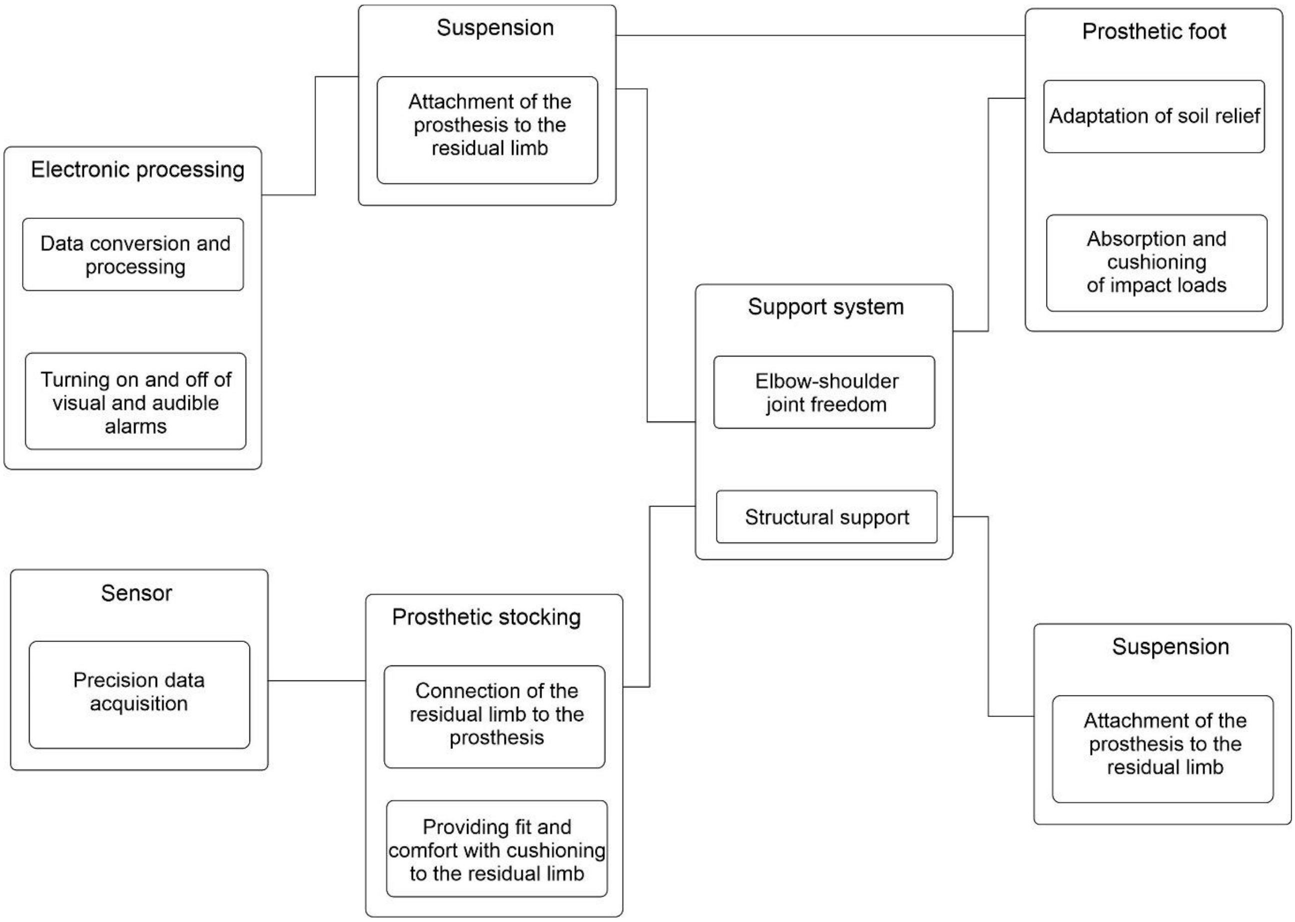

Figure 4. Product schematic

However, an approximate geometrical arrangement is elaborated.

