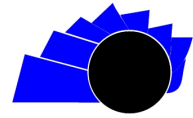








UNIVERSIDAD DISTRITAL  
FRANCISCO JOSÉ DE CALDAS



## Biomimetic prototype for flapping movement of bats

### Prototipo biomimético para el movimiento del aleteo de murciélagos

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#### ABSTRACT

The present article prototypes the fluttering style of bat wings, creating a structure to replicate the static vertical flight at a single point made by them. To achieve this, mechanical and electronic techniques are employed to develop a skeletal model, considering the angles of action connected with an electronic assembly that enables its mobility.

As a result of this schematization, a symmetrical movement is presented between the pair of wings, ensuring the amplitude of the displacement through restrictions on the bone structure and regulating the speed of movement by controlling the power supplied by the circuit in charge of it. These results demonstrate the possibility of creating archetypes that facilitate the study of behaviors observed in various species without requiring a high investment in materialization, thereby aiming to adapt such actions in facilities for daily life.

#### RESUMEN

El presente trabajo prototipa un estilo de aleteo por parte de los murciélagos, creando una estructura que replica el vuelo estático vertical en un solo punto realizado por estos animales. Para conseguirlo, se hace uso de técnicas mecánicas y electrónicas, desarrollando un modelo esquelético, tomando en consideración ángulos de acción, junto a un montaje que da lugar a la movilidad de este.

Como resultado de esta esquematización se presenta un accionar simétrico entre el par de alas, asegurando la amplitud del desplazamiento gracias a restricciones sobre la estructura ósea y la velocidad del movimiento mediante la regulación de la alimentación que recibe el circuito encargado de esto. Estos resultados demuestran la posibilidad de crear arquetipos que faciliten el estudio de comportamientos vistos en diversas especies sin la necesidad de alta inversión en materialización, aspirando así adaptar dicho accionar en instalaciones para la vida cotidiana.

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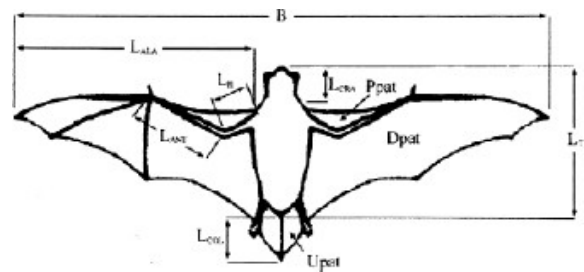
## 1. Introduction

The process of development and innovation for the engineering account with diverse points of starting point, which can arise from any field of study and even from everyday appreciations. Taking this in consideration, is born the concept of biomimetics, the which define as a field of study that has as purpose emulate characteristics either behaviors appreciable in nature and take them as inspiration for the development of technological products that benefit the daily life of society.

A relevant historical exponent of biomimetics is Leonardo Da Vinci, who throughout his life dedicated part of his research to the study and development of aerodynamic mechanisms inspired by various flying animals; in relation to the present article, finds his recognized to the delta also inspired in the style of the bat wings. The first nascent patent in this field of study is Velcro around of the years fifty by the engineer Swiss George of Mestral, who inspired in as his pet's fur stuck caltrops. Another example present in modernity are the bullet trains on the lines of Japan, which suffered from a large amount of noise due to the shock waves produced by the air pressure and their deceleration. This problem was solved thanks to the cranial adaptation of the kingfisher birds, who, thanks to their morphological properties, manage to enter the water by overcoming the water barrier without generating waves in it. [1-5] Taking into account the above, it is appreciated characteristics notable in the flutter of the bats, that them It allows maneuver aerodynamically, overcoming restrictions present in other flying species. These are the only mammalian creatures capable of flying thanks to their evolutionary process that leads to a body designed for this purpose. This is reflected in its patagio which is a membrane fine, slim and elastic that does of fur. to his time, following his nature mammals have fur all over their bodies, which covers a wide variety of shades. As there is a great variety of breeds, characteristics such as the shape of their ears

or snouts are very versatile. During their rest periods they use the aligned claws of their legs, hanging of head and according to the long of his line account with a support extra the which contributes both in recess and for their hunting practices. [2-3] Emphasizing flight ability of the bats recognize three aspects fundamental. In first place, the patagio on the wings so thin that it allows light to pass through it, favoring lightness and flexibility during the maneuverability. In second place, the strength in the muscles of torso, both back and front, allows for quick and effusive movements. Thirdly, the angles that can be covered when flapping the wings, which manage the energy consumed, speed of flight and positioning in space. Finally, the structure I mean of wings similar to human arms in number of fingers and mobility with the difference of covering enough space to deploy the complete fold of the wing. [4-5] Taking into consideration the morphological variability between the various breeds, it is necessary to take biometric data, which favor the recognition of distinctive characteristics between strains. In this work the species *Tadarida Brasiliensis* was selected; specimens of small dimensions, to the point of measuring less than a palm, due to wing measurements, flight patterns, behavior according to the habitat and lengths of both bones and between reference points (Figure 1) [7-8-14].

