Calculation of the Size of Biomimetics Robots According to Need and Purpose of Use

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Abstract—In the 4th industrial revolution era, more countries and companies tend to use specialized robots to replace workers. Especially in a hazardous and high risks working environment, robots that perform human tasks are also humanistic. It's even the unique solution to ensure life safety. Currently, scientists are much interested in robots that look, act like animals; including biomimetic robot models have capable of flexible mobility and widely application potential. However, it's difficult to calculate, design and manufacture dynamic robots. In this article, the author will present an overview of dynamic robots and propose new methods and calculation techniques to design and build biomimetic robots. The experimental results show that proposals have contributed to solve those difficulties and being practically applicable to make a biomimetic robot.

Keywords—Simulated Robot, Automatic Robot, Rescue Robot, Flexible Robot, Biomimetics robot.

1 Introduction

As a result of natural selection and development, animals in general and humans particularly are considered the most complete and optimal machines. The design and manufacture of specialized robots is essentially the process of teaching robots how to act like a person or a specific animal. Each animal has different advantages and limitations but they're considered as a complete and optimal machine to perform functions and tasks that they often do such as: bird fly, fish swim, dogs run... How robots select animals as model depends on each function, task that robots need to take charge. That's why the current robot simulation research direction has rooted and developed [1, 2, 3].

Among biomimetic robots have been built and tested, Dynamic robot is outstanding with many advantages.

The relatively successful test version called Robot Rhex by Darpa – USA. Rhex's dimensions are 57 x 39 x 7.5 cm (L x W x H), weight 12.5 kg (no battery), C-shape leg (C leg) springs' height Hleg = 20 cm. Rhex's cover made by a combination of aluminum and stainless steel (Fig. 1); equipped 6 motors (motor type Umotor = 12V/DC; speed Vmotor = 960 around/minute; gearbox ratio Kmotor = 139/1) to spin 6 legs of Rhex (Fig. 2) [4, 7].

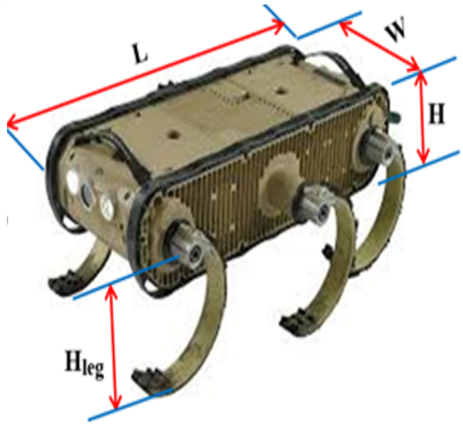

Fig. 1. Darpa tested version

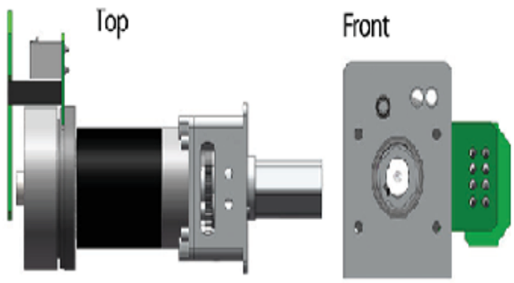

Fig. 2. A motor equipped inside Rhex

The control board uses Intel chip and control software programmed in C; using laser sensors to locate C legs; powered by Lithium batteries capacity of Cpin = 144 mAh [6]; Rhex is controlled via a remote control with frequency Frf = 2.4 GHz, at maximum distance Lrf = 700 m. Two heads equipped a LED light Pled = 3 watts, a camera 320 x 240 pixels, taking photos with a resolution of 1280 x 960 pixels (images and videos are sent back to the controller's position via radio transmissions) [4, 7].

Experimental results showed that Rhex could move flexibly (forward, backward, turn right, turn left on rough surfaces) at a maximum speed of Vrhex = 9.7 km/h; to move over many types of terrain surface such as flat roads, undulating roads with gravel ≤ 20 cm (Hfen ≤ 20 cm), wading is about ≤ 20 cm (Hwater ≤ 20 cm) [7].

The University of Pennsylvania research team has also conducted another successful version of Rhex robot. This robot basically was designed to look similar to the Darpa's test version, except it was used lighter materials and components to increase the robot's flexibility. The robot's cover was replaced by composite materials (light and good absorption), 6 C legs were built by synthetic plastic material (light and good elastic spring steel), using 6 brushless EC 45 motors of Maxon (a motor has Pmotor = 48 watts, deceleration Kmotor = 28/1). Therefore, the robot's size was H = 7.5 cm, W = 39 cm, L = 57 cm, M = 9.5 kg (including 2 batteries), Hleg = 17.5 cm, Hfen ≤ 12.5 cm [9, 10].

