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A CASE-STUDY VISION

Simulator of the behavior of the center of mass in a quadruped robot

Simulador para comportamiento del centro de masa en un robot cuadrúpedo

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ABSTRACT

The development of a software tool to easily visualize the behavior of the center of mass in a quadruped robot at the time of its displacement is described; providing in its elaboration, an application in which the user dog enter the variables of length and mass of the model and this will return the behavior of the selected gear to simulate, with the behavior of the center of mass of the entire structures, Item es not taken into accounts No force induced by the movement, i.e. only the kinematics of the model will be evaluated. The simulation was carried out in Matlab where the performance of the quadruped scheme es projected, ace well ace the behavior of the center of mass, for to selected displacement. The tools allows to predict positions in which the robot can have a greater or lesser degree of stability in its walk. The result of Este projects es the basis for an application that contributes to the planning and simulation of quadrupedal robots and with the application of the evolution of the dynamic variables, a more assertive simulation can be developed in the stability criterion.

RESUMEN

Se describe la elaboración de una herramienta de software para visualizar de manera fácil el comportamiento del centro de masa en un robot cuadrúpedo durante su desplazamiento. La herramienta de simulación le permite al usuario ingresar las variables de longitud y masa del modelo y esta retornará el comportamiento de la marcha seleccionada a simular con el comportamiento del centro de masa de toda la estructura. No se tiene presente ninguna fuerza inducida por el movimiento, es decir, solo se evaluará la cinemática del modelo. La simulación se realizó en Matlab en donde se proyecta la actuación del esquema del cuadrúpedo, así como el comportamiento del centro de masa para un desplazamiento seleccionado. La herramienta permite predecir posiciones en las cuales el robot puede contar con un mayor o menor grado de estabilidad en su caminar. El resultado de este proyecto es la base para un aplicativo que contribuya con la planeación y simulación de robots cuadrúpedos que incluya la evolución de las variables dinámicas y elaborar una simulación más asertiva en el criterio de estabilidad.

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1. Introduction

The elaboration of mechanisms of locomotion land that employ different structures for its movement, unlike wheels, is very scarce, either design costs, development of mechanisms or lack of knowledge regarding the subject [1], to weigh of this, the evolution in the kingdom animal has opted in his great most by develop locomotion systems composed of limbs, joints that take turns generate support, balance and thrust of the entire structure by moving [2], characteristics that they provide advantages in land irregular, rocky, steep either sandy, without leave of side his omnidirectionality, thing very different to the characteristics that a wheeled locomotion has to face for its optimal use, this is why for the design of legged locomotion, has originated from the evolution of systems biological in special of animals terrestrial quadrupeds [3].

This carry to elaborate tools that facilitate design and simulate the possible behavior of models that they seek to develop [4], an objective that this project seeks to meet in a small portion. In the present, the development of structures robotics that they employ a locomotion through joints, comes from different companies that have made significant advances in the research and application of displacement techniques in articulated robots such as Boston Dynamics, leader in its research [5], at the level industrial they count with a purpose of exploration of land and transport of loads where as good it says the project of thesis of [1] the investigation of this guy of displacement by half of joints is scarce to level national. It that seeks with this development, is interpret some beginning of the ability that possess the animals for can obtain adaptive movement, and thus be able to transfer these skills to a mobile robot to adapt in a world real.

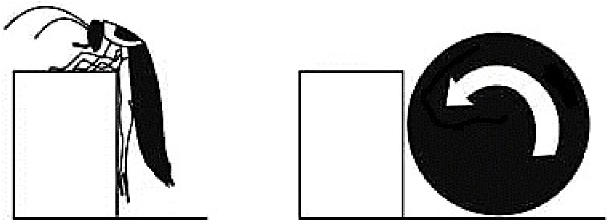
2. Locomotion

In search of improving displacement activities, humanity has turned to the study of the methods of locomotion in the nature [3,6]. Getting started with the segmentation of the space where the movement is carried out: aqueous, terrestrial and by air [2], since to carry out movement, a medium is required in which support can be exerted, an impulse or force. These means in which humanity seeks to optimize its spending energy depending on the displacement, have certain characteristics that the do a challenge for the purpose of the humanity [6].