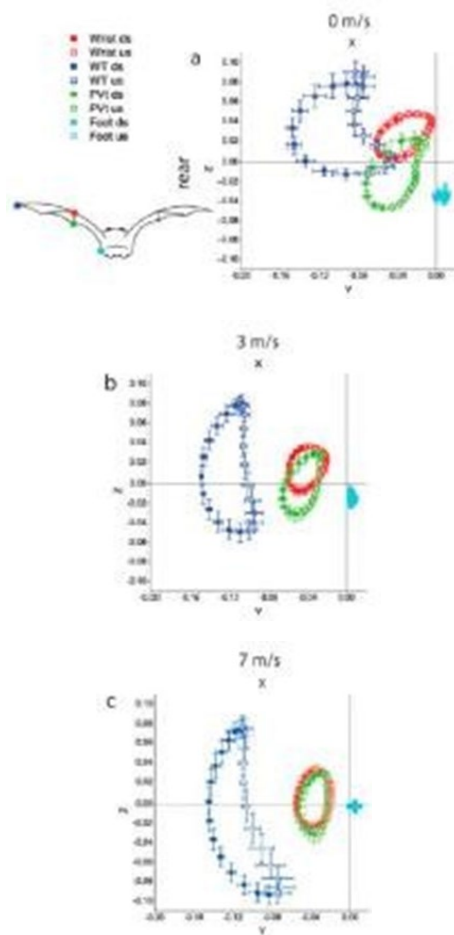
**Figure 1.** References biometric for bats *Tadarida Brasiliensis*. Source: Taken from [8].



Currently, studies have been developed where the movements involved during the flight and their influential angles are presented normalized, thus appreciating clouds of points that describe the position in the displacement of the humerus and phalanges

extremes, elongating to the middle zone of the wings or all of them for maximum and minimum points [9-10-12]. Figure 2 shows descriptive graphics for the movement from the rear perspective of a bat, highlighting different reference points in colors. It is important to emphasize in the tonality blue dark position those projects the tip of the wing, managing to recognize each moment of the movement and how, due to the speed, the width of the wing is compressed considerably [9-10-13].

**Figure 2.** Graphics of displacement to reason of speeds different from rear perspective.



Source: Modified from [9].

After the mathematical descriptions for the flapping, the need to equate the force delivered by the pectoral and lumbar muscles is considered for the design of the prototype. A gear system was used to ensure symmetrical movement between wings. Also

considered the structure designs I mean coated by a membrane enough flexible for No limit significantly the movement now be by the strain of the material either the weight that this you apply to the system [fifteen]. Finally, to stimulate this system, direct current supplies tend to be applied, technically simple of wear, as it is engines D.C. and his respective conditioning and speed control [14].

The set of previously exposed concepts gives place to the elaboration of a prototype of bat wings emulating their vertical flapping during static flight in order to recognize the complexity that involves elaborating designs biomimetics and as these can expand the development technological in diverse fields of study optimizeable with this type of aerodynamics.

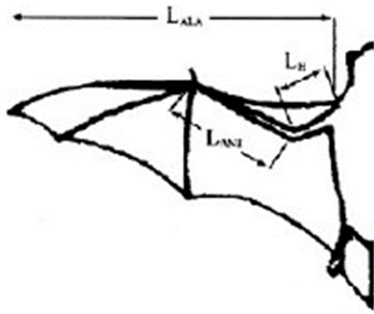
## 2. Materials and methods

This section describes the process of making a prototype of wings that belong to the bat species *Tadarida brasiliensis*. This species was selected because is wide distribution by Latin America it that entails to a great amount of studies on its morphology and flight characteristics, such as action angles, movement restrictions, aerodynamics, among others.