The publications of the test showed that the test version could move flexibly to overcome many types of terrain: flat roads, high stairs better than Darpa's one. Its speed can reach Vrobot = 7.2 km/h, payloads Mbring = 12 kg. However, because of soft C-shaped legs, this dynamic robot moves less steady than the Darpa tested version [5, 6, 8, 10].

2 Basic Biomimemics Robot Characteristics

2.1 Symmetry

Biomimetic robots are designed symmetrically opposite top and bottom, left and right, front and back (Fig. 3, symmetrical both in size, position, shape) [4, 10]. This is a notable feature of biomimetic robots. It has capable to move steadily, flexibly and minimize the phenomenon of falling, overturning thanks to its symmetry. If the robot falls or overturns, C legs will always touch the ground, so it can keep moving without waiting for rescue. From Fig. 3 shows:

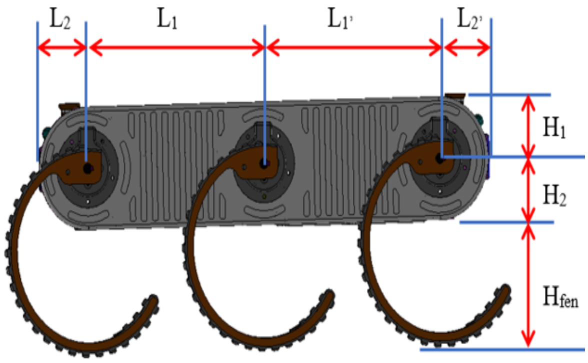

Fig. 3. Symmetry

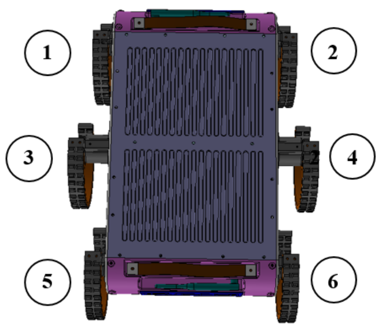

Fig. 4. C legs order

$$H_1 = H_2 \Rightarrow H = H_1 + H_2 \Rightarrow H = 2H_1 \tag{1}$$

and

$$\left.\begin{cases} L_1 = L_1' \\ L_2 = L_2' \end{cases}\right\} \Rightarrow L = L_2' + L_1' + L_1 + L_2 \Rightarrow L = 2(L_1 + L_2) \tag{2}$$

2.2 Dynamic equilibrium

Biomimetic robot's chassis and case designed for dynamic balance. Symmetrical positions are designed the same (both in shape, size and using the same material); components such as batteries, motors, etc. are also arranged inside its case so that the robot's weight is evenly distributed over its entire horizontal flat area. At the same time, its two heads are rounded, both top and bottom smoothed to minimize environment's resistance. Dynamic equilibrium is also shown by the robot using 6 C legs, at least 1 pair (leg no. 1, 4, 5 or 2, 3, 6) touches the ground at all times (Fig. 4) [4, 9].

2.3 Move like a monkey "clinging hands"

This is a remarkable feature of biomimetic robots, and that's why it called a biomimetic robot. Robot's legs are designed C-shape, one end is attached to the motor shaft (Fig. 4). Because the motor shaft mounted in the middle of the cover (H1 = H2), the effective height (Heff) of the robot reduced by H1 (compare to the motor shaft installed under the robot) and calculated by the formula:

$$H_{eff} = H_{leg} + \frac{H}{2} \Rightarrow H_{eff} = H_{leg} + H_1 \tag{3}$$

When moving, pairs of legs no. 1, 4, 5 and 2, 3, 6 take turn rotating. When legs no. 1, 4, 5 touch the ground, legs no. 2, 3, 6 leave the ground (turn up) and vice versa (Fig. 4). Therefore, the highest position of the foot (when legs turn upwards) will be:

$$H_{\max} = 2H_{leg} = H_{eff} + H_{fen} \tag{4}$$

The (4) indicates that $H_{\max} > H_{eff}$ C legs can reach obstacles that are taller than the height of the robot (in other words, it can move like monkey styles with hands clinging). At the same time, due to the way the hands clinging, C legs are not often touch the ground (but only in contact with grounds about a quarter of the length of the foot); Therefore, the robot is less affected when traveling through uneven terrains [10].