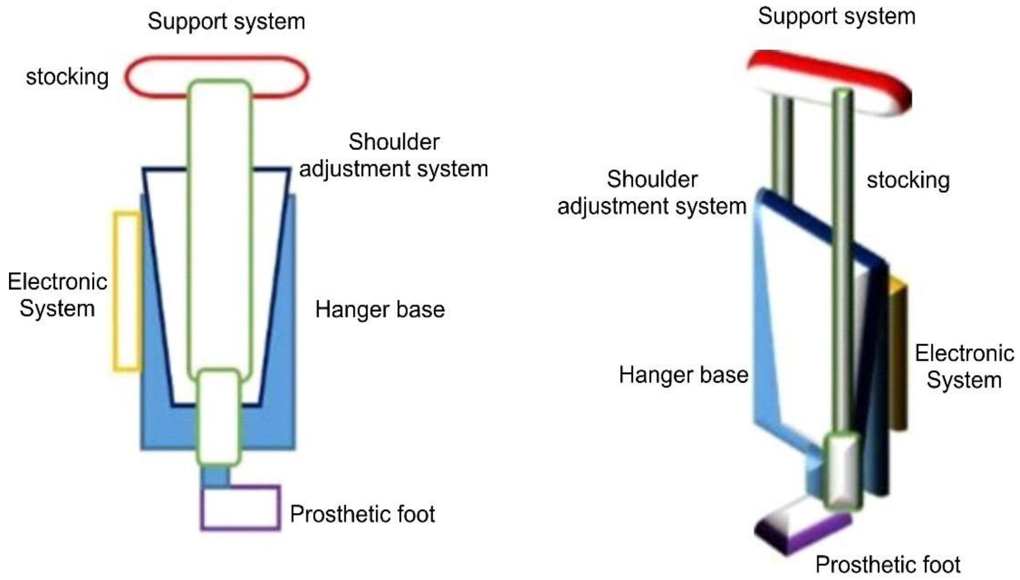

Figure 5. Geometric approximation

In addition, a diagram of fundamental and incidental interactions.

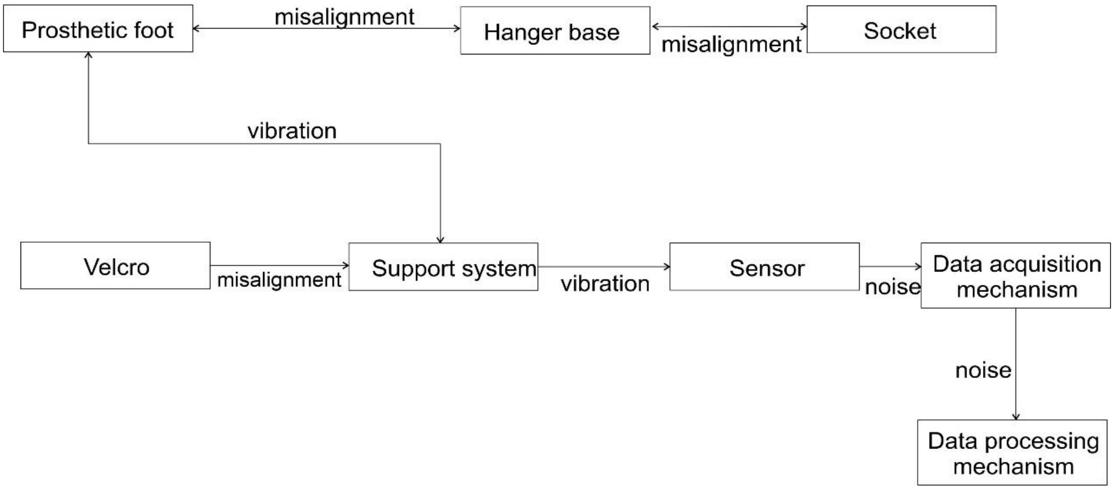

Figure 6. Diagram of fundamental and incidental interactions

On the other hand, a matrix of importance and evaluation is elaborated, where an analysis of the evaluation category is made with respect to the product, in terms of quality, repair, use and differentiating aspects, resulting in relevant aspects of the product such as ease of use, safety and aesthetics, as shown below:

Table 2. Analysis of the evaluation category

Evaluation Category	Performance Rating	Explanation of Qualification
User interface quality	High	The prosthesis is easy to install and remove from the patient's limb. In addition, the operation of the electronic system is easy to understand for the owner, therefore, there is ease of use as an owner-pet pairing.
Emotional Appeal	High	The prosthesis allows to return a lost functionality to the canine, which improves its quality of life. On an emotional level, it allows the patient to feel better because he/she now has a support for his/her movement.
Ability to maintain and repair the product	Half	The product is manufactured for daily use, so it is exposed to heavy duty situations. Therefore, its material must have a high durability, although every part tends to wear out, you should opt for an annual maintenance of the device.
Appropriate use of resources	High	The resources used are suitable for the construction of the prototype, due to the user's needs. However, according to environmental factors, it is possible to affirm that the development of the product is sustainable.
Product differentiation	Half	It is an esthetic and functional prosthesis.

In this stage the electronic design is made, in which according to the values registered by the load cell, a series of LEDs light up. Basically, the system consists of a green, a blue and a red LED and a buzzer. If the canine is distributing the loads correctly, only the green LED will light up. In cases in which the distribution is not being performed completely well, the blue LED will also light up. And in cases in which the distribution is not being carried out correctly, the red LED and the buzzer will also light up. The block diagram of the electronic system is shown below:

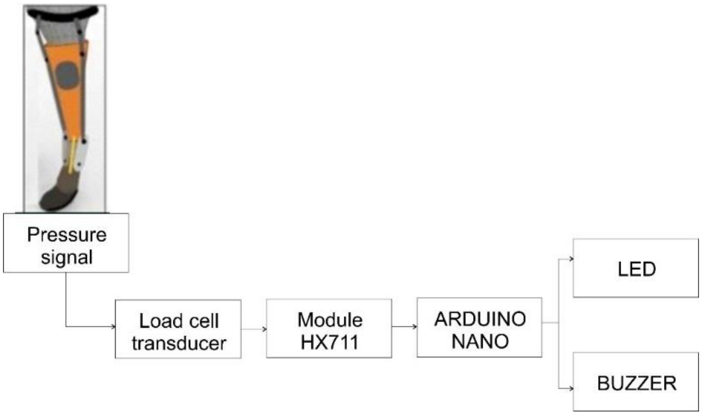

Figure 7. System block diagram

The diagram below relates all the parts of the electronic system together with the representation of the signal direction by arrows. Basically, it consists of three main stages: an acquisition stage, a processing and control stage, and a system output stage, which includes the LED display and the audio output from the buzzer.

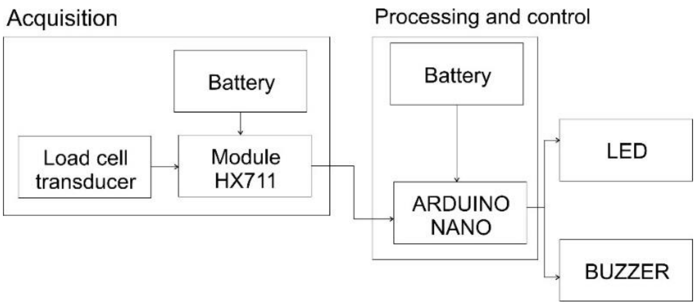

Figure 8. Block diagram of the relationship of the electronic components

After establishing the necessary functions and components, the simulation of its operation was carried out in the Proteus tool. For this purpose, the schematic shown below was designed.