### 2.1. Morphology of the at

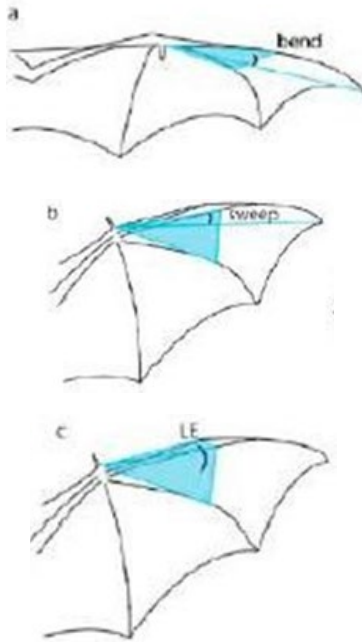
The morphology of the wings and the relationship maintained by each of the bones are analyzed. regard to the wingspan of the wing, of importance for the flight of these animals. took as reference a scheme of the view lower of the *Tadarida brasiliensis* in the which one differentiate each a of the structures basic that intervene in the flight [8]. So same, mapping of a general way the wing shape when gliding and as each one of the movements so much to the contract as expand modify the build of the to the [9] (Figures 3 and 4).

**Figure 3.** Morphometric of the *Tadarida brasiliensis*.



Source: Modified Out of [8].

**Figure 4.** Illustration of alar elongation of a bat in three moments different.



Source: Extracted from [9].

It is important to consider the morphometry of the bat since the shape in which they are ready each one of the bones of the the, their lengths and pesos intervene in its flight form by reducing parasitic drag and inertial cost [14]. The key to being able to replicate the flutter vertical of a bat gets to leave of several studies allometric who examine the Aero mechanics of these animals [15]. Table 1 shows the comparison between the bone structure data that make up the wing for both male bats of this species and males of the *Myotis chiloensis* species.

**Table 1.** Comparison morphometric between *Tadarida brasiliensis* and *Myotis chiloensis*.

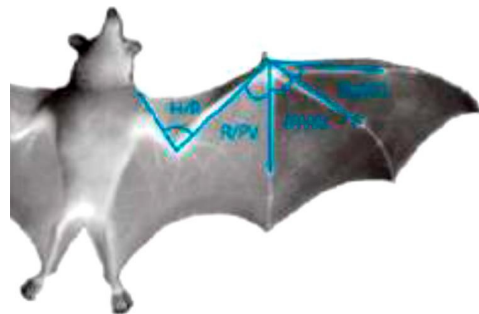
VARIABLE	TADARIDA BRASILIENSIS (N=27)	MYOTIS CHILOENSIS (N=49)
Masa (g)	11,95 ± 1,65	6,75 ± 0,66
$L_T$ (cm)	6,04 ± 0,28	4,77 ± 0,32
$L_{COL}$ (cm)	3,53 ± 0,37	3,63 ± 0,60
$L_{CRA}$ (cm)	2,12 ± 0,16	1,64 ± 0,10
$L_{ALA}$ (cm)	13,37 ± 0,80	11,09 ± 0,63
B (cm)	28,65 ± 1,67	23,69 ± 1,26
$L_{ANT}$ (cm)	4,33 ± 0,16	3,82 ± 0,14
Ppat (%)	5,17 ± 1,22	5,38 ± 1,19
Dpat (%)	88,37 ± 9,47	84,96 ± 11,10
Upat (%)	6,47 ± 2,13	9,66 ± 1,93
Apat (cm <sup>2</sup> )	83,45 ± 9,60	81,91 ± 10,10
$L_H$ (cm)	2,23 ± 0,09	2,11 ± 0,10
$D_H$ (mm)	1,23 ± 0,14	0,95 ± 0,09
$d_H$ (mm)	0,67 ± 0,09	0,48 ± 0,08
AC (mm <sup>2</sup> )	0,84 ± 0,23	0,52 ± 0,12

Source: Modified of [8].

### 2.2. Angles of action

The structures involved in the flapping of a bat's wings are a little more complex than those of other insects and birds, which gives them a great advantage over them, since they can perform a greater variety of movements and this is due to two important factors: the great flexibility of its patagio and the angles that are formed between each of the bones of the wing and the forearm, as shown in Figure 5. Being able to make movements of almost 180° allows the bat to capture more of air for hold further time the flight, can trigger elderly endurance so it They want to produce a greater forward speed when capturing their prey or make a greater angle when flapping their wings towards their body which causes a fold much closer to the body compared to other flying animals [6].

**Figure 5.** Different angles that form in the to the of a bat.



Source: Modified from [9].

