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Artículos científicos

Sistema mecánico para la recuperación motriz en perros con debilidad muscular en las extremidades

Mechanical System for the Motor Recovery in Dogs with Muscular Weakness in the Extremities

Sistema mecânico para recuperação motora em cães com fraqueza muscular nas extremidades

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Resumen

El presente trabajo deriva de una aplicación de ingeniería biomédica en el área veterinaria y tiene como objetivo evaluar un sistema mecánico de apoyo para la recuperación de perros de talla chica con debilidad muscular en las extremidades mediante la reproducción de secuencias de caminata lenta similar al andar de un animal sano. En la primera fase metodológica se realizó un análisis de marcha con el fin de obtener los parámetros necesarios a utilizar en el diseño y construcción del sistema mecánico; la segunda se enfocó en emplear los datos resultantes en la fase uno para realizar el diseño y construcción del sistema mecánico; en la fase tres se realizaron las pruebas y evaluación de funcionalidad del sistema mecánico. Los resultados obtenidos permitieron el diseño de las piezas del sistema mecánico adaptadas a la anatomía de los segmentos corporales mediante TinkerCAD. Para la construcción se emplearon barras de aluminio y finalmente, para proveer de movimiento, se implementaron servomotores con características acordes a la proporción de peso de los segmentos anatómicos correspondientes al miembro pelviano del animal. Cabe mencionar que se contó con el apoyo de un perro de raza dachshund y el análisis de la cinemática de marcha se realizó con el *software* Kinovea. El sistema mecánico propuesto reproduce los movimientos de manera similar a las secuencias normales, los materiales empleados en el dispositivo ofrecen el soporte necesario a las características del animal, dado que ofrece la movilidad necesaria sin poner en riesgo las extremidades dañadas. Finalmente, se detectó un margen de mejora en el área de tracción, al haber una ligera variación en las mediciones comparadas con los valores teóricos. Este sistema puede implementarse en perros que requieran un mecanismo de soporte para recuperarse de una condición que afecte su movilidad.

Palabras clave: biofísica, dispositivo mecánico, ensayo, investigación y desarrollo, tratamiento médico.

Abstract

The present work derives from an application of biomedical engineering in the veterinary area and its objective is to evaluate a mechanical support system for the recovery of small dogs with muscular weakness in the limbs by reproducing slow walking sequences like the gait of a healthy animal. In the first methodological phase, a gait analysis was carried out to obtain the necessary parameters to be used in the design and construction of the mechanical system; the second phase focused on using the data obtained in phase one to design and construct the mechanical system; in phase three, tests and evaluation of the mechanical system's functionality were carried out. The results obtained allowed the design of the parts of the mechanical system adapted to the anatomy of the body segments using Tinker CAD. Aluminum bars were used for the construction and finally, to provide movement, servomotors with characteristics according to the weight proportion of the anatomical segments corresponding to the pelvic limb of the animal were implemented. It is worth mentioning that we had the support of a dachshund dog, and the analysis of the gait kinematics was performed using Kinovea software. The proposed mechanical system reproduces the movements in a similar way to the normal sequences, the materials used in the device offer the necessary support to the characteristics of the animal, since it offers the necessary mobility without putting at risk the damaged limbs. Finally, a margin for improvement was detected in the tensile area, as there was a slight variation in the measurements compared to the theoretical values. This system can be implemented in dogs that require a support mechanism to recover from a condition that affects their mobility.

Keywords: biophysics, mechanical device, testing, research and development, medical treatment.

Resumo

O presente trabalho decorre de uma aplicação da engenharia biomédica na área veterinária e tem como objetivo avaliar um sistema de suporte mecânico para a recuperação de cães de pequeno porte com fraqueza muscular nas extremidades, reproduzindo sequências de caminhada lenta semelhantes à marcha de um animal saudável. Na primeira fase metodológica, foi realizada uma análise da marcha a fim de obter os parâmetros necessários para serem utilizados no projeto e construção do sistema mecânico; a segunda centrou-se na utilização dos dados resultantes da primeira fase para a realização do projeto e construção do sistema mecânico; Na terceira fase, foram realizados os testes e avaliação da funcionalidade do sistema mecânico. Os resultados obtidos permitiram projetar as partes do sistema mecânico adaptadas à anatomia dos segmentos corporais utilizando o TinkerCAD. Para a construção foram utilizadas barras de alumínio e por fim, para proporcionar a movimentação, foram implementados servomotores com características de acordo com a proporção de peso dos segmentos anatómicos correspondentes ao membro pélvico do animal. Vale ressaltar que tivemos o apoio de um cão dachshund e a análise da cinemática da marcha foi realizada com o software Kinovea. O sistema mecânico proposto reproduz os movimentos de forma semelhante às sequências normais, os materiais utilizados no aparelho oferecem o suporte necessário às características do animal, pois oferece a mobilidade necessária em colocar em risco os membros lesados. Por fim, detectou-se uma margem de melhoria na área de tração, pois houve uma pequena variação nas medidas em relação aos valores teóricos. Este sistema pode ser implementado em cães que necessitam de um mecanismo de suporte para se recuperar de uma condição que afeta sua mobilidade.