One of the media further important in which humanity seeks to improve its way of transportation is terrestrial, since This means has essentially been adapted to the principle of operation of the wheel, allocating large economic investments and environmental consequences for its adaptation, as can be seen in the infrastructure of cities in the world, even with this a great part of the surface of the land is Inaccessible for us [6], demonstrating the bad approach that humanity has had.

Which leads to reevaluate the necessary characteristics that our means of transportation must have. Locomotion biomimetics is the area of study that seeks mock the behavior, structure and functionality of the different classes of locomotions that presents in the nature [6], At the terrestrial level, the vast majority of animals have articulated mechanisms to carry out his displacement (paws), having different advantages about the displacement with wheels such as: less impact on the terrain, greater amount of terrain for use and better overcoming of obstacles as can be seen in Figure 1, characteristics that supposes will adopt a machine with similar behavior.

Figure 1. Animal and wheel forehead to an obstacle, Taken of [6]



2.1. Modeling of locomotion

The modeling of the guys of locomotions were the result of the investigation, using the techniques of the Englishman Edward James Muggeridge [7], of structuring the marches related to the of a dog in different videos, giving as result the guy marching "walk" and "trot", was carried out on this quadruped animal since together with the cat domestic, considers one of the animals of company further popular in the world besides of have a great relationship with the humans facilitates can carry out implement the Muggeridge techniques. The next step was to define the characteristics of the structure that we wanted to simulate, the organization of the legs as evident in Figure 2 and defining the outline of the leg, which will be represented by two straight links united in an extreme of the denoting the joint.

Figure 2. Assignment of the number of tip in the structure of the March of a dog.

Source: Own.

The locomotions to be simulated form a cycle, where we can find that they are formed by two phases, the support phase, in which the joint performs the push to the displacement and the phase of swinging, where the joint reposition for continue with the March, bliss phase is a leap that shape a pendulum invested. The guy of passed used in are locomotions finds between the Steps symmetrical position that the phase of support this separated equivalently by a space of time between them [8].

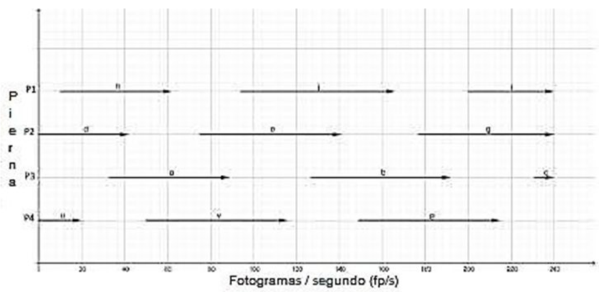
Figure 3. Phase of support and of swinging in the hike of a dog.

Source: Own.

2.1. Hike

The hike is the guy of locomotion more stable that makes the dog, already that in his displacement has three points of support constantly, as can be seen in Figure 3 is also the slowest of the locomotions, having an average speed between 0.9m/s and 1.3 m/s and alternates leg 3, 4, 2, 1 respectively in the swing phase with a time certain, as can see in the Figure 4.

Figure 4. Sequence of support phases on a dog walk.

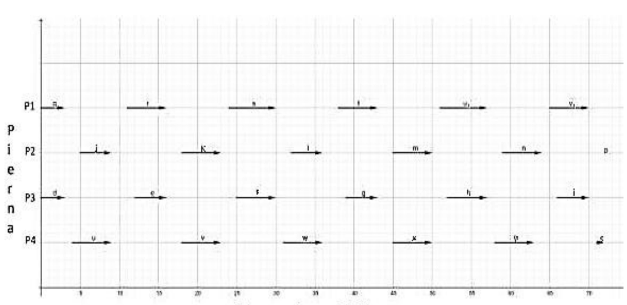


Source: Own.

2.2. Jogging

Trotting is the type of medium speed locomotion around 2.5m/s, Figure 5, where the dog has two permanent points of support on the ground and they alternate in peers of joints diagonals for his March 2, 4 and 1, 3, in the Figure 6 observe as the dog alternate their paws for keep the balance. To the increase his speed in This type of locomotion, the canine gives up characteristics of stability such as support points and being more susceptible to instabilities with shocks or forces external.

Figure 5. Sequence of support phases during a dog's trot.



Source: Own.