Each one of these angles it varies of agreement with the speed that have the bat at a certain time as we can see in Figure 6. The first thing that is achieved appreciate is that the angles H/R and P/PV the which find near of the forearm and the inner part of the wing are those that present a greater variation with respect to the elapsed time of the flight and its speed, therefore, we can say that they are more influential to the hour of carry out any guy of maneuver with regard to the angles PV/V and PIV/III which are located in the outermost part of the wing. We can also pay attention that a greater variation of the angle is required in the H/R and P/PV sections when the speed initial is 0 m/s that when the bat already goes with a speed determined, for the case of the example, 3 m/s and 7 m/s, this has to that the animal needs to concentrate the greatest amount of air under and in front of its wings when at rest for be able to make a maneuver in comparison to when carry already one initial velocity.

**2.3. Flutter of bat**

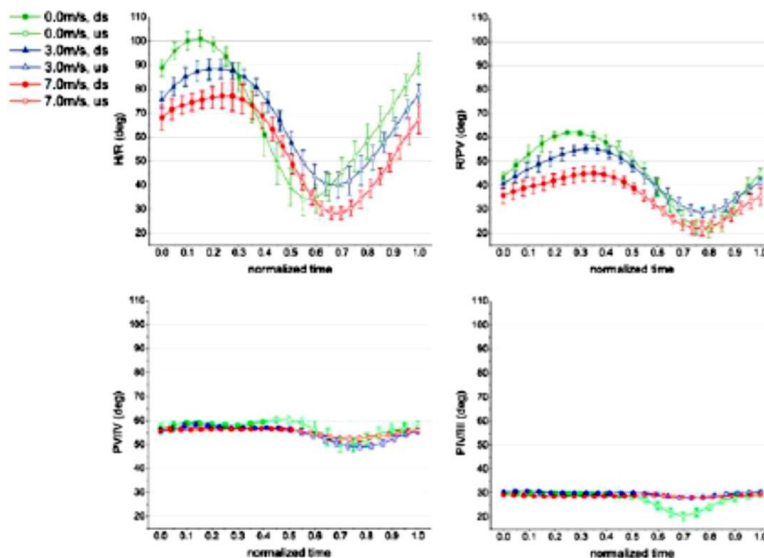
The morphological characteristics and the different angles that are formed between each of the structures of the wing and forearm are of vital importance for the

bat since together they mean that it does not have a great energy consumption when flying in a straight line. This is because, by having its wings fully extended, the patagio curves so much that the air circulation underneath causes the bats to produce a large push spending a lot less energy. The motion that bats perform in a flight normal can see in the Figure 2, perform so much a motion vertical like one horizontal, this combination gives place to what have one of the best skills of flight of the animal kingdom, can perform extremely complex maneuvers in the air, are able of carry out settings asymmetrical with their at, is say, they can perform independent movements between each one of them, which allows them to turn around in the middle of the flight in order to land.

**2.4. Circuit of feeding**

The circuit that built for can achieve a motion similar to the that they execute The bat is made up of an IRF520N MOSFET which will help us with the switching between the control signal and the ground of the entire circuit to be able to start and stop the movement of the prototype of the wings at any time, a pair of resistors so much in the pin Gate as in the drain of the transistor with values of 1 kilo ohm, a 1N4004

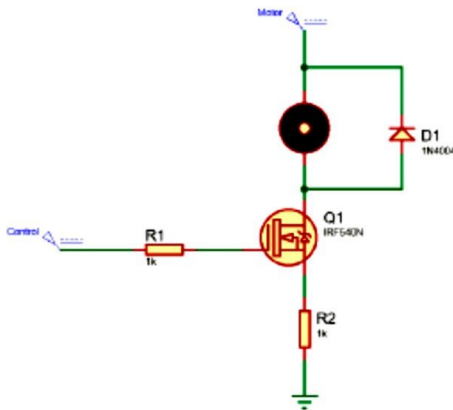
**Figure 6.** Variation of the angles in degrees regard to the time having different initial speeds.



Source: Modified of [8].

diode in parallel to the motor that will help us as a protection circuit and a gear motor that will supply the necessary speed and force throughout the process. Following to this used as feeding of the engine a fountain D.C. of 9 Volts and as a control signal a DC source which increases its intensity depending on that so fast need that the at they beat, this worth varied between the 0 Volts up to 5 Volts. Finally, for this circuit to work and be able to move the wings, a series of gears were used which were directly connected. to the gearmotor, doing movements oscillatory in each of the at next, we can see the schematic of the circuit used.