Palavras-chave: biofísica, dispositivo mecânico, teste, pesquisa e desenvolvimento, tratamento médico.

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Introduction

Throughout his training, the Biomedical Engineering student of the National Polytechnic Institute (IPN) acquires a set of knowledge that allows him to develop in various areas of health. Of course, among these various areas is veterinary medicine, where you are prepared to intervene in the development of orthopedic and rehabilitation systems that improve the quality of life of animals. An example of this is found in the present work, thanks

to which, through a gait analysis and evaluation of the characteristics of a test animal, it was possible to build a mechanical system as a support resource in the rehabilitation of dogs.

Background

Dogs with muscle weakness in all four limbs have difficulty moving around on their own and require a support system to supplement motor function and contribute to independent movement and recovery. There are precedents related to orthopedics in domestic animals, mainly dogs and cats. For example, in the iconic work by Müller and Glass published in 1911, "Diseases of the dog and their treatment", the skeleton of the dog and some fractures that it may present are described. However, previously reference sources related to the topic of veterinary surgery contained little detailed information about surgical procedures. Even at the beginning of the 20th century there was still little information about the treatment to resolve fractures; it focused rather on the use of bandages, splints and casts, keeping the animal in a cage until it recovered (Wheeler, 2011).

There are several causes that can affect the mobility of dogs. For example, chronic bone infections or osteomyelitis, which is characterized by a delay in the union or non-union of bones when they are fractured. In fact, osteomyelitis is one of the most serious and frequent complications in the treatment of fractures (Díaz and Durall, 1995).

Illescas (2003) mentions that traumatismos are considered injuries of an internal or external nature in the organism, they produce deformations that can be elastic or inelastic and that, if not treated, can become fractures. The most common causes that originate them range from vehicular accidents to wounds and injuries caused by humans.

As Suraniti (2011) mentions, there are other factors that affect mobility in dogs, those derived from neurological lesions, such as degenerative myelopathy or posterior paralysis or radiculomyelopathy, a progressive autoimmune neurological disease that mainly affects dogs. large adult dogs. On the other hand, congenital deformations must also be considered, which are not only evident in the physical structure of the animal, there are various metabolic disorders and abnormalities at both the molecular and cellular level that affect the quality of life of the animals. (Rojas y Walker, 2012).

With the advancement of medicine in all its fields, including methods for the treatment of fractures and disorders of the musculoskeletal system in humans, veterinarians have made adaptations and innovations to these techniques to be used in the treatment of dogs and cats (Valadez et al., 2004). Until recently, information related to the use of

prostheses in animals was scarce, only a few vestiges of the first prostheses designed for animals, among which stands out the one designed by US Air Force General Harry A. Gorman, who implemented a prosthesis on a dog (Félix, 2008).

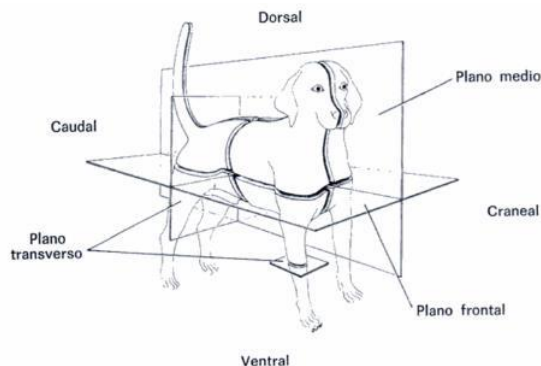
According to authors such as De la Fuente, García, Prandi, Franchy Peña (1997), some dogs were diagnosed with dysplasia and a hip prosthesis was implemented, an adaptation of human surgery to veterinary surgery, whose base was the same. than in humans regarding the use of orthopedic cement for its implantation, the use of polymethylmethacrylate as a fastening element of the prosthesis as a support to restore the movement and function of the canine hip.

Getty (1985) mentions that anatomy is the branch of biological science focused on the form and structure of organisms. It is important to mention that a part of veterinary medicine specializes in the study of animal anatomy. There are three main approaches to approach the study of this science: the systematic approach, the topographical and the applied approach. The systematic method focuses on the study of anatomy according to the systems that make up the body and is usually studied following the following division: osteology (skeleton), syndesmology (joints and ligaments), myology (muscles), angiology (circulatory system), splanchnology (viscera), neurology, sensory organs, etc. The topographic method is based on the systematic method with the difference that it focuses on a specific part of the body. Finally, applied anatomy focuses on anatomical facts that are related to practice, such as surgery and diagnosis.