3 Technical Proposal for Calculating and Designing Biomimetic Robot

Unlike traditional robots, biomimetic robots move with 6 C legs therefore its legs are not allowed to entangle with each other. At the same time, to move flexibly across many types of terrain, robots must ensure characteristics presented in Section 2. In addition, depending on each task robots have to carry out (climbing stairs, wading...), components (especially motors), size of covers and C legs are also different. Therefore, to ensure the accuracy, reduce calculation time and design, in this section, the author presents some calculation techniques to design biomimetic robots' C legs and covers.

From Fig. 1, 3 and formulas 1 and 2, we see that basically the smaller values of L, H, W is, the smaller, more secret and flexible to move a biomimetic robot is. However, L, H, W depends on cover materials, purposes of the robot, as follows:

3.1 Calculate the width (*W*)

W depends on components installed in the robot (especially motor).

The motors often placed horizontally and symmetrically (Fig. 5) so:

$$W \geq 2L_{motor} \tag{5}$$

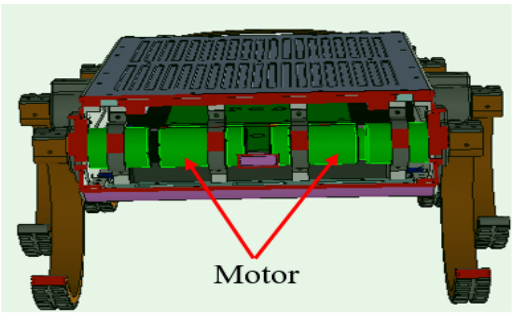

Fig. 5. Installing motors in a robot

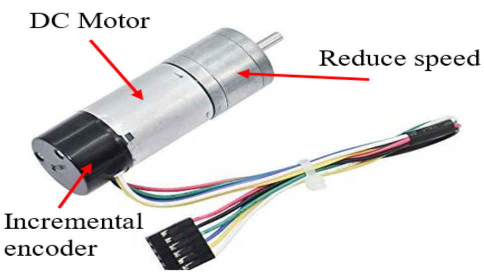

Fig. 6. Components of motor

In which Lmotor is the length of rotating legs motor (including motors, gearbox and encoder) of the dynamic robot (Fig. 6). Therefore, if you want a biomimetic robot with small size, you must choose a small motor but still meet requirements of rotation speed (Vmotor), voltage (Umotor), torque.

Normally for the convenience of wearing biomimetic robot on a person's back the W is usually chosen W ≤ 45 cm.

3.2 Calculate the height (*H*)

H depends on the diameter of motors and boards, components and batteries installed in the robot housing, so H must be larger than the diameter of motors (Dmotor).

$$H \geq D_{motor} \tag{6}$$

Normally choose H within the range of 7.5 cm to 12 cm, and let the robot balanced at the same time then $H_{leg}/2 \geq H \geq D_{motor}$.

3.3 Calculate the Height of C Legs (H_{leg})

+ Method 1 (Calculate Hleg according to the height of the obstacle (Hmax) that the robot can climb):

From Fig. 3 we have:

$$H_{leg} = H_{fen} + H_2 \tag{7}$$

From (7) shows that H_{leg} depends on ground clearance (H_{fen}) and robot's *H*. It is necessary to base on the terrain that biomimetic robots have often to operate and determine the H_{fen} needed for it easily move through low obstructions (obstructions with height ≤ H_{fen}) before determining H_{leg} according to (7).

In addition, when calculating H_{leg}, it is necessary to base on the maximum height of obstacles or stairs that the robot can climb (H_{max}). From (4) we have:

$$H_{leg} = \frac{H_{\max}}{2} \tag{8}$$

In fact, if C legs can grip and rest on the obstacle so that the robot can climb over and through obstacle fields, the actual height of C legs (H_{leg1}) must be larger than H_{leg} (meaning the actual obstacle height. (H_{max1}) that the robot climb are lower than H_{max}). From Fig. 7 you can see:

$$H_{\max 1} = H_{leg1} + \frac{H_{leg1}}{2} \tag{9}$$

Therefore, the actual height of the C-shaped legs must be calculated by the following formula:

$$2H_{\max 1} = 3H_{leg1} \Rightarrow H_{leg1} = \frac{2}{3}H_{\max 1} \tag{10}$$