**Figure 7.** Circuit of feeding of the prototype.



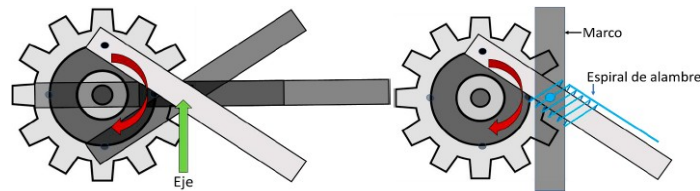
Source: own.

### 3. Implementation

For the mounting of the prototype of at of the bat *Tadarida brasiliensis*, need to know which one goes to be the material of the what are they going to be made the most important bones of the wing, for this, balsa wood was selected which is light enough to be able to make the motion of shake the at without interrupt in the same, but also it Stiff enough not to break. Since it is already clear what material they will be made of the bones, now needs get a material for the patagio, due to this end, it was decided to use tracing paper which has properties similar to the membrane that covers the wings of bats, these are its flexibility, great resistance to stress and low weight, which makes it an ideal material. The assembly of the wings can be seen in Figure 8, for this it was decided not to overload them and determined use only three parts of wood of raft the which They serve to provide support and rigidity to the prototype.

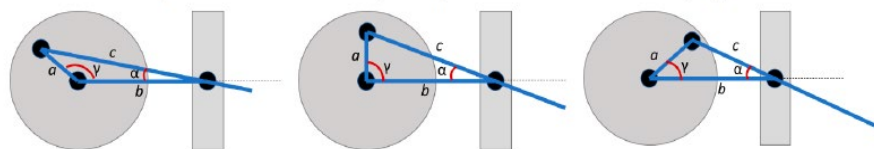
The motion of the at achievement considering the change of a triangle obtuse that shape with vertices at: the pinion axis (vertex ab), insertion point of the mobile lever at a extreme of the pinion (vertex ac) and axis of the frame (vertex bc). The Figure 9 sample some

**Figure 8.** Graphics of displacement to reason of speeds different from rear perspective.



Source: Own.

**Figure 9.** Change of the angle  $\alpha$  with the rotation of the engine. angle  $\alpha$  It represents the angle achieved in the flutter of the prototype.



Source: Own.

changes of the triangle obtuse when the engine tour. The angle  $\alpha$  indicates the angle that can achieve the prototype of the wings during the flapping simulation.

The design for achieve the angle wanted performed using the theorem of cosines, the side a was set to 0.8cm, the side b was set at 2cm, the side c and the angle  $\alpha$  vary according to the motor movement, for its calculation the following equations were used:

$$c = \sqrt{a^2 - 2ab * \cos(\gamma) + b^2} \quad (1)$$

$$\alpha = \cos^{-1} \left( \frac{-a^2 + b^2 + c^2}{2bc} \right) \quad (2)$$

A time they have so much the assembly of the at the physical restrictions of motion and the already prepared and functional power circuit, each of the elements are joined to obtain the final prototype as can be seen in Figure 10.

**Figure 10. Prototype final.**



Source: Own.

## 4. Results

By applying different control voltages, the movement described by the prototype changes substantially, between range from 0 to 2.5 Volts all system does not move, this is because there is very little energy supplied, the total weight of the pair of wings and the force generated is high so the gears cannot move properly. The control voltage needed for can Activate all the system has that be elderly to the 2.5 Volts, to the have a greater tension, the system begins to function as planned, that is, the wings

perform a vertical displacement which resembles a circular shape seen from the front as seen in Figure 4, to this displacement a small horizontal component is added. which has similarity to the moment in that the bats extend their at completely for can plan and reduce the cost energetic in the flight. To the cape of a moment could show that the patagio did not allow the air to circulate well under the wings, which caused a great upward force that was detrimental to the entire assembly. In order to solve this, small transverse cuts were made on the wings, the purpose of which is to allow air to pass through from the side. bottom of the wing towards the top without generating friction.

Finally, when a voltage above 4 Volts is applied, the pair of gears that perform the circular movement have such a high speed that, when adding the weight generated by the axles and the at these disengage the one of the other achieving that the system collapse, the axles become dislocated and the wings lose stability. Since this is not the objective of the prototype, but to closely replicate the movement of bat wings, it is necessary to maintain the control voltage between 2.5 to 4 Volts.