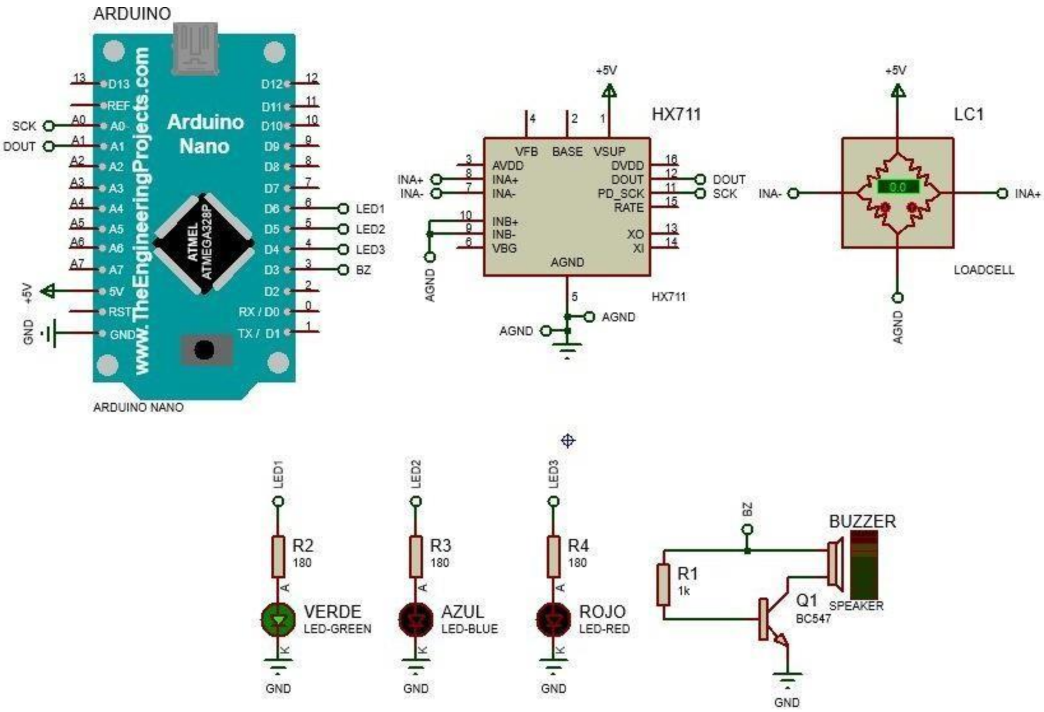

Figure 9. Schematic of the electronic system in Proteus

Subsequently, the PCB design was developed. This design was carried out according to IPC 2221 standard, which establishes all the requirements for the design of printed circuits. This standard is intended to facilitate the interaction between the manufacturer and the purchaser. The application of this standard is voluntary and can be applied in any country. In the specific case of this project, we took into account the requirements of this standard regarding the positioning of its components on the board, which must be related at 90° to each other. Also, the standard distance for the separation between each of the components. As for the width of the lines, 30th was established since it is one of the most applied measures and considered as standard. Figure 10 shows the design, whose specifications are as follows:

Width: 5.6 cm.
Length: 6.5 cm.
Number of layers: 2.
Number of components: 15.

Figure 10. PCB layout

2.1.4. Phase 3: Detail design

Eleven (11) parts are designed and assembled using Solidworks software, as shown below:

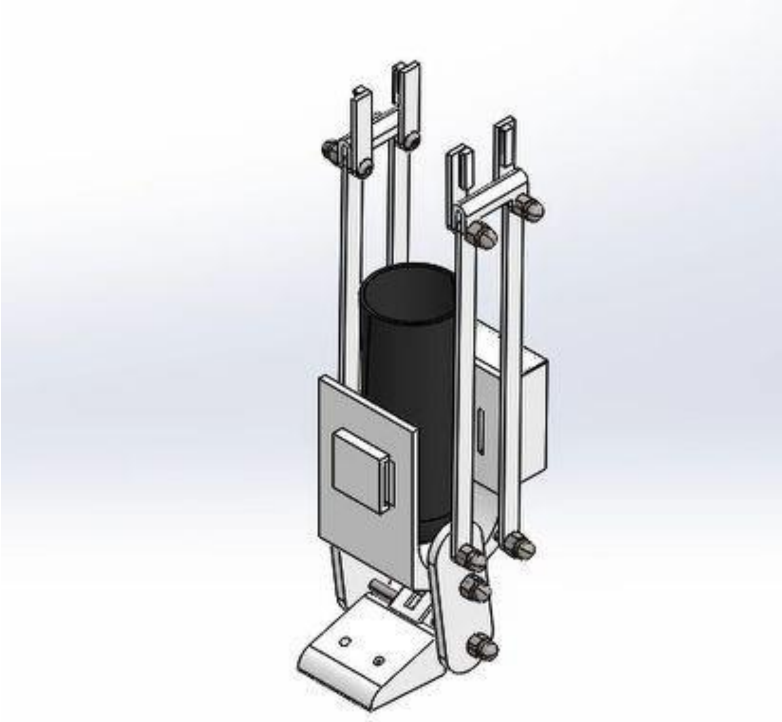

Figure 11. Anterior prosthesis assembly for canine in isometric view

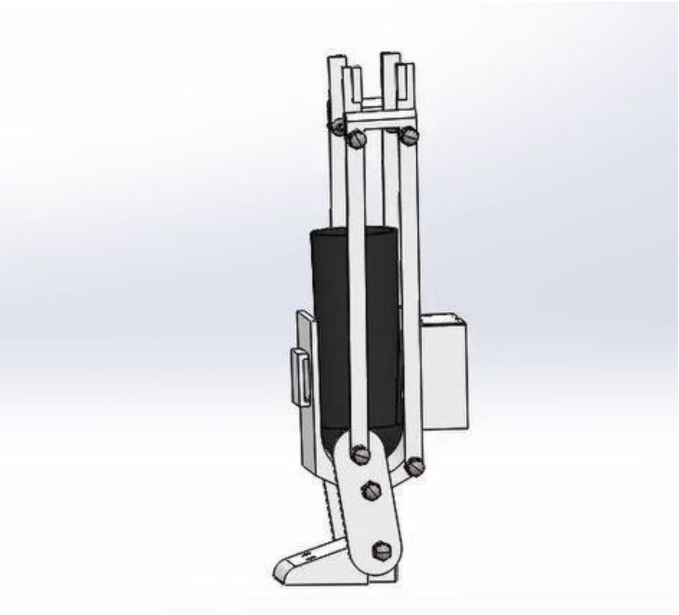

Figure 12. Anterior prosthesis assembly for canine in lateral view.

PLA was chosen as the material for the prosthesis parts, since it can be easily printed in a 3D printer, it is more environmentally friendly, biodegradable, and resistant to humidity.

Similarly, neoprene was chosen as the material for the orthopedic stocking in which the canine stump will rest, since it is resistant to degradation caused by the sun, the weather, bending and torsion and to blows thanks to its flexibility.

2.1.5. Phase 4: Prototype development

As a result of this phase, the impression of each of the pieces of the prosthesis was obtained, as well as the other components that make up the prosthesis. Likewise, the printing of the PCB circuit board was also obtained, to which its electronic components were later soldered.

Figure 13. Printed prosthesis with its component elements such as Velcro, elastic, screws and nuts

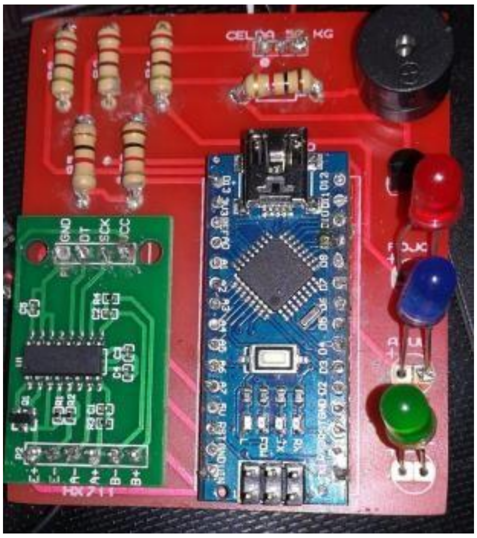

Figure 14. PCB board with the other components of the circuit

3. Conclusions

With the project, it can be concluded that, according to the results of the Leopold matrix, the development of the product is an initiative that does not generate a high negative environmental impact, which makes it a favorable alternative. On the other hand, regarding the design of the prosthesis, it can be established that it meets the proposed objectives, guaranteeing functionality, comfort and durability.

Finally, the electronic component provides a value proposal to the project oriented towards the constant monitoring of the distribution of the body load performed by the canine, in order to recognize its adaptation to the prosthesis and its functionality.

Declaration of competing interest

The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.

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