In directional terms, the anatomical position in dogs is directly compared to the directional coordinates of humans. According to Getty (1985), when the dog is in a quadruped position or in a vertical posture, different regions or planes can be differentiated in order to locate the structures found in a specific region and facilitate their knowledge. To know these regions, start with the figure of a standing quadruped animal like the one seen in figure 1. The first plane to identify is the median longitudinal plane that divides the body vertically into two equal parts and nearby regions. This axis is known as medial, in such a way that the remote regions are known as lateral or external, parallel to this plane are the sagittal planes. The next plane is the transverse, which crosses the longitudinal plane. In this orientation, the cranial or anterior region is considered as the part of the body that is closest to the head and the caudal or posterior region in which structures close to the tail are found. The frontal plane divides the body horizontally, traversing the median and transverse

longitudinal planes. The structures that are directed towards the ground are called ventral, while those that are directed upwards are known as dorsal.

Figure 1. Main anatomical planes of the dog



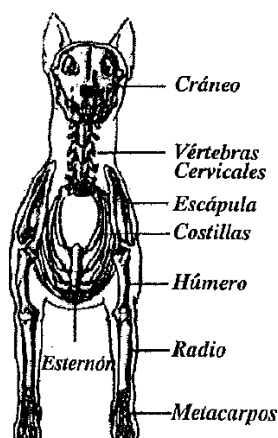
Source: Getty (1985)

Knowing that each animal is different from one another despite belonging to the same species, it is possible to establish an average or normal model for any group of animals and recognize deviations from these models.

König and Liebich (2001) define the musculoskeletal system of dogs as "a complex organic system whose central function is mainly to perform mechanical work" (p. 4). The locomotor system is made up of the muscles and the skeleton, which is not only made up of the bones, but also of the cartilage, which includes the joints and ligaments. Among the functions of the locomotor system are support, modeling, protection of the body, locomotion and metabolic function.

Dogs are considered quadruped animals due to the transfer movement they perform through the use of their four limbs: the forelimbs known as the thoracic limbs or pectoral limbs and the hind limbs known as the pelvic or hind limbs (Dyce, Sacky Wensing, 2012). Quadrupeds have two forelimbs also known as arms, these limbs end in hands with a varied number of fingers and the main function is locomotion (Carrier, Deban and Fischbein, 2008). The forelimb is made up of: shoulder girdle, arm, whose bony base is the humerus bone, forearm, which is made up of the ulna and radius bones, and hand made up of the carpus, metacarpus and fingers with three phalanges, this is shown in figure 2.

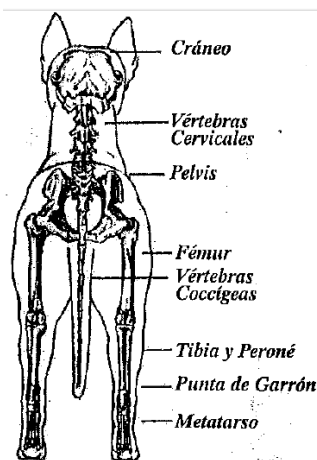
Figure 2. Frontal bone structure



Source: Argentine Cynological Federation [FCA] (2016)

On the other hand, the posterior limb of quadrupeds is made up of a system of segments, joints and muscles which provide propulsion in the movement of the dog. The leg muscles act as extensors and flexors of the tarsal joint and as extensors and flexors of the finger joints. To maintain a balanced position, the posterior and anterior train must be coordinated, in the same way the angulations must correspond, this is observed in figure 3.

Figura 3. Estructura ósea posterior



Source: FCA (2016)

Rear angulations are considered correct when the ischium bone forms an angle of 45° with the dorsal line and 90° with the femur. On the other hand, the femur must maintain an angle of 90° with the tibia, from which the front angulations are correct when the longitudinal axis of the scapula bone forms an angle of 45° with the dorsal line and in turn forms an angle of 90° with the humerus.

Problem Statement

In dogs there are multiple conditions that can limit their movements. Some common diseases that affect their mobility are related to trauma, chronic-degenerative diseases, among others, an example of this is intervertebral disc disease, which frequently affects small breed dogs such as dachshunds or sausage dogs. The lack of movement can imply greater degenerative consequences in the muscles and nerves, so it is necessary to have a series of devices that provide support and seek a better adaptation to complement the motor function, contributing to their recovery when they present limitations in their mobility. .

Currently, the use of prostheses in animals not only occurs due to amputations, due to diseases or some type of cancer, it also occurs when the animal suffers some trauma. The development of adapted prostheses in animals has evolved considerably and nowadays it is not only limited to extremities, various parts of the lost or damaged anatomy have currently been developed (De la Cuenca, 1996). Although, from an evolutionary point of view, wings, fins, and arms can be considered as modified limbs, animals that for some reason are forced to use three of their limbs are able to support themselves in almost the same way as those that do. with four limbs, but with modified or irregular weight distributions and balance points, which eventually compromises the quality of life of the animal and therefore can mean a shorter life expectancy (Callado, 2005).