It was also observed that, by changing the diameter of the coil and its position with respect to the axis, we can generate more vertical displacement by decreasing the diameter and create greater angles between further near this the turn of the axis of the gears.

To validate the length selection of the leg b is validated maximum angle achievable at a rate of the same, the extent part from 1.5 cm due to that a minor distance of b (Figure 9) it implies a proximity of the frame to the gear radius. Taking the above into account, Figure 11 shows the resulting angle curves for different values of b (Figure 9), where it can be seen that the smallest measurement allows the greatest angle of movement, however, at the time of assembly The measurement of 1.5cm is not viable as it would imply excessive proximity to the frame that delimits the angles. In this study we select 2cm for side b.

**Figure 11.** Curves of the degree Alpha to reason of the length of the cathetus b.

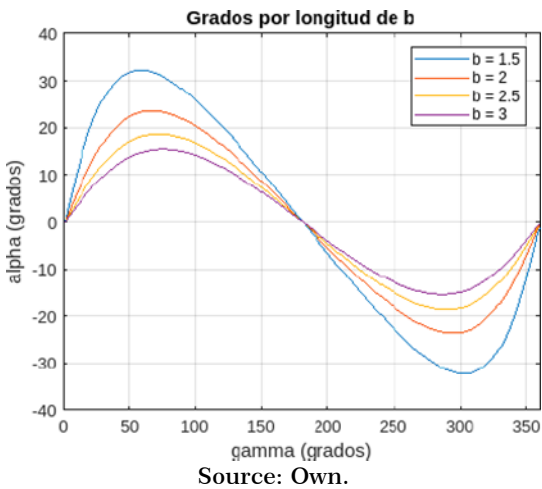
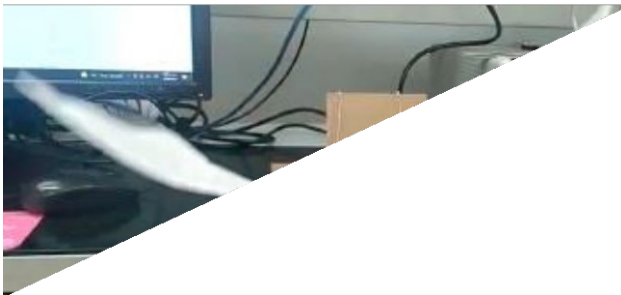
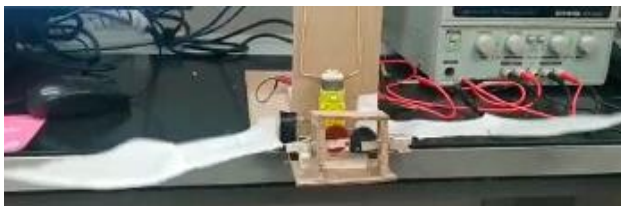


Figure 12 shows the flapping movements of the prototype (a) corresponds to the maximum average height reached by the tip of the wings, (b) is the intermediate movement, when the wings are more extended and (c) the minimum value average wing tip, achieved by the prototype.

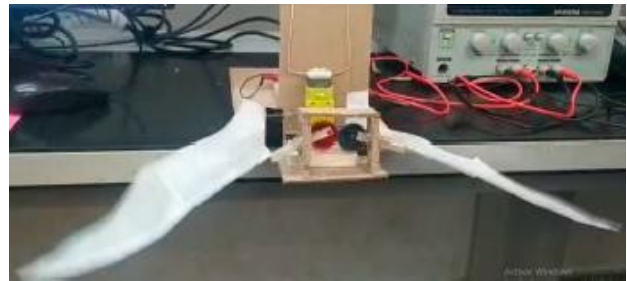
**Figure 12.** Movements of the prototype.



(a)



(b)



(c)

Source: Own.

## 5. Conclusions

The present article shows as the development of prototypes biomimetics imply a numerous amount of mathematical and physical bases which significantly condition the actual assembly, reflected in conditioning such as structural weight or angular limitations.

Likewise, the use of electronic components in biological environments helps to recreate movements such as bat wings. However, these same require properly established power bases since the power demand requested by the action system can lead to overloading the components, causing them to become fatigued.

The flight of bats shows a highly interesting aerodynamic system, to the point of carrying out unique maneuvers both in speed and mobility, which if fully recreated would have the potential to be applied in a number of abundant areas, facilitating tasks of rescue, reconnaissance or even commercial such as package delivery.



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