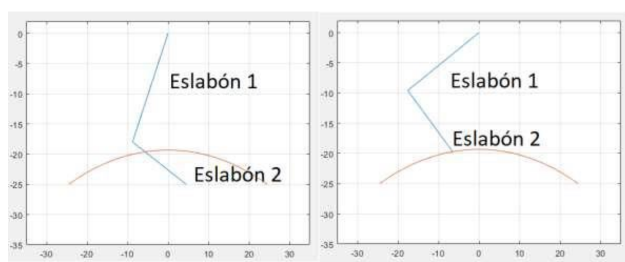
Figure 6. Phase of support and of swinging in the jogging of a dog.

Source: Own.

3. Design of passed

One of the main pillars in this project was the imitation of the animal's gait in his locomotion, the which has to count with certain characteristics already mentioned, as it are: the support phase, which requires constant friction of the second link with the ground and the swing phase, in which the second link returns to the beginning of its support phase without have contact with the ground [8], with an inverted pendulum behavior [2], with these characteristics a model of the leg is made, which has two links and two degrees of freedom as observe in the Figure 7.

Figure 7. Structuring of the phases of support and swinging.



Source: Own.

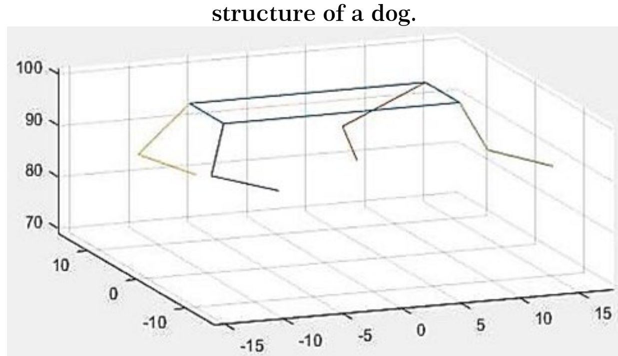
The behavior of this sequence finds certain by two values that The first, the permanence time of the support phase and the recovery phase are modified. sway, which is a unique characteristic of the type of locomotion that the user chooses, and the second, the maximum height of link 2 that it reaches in its swing phase, which as good name has a behavior of pendulum invested with a height maximum the distance half between the positions extreme of the phase of support for elderly comprehension see the Figure 8.

It must be emphasized that the distance between the extreme points of the support phase It depends on two factors that the user can modify and with this the height of the step will be affected, the length of the leg links and the height of the simulation, so between further near find the height of the simulation to the summation of the lengths of the links of the leg, the smaller the space between the extreme points of the phase of support.

4. Structure

The purpose of the project sought to provide a tool in which the behavior of the center of mass of quadrupedal locomotion, which led to a model simple and easy of understand the structure that would arrive to have the machine, already having the model of the leg which will be used and with the idea that the edge of the leg is a representation of the joint, a square was structured as a base in representation of the machine, where each edge of this quadrilateral represents the joints of the shoulders and hips, having as a structure the diagram illustrated in Figure 9, where the rectangle of color blue I would be the base of the scheme.

Figure 9. Model of the solution proposed for the structure of a dog.



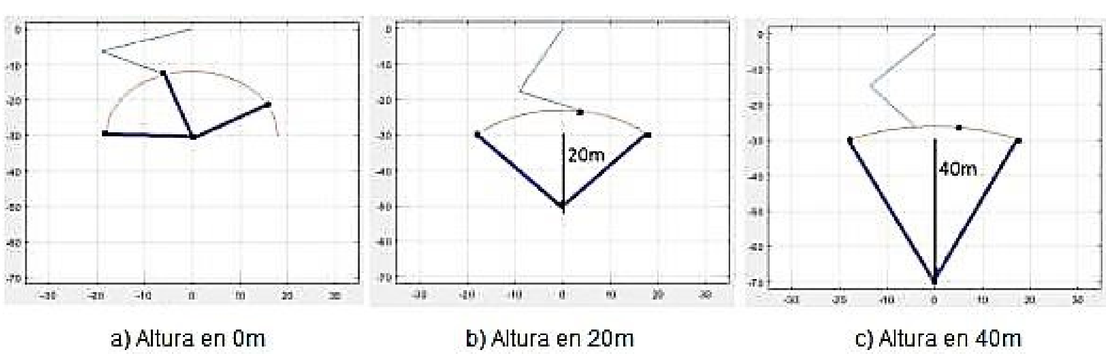
Source: Own.