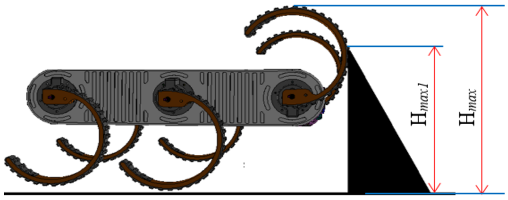

Fig. 7. Description of C leg when climbing

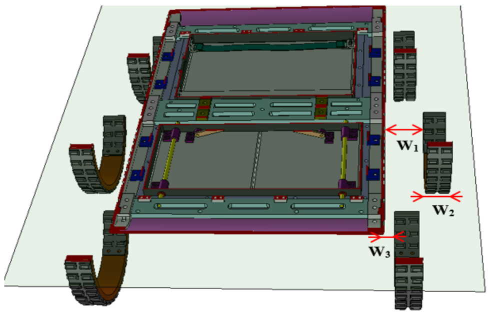

Fig. 8. The gap between legs and the cover

+ Method 2 (Calculate Hleg1 according to the water depth (Hwater) that the robot is expected to move through):

- Case 1 (Biomimetic robots cover is not watertight): The depth of water (Hwater1) that the robot can move through will be equal to the ground clearance (Hfen):

$$H_{water1} = H_{fen} \tag{11}$$

Then Hleg1 is calculated according to (12)

$$H_{leg1} = H_{water1} + \frac{H}{2} \tag{12}$$

- Case 2 (Biomimetic robots' housing is watertight, non-watertight motor shaft): Then the robot can move through the depth of wetland (Hwater2) to the motor shaft.

$$H_{water2} = H_{fen} + H_2 \tag{13}$$

Then Hleg1 is calculated according to (14):

$$H_{leg1} = H_{water2} \tag{14}$$

- Case 3 (Robot cover and watertight motor shaft): At that time, the robot's ability to submerge does not depend on H_{leg1} (but the ability to withstand high pressure of the cover and the ability to remote control when the robot drowned). In this case, H_{leg1} can be calculated using formula 10.

3.4 Calculating the Length (*L*)

From Fig. 3 we have:

$$L = L_{2'} + L_{1'} + L_1 + L_2 \Rightarrow L = 2\left(L_1 + L_2\right) \tag{15}$$

Calculate Segment L2' = L2: $L_{2'} = L_2$ is the beginning and the end of the robot. To make C legs reach above the obstacle (when climbing stairs or steps) then $L_{2'} = L_2 < H_{leg1}$. In fact, in order to have C legs with and rest on the obstacle the best (Fig. 7), L_2, $L_{2'}$ are chosen as follows:

$$L_{2'} = L_2 = \frac{H_{leg1}}{3} \tag{16}$$

3.4.1 Calculate Segment $L_1 = L_{1'}$

Case 1 (do not extend the motor shafts no. 3, 4): Then motors 3, 4 must be pushed out to C legs no. 3, 4, so the segment L_1, $L_{1'}$ will have an additional D_{motor} interval (Fig. 4). To ensure that C legs no. 1, 2, 5, 6 do not touch motors during the rotation of C legs then:

$$L_{1'} = L_1 = H_{leg1} + \frac{D_{motor}}{2} + D_{case} + D_{slot} \tag{17}$$

Therein D_{case} is the thickness of the cover (at the position of motor 3, 4), D_{slot} is a safe gap so that when the C-leg is stretched, it cannot touch motors no. 3, 4. D_{slot} depends on the form of C legs, if the leg is hard type, D_{slot} is usually small (D_{slot} = 1 cm to 2 cm); if the leg is soft type, the D_{slot} is usually larger (D_{slot} = 2 cm to 3 cm).

Combining (17, 16, 15), L is calculated by the following formula:

$$L = 2\left(\frac{H_{leg1}}{3} + H_{leg1} + \frac{D_{motor}}{2} + D_{case} + D_{slot}\right) \tag{18}$$

Case 2 (extension motor shafts no. 3, 4): Motors no. 3. 4 are still installed in the normal housing (such as motors no. 1, 2, 5, 6) but only the shaft is extended outside the housing. Then D_{motor} will be replaced by the diameter of the motor shaft (D_{shaft}) and due to no need of motor shaft cover, $D_{case} = 0$. From there the formula (18) will be rewritten as follows:

$$L=2\left(\frac{H_{leg1}}{3}+H_{leg1}+\frac{D_{shaft}}{2}+D_{slot}\right) \tag{19}$$