In dogs, the prostheses that are mostly used are hip and limb prostheses, according to what Font and Closa (2006) mention. In the case of hip prostheses, these are used for the treatment of degenerative diseases, coxofemoral trauma with irreparable fractures or chronic hip dislocations, and there are mainly two types; cemented or total and those not cemented.

The total hip prosthesis, as indicated by Mele, Corral, Pierce and Guerrero (2010), is implemented when joint pain occurs and compromises mobility, they are indicated in those animals that have finished their growth. On the other hand, the non-cemented hip prosthesis is used when the animal presents a condition that does not put its life at risk and with a high possibility of recovery. These prostheses are designed with biocompatible metals such as titanium, their design allows bone growth on the implant, achieving a permanent anchorage and avoiding the use of cement (Sánchez, Zúñiga, Bellver & Martínez, 2006). The use of prostheses in one or more extremities gives dogs greater mobility, a solution to the motor problem. It is worth mentioning that in the gait of dogs, the forelimbs receive the push while the hindlimbs are important for the dog's pushing and trotting (Lima-Netto, 2002).

On the other hand, there are various devices such as wheelchairs or walkers that help improve the movement of the animal; however, they have some limitations, among which are the designs, since these are built for specific cases, in addition to not incorporating elements that They contribute to the movement of the muscles of the limbs, which is extremely important for the preservation of muscle tone and the prevention of atrophy. Faced with this problem, the use of a support mechanism is a viable alternative that allows the recovery of motor function and thereby increases the quality of life of the animal.

Given the context in the use of prostheses in animals, the following research question was posed: will the implementation of a mechanical system help in the recovery and rehabilitation of dogs with limb problems and will it improve their quality of life?

Justification

Undoubtedly, resuming the course of daily activities after the 2019 coronavirus pandemic (covid-19) is not an easy task, since the health emergency, among other things, affected people's lives, disrupted the members of all groups family, including pets. During these days of confinement, an increase in the abandonment of pets was observed. One of the causes that originated this phenomenon of abandonment was the lack of resources for the maintenance of the animal, this puts at risk of abandonment all those animals that, for some reason, are impeded in their mobility, dogs being the most affected . The present work aims to analyze the feasibility of building a support mechanism for dogs that present a decrease in motor function in their thoracic and pelvic limbs as a sample of biomedical engineering in solving problems in medical areas. This mechanism seeks to offer an alternative for assisted walking by supporting body weight and promoting movement of the four limbs. The design of this mechanism is based on the analysis of the dog's gait kinematics, taking as reference parameters considered normal in gait, as well as the prevention of muscle atrophy and articular cartilage degeneration that affect displacement and induce future disturbances in the dog's gait.

General objective

To evaluate the functionality of a mechanical system for the motor recovery of dogs with muscular weakness in the extremities from the reproduction of the walking sequence similar to the movements of a healthy subject.

Specific objectives

- Perform the gait analysis of a dog to determine the characteristics of the mechanical structure.
- Build a mechanical system capable of supporting a small breed dog while maintaining patterns according to the gait phases.
- Analyze the functionality of the mechanical system from its implementation in a test animal.

Type of study

For the development of the mechanical system, a single-subject quasi-experimental design was proposed. For this, three phases were contemplated within the methodology, which included the analysis of the gait of a test subject, with the acquired data the mechanism was built and the necessary electronics were implemented to favor the movement and finally the tests were carried out at the system.

Methodology

Phase one. gait analysis

We proceeded to carry out the analysis of the gait kinematics of a small breed dog. In this study, a dachshund dog known colloquially as a dachshund was chosen. The age of the animal was estimated at approximately four years. The criteria taken into account for the selection were:

- Breed type: dachshund.
- Physical dimensions of the animal: in general, small in size with a long back in proportion to the limbs.
- Gait characteristics: general appearance, without apparent gait disturbances.
- State of health: no physical alterations

For the gait measurement, a conventional camera set to a recording speed of 30 frames per second was used, mounted on a fixed support at a distance of two meters from the target.

The study subject walked on a flat and rigid concrete surface maintaining a straight line trajectory with the intention of measuring the angles in the sagittal plane in two directions. A repeatability in the measurements was ensured from the analysis of data in three different sequences. According to what Light, Steiss, Montgomery, Rumph and Wright

(2010) mention, it was considered that the gait had an approximate speed of 60 to 90 cm/s and a minimum of turning in the head.

For the gait analysis, height measurements were obtained in the structures of interest with respect to the ground, as shown in Table 1.

Table 1. Measurement of height with respect to the ground in the structures of interest

Parámetro	Longitud (cm)
Altura esternón-suelo	11
Altura brazo-suelo	14
Altura muslo-suelo	15

Source: self made

Subsequently, the measurements of the dog's body segments were obtained, as shown in Table 2.