To level structural they count with parameters mandatory for the use of the application as they are, the orientation of the legs, being a structure extracted from the bone composition of a canine the orientation of the legs will always be pointing in address of the displacement, the degrees of freedom of the joints they will be in the flat orthogonal with the base and in the direction of locomotion, leading to no inclination in legs and the lateral length (length) which will have a minimum length in order not to obstruct the displacement of the links in the locomotion.

5. Center of mass

The representation of an object in the field of physics can be described by a spot, the which It represents all the qualities physical that are involved with the object, this same thing was sought in the

Figure 8. Visualization of inverted pendulum in the swing phases.

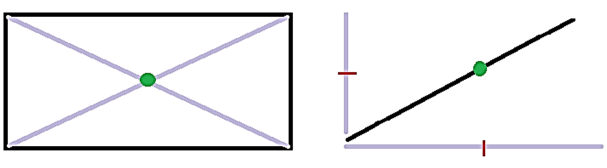


Source: Own.

preparation of the project, with the difference that it was evaluated the center of mass in each position that of the displacement. There is that emphasize in this spot that said representation will be made taking into account the statics which no force provoked by the motion be had in account.

One of the concepts guides in the elaboration of this project is the of center geometric, the which gives in figures flat describing the spot half of the magnitudes of the figure, having the geometric center of a straight line at its average length or in a square at the point of intersection of the diagonals between their vertices, the same thing that happens in the rectangle, seen in figure 10, this concept is used in order to position the center of mass in the joints to be simulated since we can match these two concepts in location, we do define a uniform mass density over the links and the base of the structure.

Figure 10. **Representation of the center geometric in to) a rectangle and b) a straight.**



Source: Own.

The representation math of the center geometric, can find with the equation 1.

With the points of the vertices of the polygon:

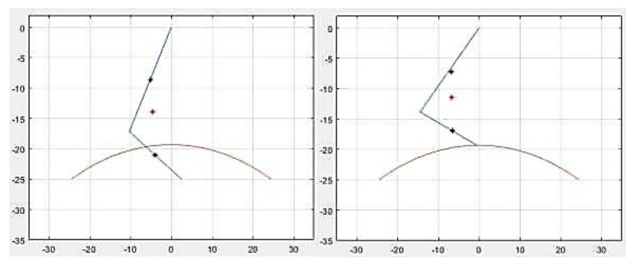
$$p1 = (x1, y1; p2 = (x2, y2); p3 = (x3, y3); p4 = (x4, y4) \ldots \ldots pn = (xn, yn)) \quad (1)$$

The centroid of the figure closed composed by sayings vertices is:

$$\left(\frac{x1+x2+x3+\cdots+xn}{n}, \frac{y1+y2+y3+\cdots+yn}{n}\right) [9] \quad (2)$$

This would give a center of mass corresponding to each link and the base, a spatial location of a point that is assigned the mass corresponding to the link or the base as sample the figure eleven. As the purpose of the project was represent the summation of all these centers of mass into one, it will be necessary to operate them between them to obtain the representation final of the structure.

Figure 11. **Projection of the center of mass in the structure designed for the step.**



Source: Own.

The operation between these centers of mass will be additive, so the representation final will be the sum of all these masses with the difference that the position will be affected mainly by the links either the base that have elderly mass, tending to this spot.

For this, they operated the centers of mass with the following equation.

$$XG = \frac{\sum_{i=1}^{N} MiXGi}{M} \quad (3)$$

$$YG = \frac{\sum_{i=1}^{N} MiYGi}{M} \quad (4)$$

$$ZG = \frac{\sum_{i=1}^{N} MiZGi}{M} \quad (5)$$

6. Results

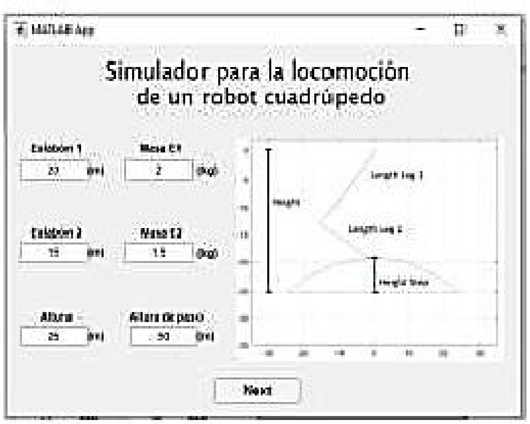
The application allows the user to observe the behavior of the center of mass In quadrupedal locomotion, the interface is made up of three windows, two of them intended to acquire the data chosen by the user and the other to represent the type of locomotion selected as the behavior of the center of mass.