3.5 Calculate the segments W_1, W_2, W_3

From Fig. 8 we see the C legs are arranged disparity and have a gap W_3 with the cover, while W_2 is the width of the leg. From Fig. 8 we have:

$$W_1 = W_3 + W_2 + W_3 \Rightarrow W_1 = 2W_3 + W_2 \tag{20}$$

From (20) shows that W_1 depends on W_2 and W_3; in which: W_2 depends on following factors: robots' weight (M) (W_2 is proportional to M); C legs types (if legs are soft, W_2 will have to be large). W_3 also depends on the following factors: C leg types hard or soft (if the leg is soft, it will fluctuate horizontally so W_3 needs to be large); It is expected that obstacles (trees, grass ...) may be stuck in the W_3 slot (if the robot works in a terrain with taller plants than H_{leg1}, W_3 must be larger than the diameter of that plant). Experiments show that: With $M \approx 15$ kg, $W_3 \approx 2$ cm (with a hard C leg) and $W_3 \approx 3$ (with a soft C leg). W_2 gap is usually chosen at about 1 cm to 2.5 cm.

4 Experimental Results and Evaluation

To demonstrate the above mentioned methods and techniques, the author has calculated, designed, processed the robot case and tested with input parameters: Using motor with parameters: $L_{motor} = 21$ cm, $D_{motor} = 4.5$ cm, $V_{motor} = 960$ around/minute, $U_{motor} = 24$ V/DC, $K_{motor} = 139/1$. Expected staircases $H_{max1} = 30$ cm that the robot would have to climb. Ground clearance for the robot to easily pass through low obstacles $H_{fen} = 16$ cm. Cover thickness $D_{case} = 0.2$ cm, without extending motor shafts 3, 4 and watertight to motor sharps, the robot can move through the flooded area with a depth of $H_{water1} = 20$ cm. A C leg is made of hard material (steel spring); the weight is expected $M \approx 15$ kg; the terrain with small trees has diameter ≤ 0.5 cm.

From the above parameters, the author has calculated the dimensions of the robot as follows:

+ Calculate W: From (5) $W \geq 2L_{motor} \Rightarrow W \geq 2 \times 21 \Rightarrow W \geq 42 \Rightarrow Select\ W = 43$ cm

+ Calculate H: From (6): $H \geq D_{motor} \Rightarrow H \geq 4.5 \text{ cm} \Rightarrow \text{Select } H = 8 \text{ cm}$

+ Calculate H_{leg1}: From (10): $H_{leg1} = \frac{2}{3}H_{\max 1} \Rightarrow H_{leg1} = \frac{2}{3}30 \Rightarrow H_{leg1} = 20$ cm (for the robot climbing 30 cm), At the same time applying (14) will have $H_{leg1}=H_{water2}=20$ cm (for the robot to move through a 20 cm deep wetland). Combining the two cases above choose $H_{leg1} = 20$ cm.)

+ Calculate L: From (18) and select $D_{slot} = 1$ cm:

$$L = 2\left(\frac{H_{leg1}}{3} + H_{leg1} + \frac{D_{motor}}{2} + D_{case} + D_{slot}\right)$$
$$\Rightarrow L = 2\left(\frac{20}{3} + 20 + \frac{4.5}{2} + 0.2 + 1\right)\text{cm} \Rightarrow L = 60.3\text{ cm}$$

In which, according to (16, 17) segment $L_2 = L_2' = \frac{H_{leg1}}{3} = 6.7\text{ cm}$, segment

$$L_1 = L_1' = H_{leg1} + \frac{D_{motor}}{2} + D_{case} + D_{slot} = 23.45\text{ cm}$$

+ Calculate W_1, W_2, W_3: Based on given terrains, choose $W_2 = 2$ cm, $W_3 = 2$ cm, from (20) there will be $W_1 = 2W_3 + W_2 = 6\text{ cm}$.

As results mentioned above, the author has designed and processed mechanical parts (aluminum and synthetic materials) to assemble biomimetic robots' cover. In addition, the author also used motor control modules, Pic microchip from Microchip - USA to control the robot in operation. The robot is proceed to moving at the terrain: flat terrain (Fig. 9), assess the ability and speed of movement (V_{rhex}); terrain is covered with vegetation (Fig. 10), assessing the distances W_1, W_2, W_3; High-level terrain with water (Fig. 11), assessment of climbing ability (H_{max1}), amphibious (H_{water}) of the robot to compare with the initial requirements.