Table 2. Measurement of body segments of the dog under study

Segmento corporal		Longitud (cm)
Miembro anterior	Brazo	8
Antebrazo		8
Mano		3
Dedos		4
Miembro posterior	Muslo	9
Pierna		8
Pie		3
Dedos del pie		4
Tórax	Circunferencia	35
Anchura del pecho		12
Anchura hombros		18

Source: self made

Once the previous data was obtained, the gait analysis was carried out using the videographic technique using the Kinovea software. It is worth mentioning that this software is free and open source, dedicated especially for biomechanical applications, evaluation and

sports medicine. Kinovea provides different tools for video analysis such as angle measurement, length, trajectory tracking, and time measurement. In this study, version 0.8.15 of the software was used. In this way, the angles of joint movement formed by the body segments were measured at the initial and final moments of each gait phase in three different steps and the average for each phase was obtained.

The letters L, B, S and E were assigned to refer to the phases of elevation, swing, support and push, in the same way the initial (i) and final (f) instants of each phase corresponding to each extremity and the angles were considered with respect to the horizontal.

With the information obtained, the structural design of the prototype was carried out, which should support the weight of the dog. According to different authors, when tetraparesis occurs, it is necessary to provide support so that the dog can support itself and move; therefore, the structure must also allow mobility of the dog's limbs and ensure the maintenance of muscle tone, as well as prevent future complications.

In the design of the support structure, the weight distribution in the cranial and caudal part of the animal's body was considered, in addition to considering the shape of the structures in the support part where the weight of the dog's trunk would rest and that will serve also as a base for the placement of actuators and electronic elements.

It is important to highlight what was mentioned by Nickel, Schummer, Seiferle, Siller and Stokoe (1986) regarding the fact that the center of gravity in the dog is located at the level of the ninth intercostal space in the xiphoid process, for which reason they made sure to have a greater support at that point, since the center of gravity and balance are affected around it. It is worth mentioning that the forelimbs behave as support structures that support about 60 % of the animal's body weight and since the gait is exerted forward, the structure should have a reinforcing element in the anterior part.

Phase two. Construction of the mechanical system

The design of the structure was carried out using the TinkerCAD application, which is a 3D CAD design software from the Autodesk company. This tool allows the design of structures from basic shapes, and being an online tool, it does not require any installation, this allows for complex designs and its handling is highly simple; Lastly, it allows you to generate files with an .stl extension that are commonly used for printing 3D structures.

For the structure of the prototype, different materials were evaluated, opting in the end for aluminum 6063 T5, due to the fact that its characteristics meet the required parameters, as it is a material of high resistance and low density. Once this decision was made, 3-inch bars were used. /8” of aluminum, as shown in table 3.

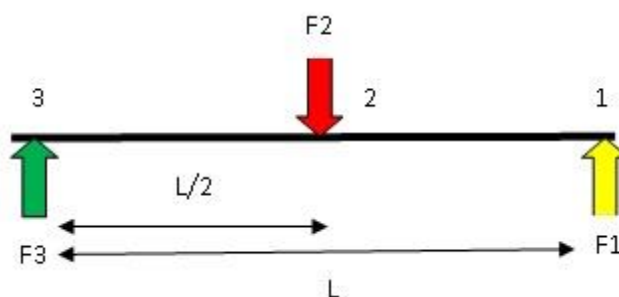
Table 3. Mechanical and physical properties of aluminum alloy 6063 T5

Carga de rotura N/mm ²	Límite elástico N/mm ²	Límite a la fatiga N/mm ²	Resistencia a la cizalladura τ N/mm ²	Dureza Brinell (HB)	Densidad gr/cm ³
215	175	150	135	60	2.69

Source: self made

Screws and pegs were used to join the pieces, and they were reinforced with epoxy adhesive. Additional to the structure, a pair of light plastic wheels were placed on the support beams in order to facilitate movement. On the other hand, the moments of force were calculated taking into account the body weight on the central support aluminum beam located in the thorax, this is shown in figure 4.

Figure 4. Force diagram of the mechanical system



Source: self made

If it is considered that F1 and F3 are the support bars of the central structure, it is necessary to:

$$L=12 \text{ cm}$$

$$\sum M_{F3} = 0 = -F3(0) + F2(0.06) - F1(0.12)$$

$$F1 = \frac{F2/0.06}{0.12}$$

$$F2 = (6.1Kg) \left(\frac{9.81m}{s^2} \right) = 59.84N$$

$$F1 = \frac{59.84N * 0.06m}{0.12m} = 29.92N$$

$$\sum M_Y = 0 = -F3 + F2 - F1$$

$$F3 = F2 - F1 = 29.92$$

In the construction of the mobile parts, it was decided to use foamed PVC material because it is light, insulating and resistant, this allowed it to be easily molded by heat and to be able to adapt it to the curvatures of the members.

To limit the angle of movement in the carpal joint, physical limits were implemented in the structure of the forearm, in order to facilitate the movement of the hand without impeding it, but respecting the maximum limits obtained in the analysis and to provide greater support. from the structure to the limb, Velcro straps were placed.