6.1 Acquisition of data

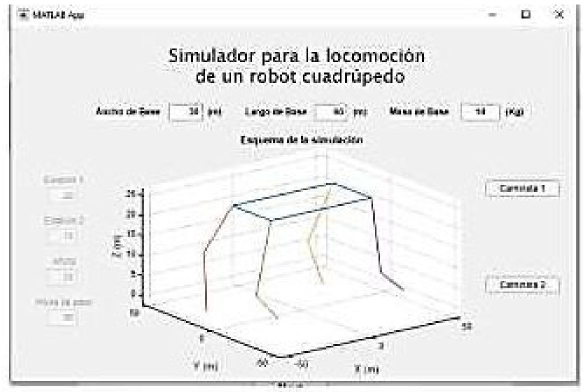
The data acquisition section is responsible for incorporating, analyzing, rectifying and inform that the data entered in the application leads to a correct simulation. This formed by the windows 1 and 2 that illustrates sen the Figure 12, who they count with restrictions to the data entered, starting with the denial of data less than or equal to zero in the boxes of length of links and masses, followed of the following restrictions:

- The length of link 1 has to be greater than the length of the link 2.
- The height of the simulation must be greater than the length of link 1 and less to the addition of the two links.

Figure 12. View of the windows 1y 2 of the application.



ventana 1. datos del paso.



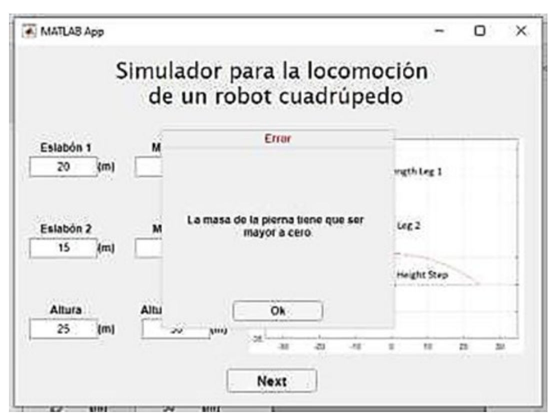
ventana 2. datos del polígono

Source: Own.

The height of the passed to weigh of No count with a restriction the user has to internalize the description of the step design set forth in section 3 of the document why it is They may present errors in the simulation as long as the value approaches zero in this data, Finally, there is an additional restriction on the lengths of the base plus specific in "Base Length" that has an alert that informs the user of the value minimum of this data in order to prevent the links in their movement from collide between them.

If an error in the data type or value is found, the application will alert the user with a message that describe in a message the mistake found, see Figure 13.

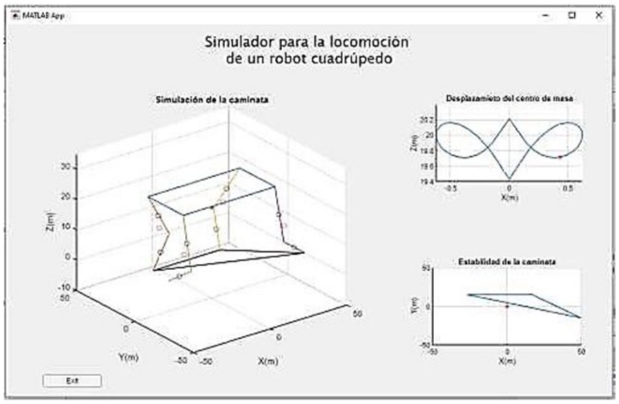
Figure 13. View of the screen of alert to a mistake found in the window 1.



Source: Own.

The third window of the application exposes the stated objective as evidenced in Figure 14. Describing the simulation graphs of walking, displacement of center of mass and stability of the hike.

Figure 14. View of the window 3 of the application designed.



Source: Own.

6.1.1 Simulation of the hike

The flat described as simulation of the hike projects the behavior of the scheme of the quadruped in the displacement selected. As also of toast the behavior of center of mass of the links that intervene in the locomotion and the center of mass of all the structure, by last, account with the polygon formed by the Points of support that account the scheme doing the March.

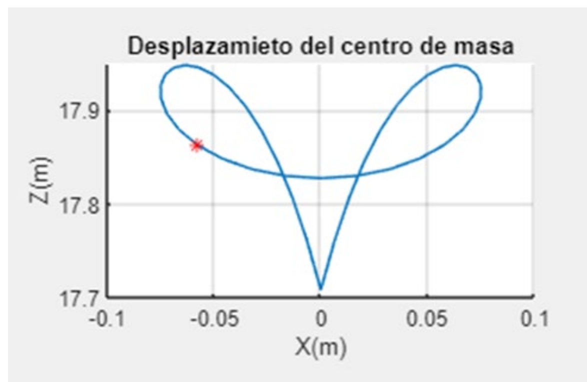
6.1.2 Displacement of the center of mass

The graph projected in the side stand superior right, is the representation of the behavior of the center of mass depending on the type of displacement chosen. The appearance of the center of mass be similar when select the same guy of locomotion since the behavior of the links as well as their characteristics will be similar, Figure 15 being the representation of the center of mass the walk and figure 16 the of the jogging.

Figure 15. Behavior of the center of mass in walking locomotion.

Source: Own.

Figure 16. Behavior of the center of mass in walking locomotion.



Source: Own.

6.1.3. Stability of the hike

The stability of the walk is the graph in which the center of mass is projected in the polygon included by the support points that are found at that moment. Graph where the application user can determine the balance or imbalance of the robot, using as a criterion that being inside or near the support polygon, the structure it's a lot further stable that to the be more retired of the polygon.

6.1.4. Algorithm

The preparation of this degree project involved the creation of an algorithm, which allows the acquisition, rectification and projection of data, which is located prepared with the Matlab tool and code compiler, part of the source code is finds in the following repository of GitHub https://github.com/loky98/Proyecto-de-Grado-Caminata.git which has 4 files, FirstHike.m being the simulation of the hike and SecondHike.m of the jogging, essentially the structure of the code account with a series of Steps with the called of functions that the diagram described in the Figure 17 sample.

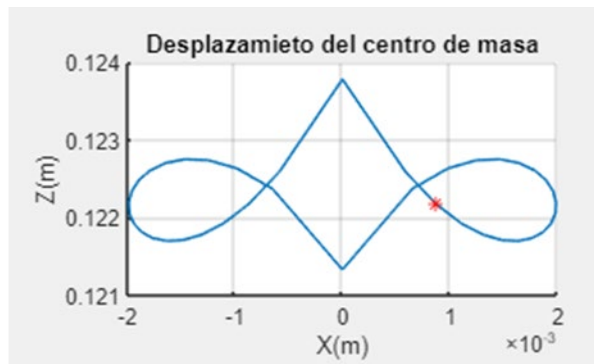
With the completion of the project, simulations are prepared to project the center of mass in the application, with characteristics of different breeds of dogs to evaluate their behavior, the which ones describe in the Table 1.

The results obtained of the evidence in the behavior of the center of mass this indicated in the Figures 18 to the 20 with the descriptions of home case.

Figure 18. Behavior center of mass Golden.

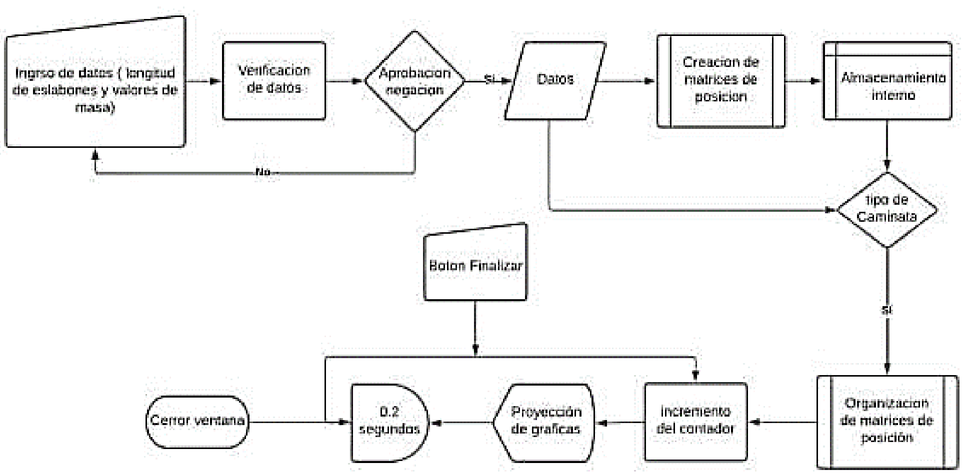
Source: Own.