From the gait analysis, it was obtained that the joints do not exceed the limit established at 180° given the origin, so a high-torque servomotor was considered appropriate without requiring a control algorithm for its operation.

The choice of the servomotor was made by calculating the torque necessary to move the load represented by each limb. It is worth mentioning that the hind limbs weigh approximately 15.25% of the total weight of the dog's body.

This percentage is considered the maximum for each extremity, in addition to considering the weight of the structure for each member, the total weight to be moved was obtained from the following formula:

$$M = F * d$$

In said formula, M=torque, F=force and d=distance.

$$M(0.366Kg + 0.145Kg) * 9.81 \frac{m}{s^2} * 0.15m = 0.751Nm$$

The value of M would be equivalent to 7.5 kgf/cm, so actuators with a torque higher than this value were chosen.

The servomotor used was the MG995, whose characteristics are the following:

- Size: 40.7 * 19.7 * 42.9mm; weight: 54g.
- Torque: 15kgf/cm.
- Operating temperature: -30 ~ +60°.
- Rotation angle: maximum 180°.
- Current: 100mA.



- Voltage: 3-7.2V.
- Operating speed: No load 0.17 sec/60°, with load 0.13 sec/60°.

For the elbow and knee joint, the servomotor was chosen, since the necessary torque is:

$$M = (0.146Kg + 0.070 Kg) * 9.81 m/s^2 * 0.07m = 0.148 Nm$$

Which is equivalent to 1.5 kgf/cm, so an MG90S type servomotor was chosen, which has a torque of 2.2 kgf/cm.

For the electrical circuit, a control system was contemplated by means of a microcontroller in order to coordinate the movement of the actuators through a sequence obtained as a result of the kinematic analysis carried out. It was decided to work with an Arduino card, which is an open source electronics creation platform, choosing this as a control system due to the feasibility of working with its 14 digital pins focused on managing servomotors and implementing sensor sensors. inclination. The sensor used was the SW-520D, better known as tilt switch or ball switch, this was placed on the structure corresponding to the segments of the hand in a horizontal position with the circuit open, so that the movement of the hands closes the circuit and produces the step sequence start signal.

Phase three. Mechanical system functionality

With the system fully built, it was attached to the test subject. The control program of the mechanisms was based on the continuous reading of the sensors when activating only one of these, the signal produced is interpreted as a signal to start the sequence, thus starting the sequence with the limb being raised at the same time. that the actuators of the remaining limbs are coordinated in the different phases according to the theoretically established sequence.

At the end of a cycle, the reading of both sensors is carried out again and the previous operation is repeated depending on the activated sensor. If there is no reading on any sensor, all the extremities are kept in a support position.

Results

The results of the gait analysis were obtained in three different sequences for each joint, as shown in Figure 5.

Figure 5. Points to assess in the gait analysis



Source: self made

The measurement values were averaged and the following data was obtained:

1) Average measurement of the angles in the joints in the left forelimb, this is shown in table 4.

Table 4. Average of the angles in the joints of the left forelimb

Fase	Articulación del hombro	Articulación del codo	Articulación del carpo	Articulaciones de los dedos
Li	-37.66	50.7	152.3	109
Lf	-24.3	69.7	-132.3	106.3
Bi	-22.3	117.4	-66	179
Bf	-53.3	80.4	169.3	179.3
Ai	-63.3	64.7	176.3	136.3
Af	-55..6	54.5	172.6	127.6
Ei	-39	54.7	168.6	124
Ef	-29	47.7	157.6	103.3

Source: self made

2) Average measurement of the angles in the joints in the right forelimb, this is shown in table 5.

Table 5. Average of the angles in the joints of the right forelimb

Fase	Articulación del hombro	Articulación del codo	Articulación del carpo	Articulaciones de los dedos
Li	158	-138.33	-177	109
Lf	148.2	-127.66	116	106.33
Bi	144.4	-86.33	71.33	179
Bf	124	-72.66	-177.3	179.3
Ai	118	-109.33	-171	140.3
Af	147.4	-123	-172.66	127.6
Ei	155.2	-125.33	-167.33	124
Ef	157.8	-135	-168.33	113

Source: self made

3) Average measurement of the angles in the joints in the left hindlimb, this is shown in table 6.

Table 6. Average of the angles in the joints of the left hindlimb

Fase	Articulación de la cadera	Articulación de la rodilla	Articulación tarsiana	Articulaciones de los dedos del pie
Li	-164.6	-136.3	141	153
Lf	-164.3	-123.3	133.6	124.6
Bi	167	-105	98.6	178.6
Bf	154.6	-145	127.6	176.6
Ai	158	-153.3	133.6	159.6
Af	168.6	-142.3	128.3	149
Ei	166.3	-137	131.3	138.3
Ef	-177.3	-142	132.6	117.3

Source: self made

4) Average measurement of the angles in the joints in the right hindlimb, this is shown in table 7.