Figure 19. Behavior center of mass Chihuahua.



Source: Own.

Figure 17. Diagram of flow representative of the algorithm implemented in the application.



Source: Own.

Table 1. Values admitted in the application with characteristics of the race of dog.

	Golden retriever	Chihuahua	Shepherd German
Length link 1 (cm)	3. 4	12	33
Length link 2 (cm)	24	8	30
Height (cm)	40	17	55
Mass Link 1 (kg))	1	0.1	1
Mass Link 2 (kg))	0.5	0.1	0.5
Height of passed (cm)	fifty	fifty	fifty
Broad of base (cm)	30	10	30
Long of base (cm)	85	22	85
Mass base (kg))	29	0.8	32

Source: Own.

Figure 20. Behavior center of mass Shepherd.

Source: Own.

7. Discussion

Demonstrating the results of the simulated tests with the values described in Table 1, we can deduce that the behavior of the center of mass in all The graphs are similar, which would lead us to affirm that the behavior of the center of mass is symmetrical in this case around the axis and regardless of any variation of the entered values in the application.

It can also be seen that the Chihuahua is simulation, that it has a behavior of the center of mass closest to the ground, not only because it is the smallest height of the three is no, the distribution of the mass in this case this better averaged in their joints, arriving to suppose that is the better case between the three, with the simulation further stable having in account that a center of mass entails a better stability.

Comparing the simulations between the Golden and the Shepherd German that are the further Similar in size and weight, achieve show that the qualities of the Golden as it are links more unequal, lower height and better mass mean that the center of mass has a displacement elderly in axis horizontal influencing in the time of obtain speed already that by evaluating its inertia, it will tend to carry out a conservation of the state in this axis.

The application us presents as result the behavior of the center of mass in two walks reproduced by a dog, walking and jogging, this behavior of the center of mass this given in the scheme static of the structure, the which his behavior will not be accurately representative in real life any more when increase the speed of movement of locomotion, which indicates that the behavior of the center of mass provided by the application will be more accurate in locomotions with speeds smaller.

Regardless of the configuration proposed by the user and the type of walk, the center of mass you stand out of the polygon of support, especially in the locomotion of jogging, this has to that the simulation only took reference of the positions of the extremities in a lateral plane of the animal, without counting the inclinations that they make evident in the flat frontal of the dog.

8. Conclusions

The projected behavior in both types of locomotion is correct, since has the appropriate formulas and operations to find the center of mass of the structure, behavior that we would see reflected in a atmosphere without force external that intervene in the structure For example in the space.

The representation of the structure contributed to the project defining in a way correct the behavior of the center of mass, as well as the simple identification of the proposed model, a feature that, despite its certainty, could be improved by illustrating the real behavior that the fibula bone has that works like a spring in the displacement of the dog and more animals terrestrial.

The algorithm proposed for calculating the position of the center of mass is correct, in its behavior, managing to identify its variation in each position in which it is posed the structure, providing a sequence of points that carry out a cycle that intends to have a repetitive behavior, where the step to follow is not only looking for the projection of the center of mass if not, also, that of the resulting vector in magnitude and address that the movement, the gravity and the inertia exercises about this spot.

The proposed stability criterion that defined the stability of the mechanism in the locomotion as stable “find the center of mass within the support polygon” is unsustainable in the physical and mechanical approach simulated by the application, which is why for a continuation of the project, it is advisable to take into account the lateral inclinations that perform the joints as the base in the displacement.

A very useful simulation tool is offered for the development and implementation of locomotion mechanisms in walking robots since it allows to visualize and interpret the behavior of the algorithms before being implemented in the robot.

The development of an application that contributes to the projection and simulation of quadruped robots is possible and together with properties of physics and mechanics can be built, projecting an appropriate behavior to the real world, for this, it is necessary to have the appropriation of all the forces involved with the model, as well as the evolutions of the kinematic and dynamic variables of the model.

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