Table 7. Average of the angles in the joints of the right hindlimb

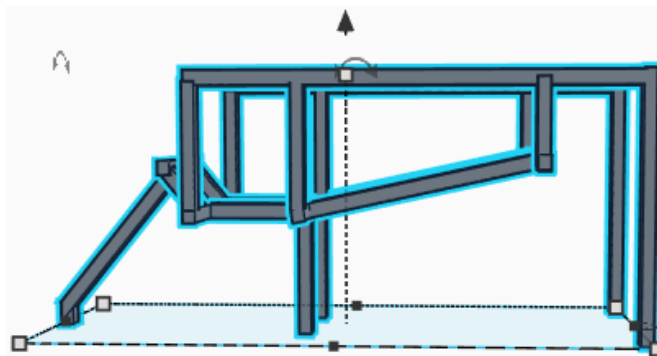
Fase	Articulación de la cadera	Articulación de la rodilla	Articulación tarsiana	Articulaciones de los dedos del pie
Li	164.3	117	-128	-133.6
Lf	168.6	113	-129.3	-175
Bi	-163	108	-90	178.3
Bf	-153.6	143.6	-110.6	173.3
Ai	-154.6	141.6	-128.6	-156.6
Af	-159.6	129.3	-109.6	-137.6
Ei	-165.3	125.3	-115.6	126
Ef	-172.3	120.3	-121.3	126.6

Source: self made

As can be seen in the results, the angular changes in the joints of the hand correspond to flexion and extension movements.

The design of the structure in TinkerCAD is shown in figure 6.

Figure 6. Preliminary design of the support structure



Source: self made

The implementation of actuators was carried out only in the shoulder, elbow, hip and knee joints of both members because there is a greater muscle mass compared to the hand and foot, in addition to being convenient not to increase the number of actuators, this is shown in figure 7.

Figure 7. Physical structure where the updaters dedicated to the movement of the dog can be seen



Source: self made

After the assembly of the structure, an analysis was carried out on the angular displacements of the segments of the structure corresponding to the arms with three different measurements. Table 8 shows the average of the angles in the joints of the left forelimb.

Table 8. Average of the angles in the joints of the left forelimb

Fase	Articulación del hombro	Articulación del codo
Li	-32	41
Lf	-19.3	60.3
Bi	-16.6	110.3
Bf	-44	73.6
Ai	-56	59.3
Af	-46.3	54.5
Ei	-39	46.3
Ef	-29	39.6

Source: self made

Table 9 shows the average of the angles in the joints of the right forelimb.

Table 9. Average of the angles in the joints of the right forelimb

Fase	Articulación del hombro	Articulación del codo
Li	151	-133
Lf	141	-115
Bi	133	-79
Bf	115	-64
Ai	106	-103
Af	138	-111
Ei	147	-116
Ef	150	-129

Source: self made

Table 10 shows the average of the angles in the joints of the left hind limb.

Table 10. Average of the angles in the joints of the left hindlimb

Fase	Articulación de la cadera	Articulación de la rodilla
Li	-153.3	-128
Lf	-156.3	-115.6
Bi	154.6	-99.3
Bf	146.3	-137.6
Ai	147.3	-145.6
Af	161.3	-135
Ei	158	-131.6
Ef	-170.6	-136.3

Source: self made

Table 11 shows the average of the angles in the joints of the right hind limb.

Table 11. Average the angles in the joints of the right hind limb

Fase	Articulación de la cadera	Articulación de la rodilla
Li	154	112
Lf	161.3	104
Bi	-155	100
Bf	-146.6	135
Ai	-144	136.3
Af	-151.6	122
Ei	-156.3	119.3
Ef	-166	112.6

Source: self made

Discussion

According to the results obtained, the proposed system fulfills its function of supporting and providing movement to a small breed dog. In similar works such as that of Bustos (2020) the development of a canine prosthesis is presented that expands the capacity and autonomy in the movement of dogs, like the one proposed, said design was conceived for small breed dogs where the design is based in the proposal of a cart (walker), whose components work dynamically, which allows the canine to adopt a resting position. In this sense, the design described throughout this work considers it essential to have a comfortable position for the animal, in addition to favoring the movement of the extremities in order to maintain muscle tone.

Among similar works, the one presented by San Miguel, Díaz and Vega (2021) also stands out, who used SolidWorks 3D software to design a prototype support for dogs. Similarly, for the design proposed in this work, the results obtained in the gait analysis from the Kinovea software application were taken into account, this facilitated the design of the structure, which was drawn with the TinkerCAD application, which in turn time allowed to exemplify several options. And given the requirements set forth, a design was chosen that was lightweight, simple in its construction, but at the same time robust to support the weight and mechanical force exerted by the dog, as specified above.

For their part, Meza, Vázquez, Muñoz and Monfil (2018) presented a four-wheel chair prototype which, according to the authors, can be adapted to any dog. In this work, like the one developed in the Interdisciplinary Professional Unit of Biotechnology (UPIBI) of the IPN, it was necessary to have a mechanism that would allow the mobility of the animal while it was in the recovery stage.

One of the criteria that were considered in the construction of the proposed system was the use of light materials in order not to generate an additional effort to the animal that used the mechanism. In the work developed by Bros (2008) a canine wheelchair-type support project is presented with the characteristic that the material used for its construction is PVC; a similar design is the one proposed by Charbonneau, Sellen and Seeschaaf (2016), who designed a wheelchair from 3D printing. This study mentions the advantages and disadvantages of implementing Downloadable Assist Technologies (DAT) for wheelchair construction. In comparison, the work developed at the UPIBI where important aspects of the dog's anatomy, the functioning of the joints and the movements in the fore and hind limbs were considered. The gait analysis allowed us to understand the relationship that exists between the joints and the movement that favors the displacement of the animal from which the design and the choice of material were proposed, that is. aluminum given its characteristics of rigidity and weight.

In addition to the previous examples, García (2019) made an intelligent mechatronic prosthesis based on a fuzzy controller and an embedded system that processes movement through a position sensor. For the system proposed in this work, the control system was carried out by means of a microcontroller to coordinate the movement of the actuators coupled to plastic wheels to facilitate movement and minimize the effort of the dog, with the sequence obtained from the kinematic analysis. , the corresponding algorithm was carried out to program a control system based on the Arduino platform in which the servomotors whose control instructions come from two SW-520D sensors were connected, which were placed on the structure corresponding to the segments of the hand. in order to obtain the step sequence start signal.

According to what Megia, Zapirain and Antoñana (2021) point out, the tests carried out in the laboratory have demonstrated the viability of the personalized design of intelligent orthoses for pets with mobility problems. With the proposed system, data were obtained by means of a comparison of sample means with a tStudent-type test, with a two-tailed $\alpha=0.05$ for the knee joint of the right hindlimb in the lifting phase, $H_0 \mu = 127.66$ $H_1 \mu \neq 127.66$, we

have a t-statistic value of -2.8721. The critical value, according to the tables, is ± 2.3534 , which is why it is outside the range.

This led to reflect on the functionality of the mechanism, observing that in the tests the animal presents slight changes in its gait, variations that are attributed to the coupling of the mechanism, in addition to considering that the dog as a test subject did not present physical damage that affected its movement. Therefore, when the mechanism engages, it tries to maintain its normal gait, therefore, said gait correction effect affects the values in the results obtained. On the other hand, knowing that the angles of the device are different from those obtained from the gait analysis, by changing the significance level to 0.025, the critical value is ± 3.128 , so in this case the result obtained is considered significant.

From the documentary review of similar works, it can be said that there is an area of opportunity and improvement in the proposed system. This opens the opportunity to carry out various tests on construction materials, design ergonomics and control and census systems. It is worth mentioning that this is one of the research works developed in the biomedical area within the UPIBI, so that work continues within this disciplinary field of veterinary medicine.

Conclusions

Within the training of Biomedical engineering students is the training to develop and disseminate knowledge, as well as to solve the technological and ethical challenges present in the areas of health. Undoubtedly, the work developed in this writing is an example of an application in the area of veterinary medicine, a viable alternative solution to the lack of mobility in small breed dogs. It was possible to observe through the results obtained that the design of the device achieved the reproduction of the movement sequences, that is, it reproduced the flexion and extension movements in the appropriate phases.

Thus, the general objective was met, since the device reproduces movements in a similar way to normal sequences, although there is an area for improvement in relation to the values obtained, since there is a slight variation that is attributed to the structure, since the axis of the servomotor is by means of gears which are susceptible to presenting a mismatch due to mechanical tension.

The research question posed is answered positively, since the design and construction of the proposed prototype presents a low-cost alternative with great potential in the rehabilitation of small dogs when they present a condition that affects their mobility.

Future lines of research

From the experimental results obtained from the mechanical system, lines of research have been revealed with which this project can be improved. Here are a few:

- Development of a more robust electronic system that allows the control of the phase change and the adaptation of the advance speed according to the census, this to facilitate the change in speed and adjust the type of advance according to the evolution of improvement of the dog.
- Analysis of a larger sample to minimize the error in the readings to improve the traction system.
- Trials with dogs of various breeds to adjust the characteristics of the system developed so that it can be implemented to the particular needs that arise from the comparison of the angular parameters.
- Effort tests on various materials in order to have other options in the use of materials making the system lighter, but fulfilling the functionality and rigidity necessary for the rehabilitation of the animal.

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Possibly, other alternatives in the construction of prostheses and orthoses that are used in rehabilitation, not only of people, but also within the field of veterinary medicine, still need to be investigated. This work provides the opportunity to explore other applications and provides students a broader picture in their professional training.

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