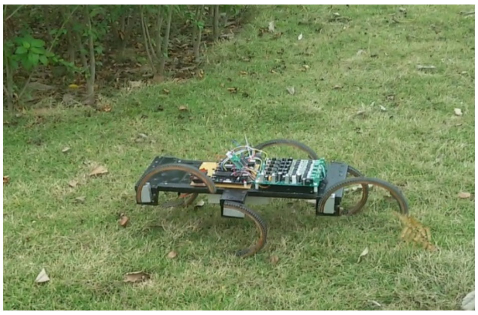

Fig. 9. The robot moves in the flat area

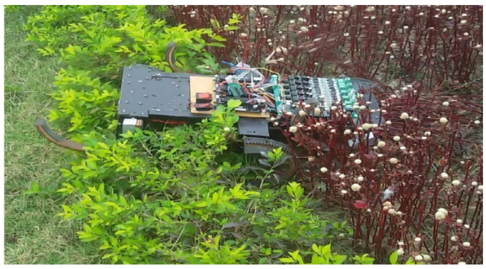

Fig. 10. Robot moves in the rass-covered area

Fig. 11. Robot moves in sand and gravel terrain

Fig. 12. Ability to climb and wade

The test shows that the robot moved (forward, backward, turn left, turn right) flexibly and overcome many kinds of complex terrain.

When the robot move on the flat road (Fig. 9): 1) the robot can reach speeds of 9 km/h (forward movement) and 7 km/h (backward movement); The speed of turning left and right is slower than the speed of forward and backward. Those speeds achieved thank to using motors with V_{motor} = 960 around/minute, deceleration with K_{motor} = 139/1, C leg with H_{leg} = 20 cm; so in the C leg nominal mode, it will turn around/minute, combined with embedded software to adjust the C legs position to get the moving speed of the robot as required. 2) Obstacles with width < the robot's width (< 43 cm) and height < ground clearance (< 16 cm) hardly affect the moving process. This is because the robot has a ground clearance of H_{fen} = 16 cm, a C leg has a width of W_2 = 2 cm, because the foot rotates upwards, so the time the C leg is in contact with an obstacle is less affected by low and small obstructions.

When robots moves on grass, covered trees (Fig. 10): 1) If grass, tree is soft robots will overlap it (C legs still touch the ground) and move as normal as on a flat road. This is because the C leg is only W_2 = 2 cm wide, H_{leg} = 20 cm so it is easy to rotate the grass and trees to contact the ground, pushing robots to move. 2) If the grass or tree is hard, the robot will float to the surface of the grass, the tree (the C legs do not touch the ground) and the robot can still move forward (because the C leg is a curved shape so it creates a force), lift and push forward). However, moving back, turn left, turn right will be difficult and the speed of travel will be significantly reduced compared to when moving on a flat road, however the robot can still move (not entangled or entangled or stuck).

When the robot having tested to move on sandy terrain (Fig. 11), its's legs still cling to the ground well, do not slip and the process of moving forward, backward, left turn, right turn normal (due to the C shape leg is a curved form).

The robot moves well in some other terrains (Fig. 12): The terrain has vertical steps of 30 cm high (due to K_{motor} = 139/1; H_{leg} = 20 cm so legs can reach at H_{max} = 40 cm); The terrain is deeply submerged by 20 cm (because H_{fen} = 16 cm and about H_2 = 4 cm is not affected by water); The terrain has a slope of about 45 degrees (due to K_{motor} = 139/1, using C legs to bend up when rotating the coordinates to lift, push the robot forward).

However, the test also found, when climbing a slope or moving into flooded areas, the robot speed must be slow to avoid slipping or water splashes on the boards on the robot's back. On the contrary, when climbing to higher levels, it is necessary to have a higher speed. The vertical step is as high as ≈ 50 cm, so the robot can still climb (by 2 feet up the step).

5 Conclusion

Biomimetic robots with ability to move flexibly, promising wide application potential is currently received attention from scientists. However, the calculation of the design and manufacture of this robot is relatively complicated and is being researched and solved by scientists. In this paper, the author presented an overview of biomimetic robots, outstanding features compared to other robot models; At the same time, the author has proposed techniques and methods to calculate the size of biomimetic robots' body and legs according to needs and purposes. From the results of analysis and calculation, it is necessary to determine the parameters V_{rhex}, M, V_{motor}, K_{motor}, D_{motor}, L_{motor}, D_{case}, H_{fen}, H_{max}, H_{max1}, H_{water1}, H_{water2} before performing calculations and designing body, legs parts. Experiments show that the above mentioned techniques and methods are feasible; biomimetic robots can move and climb terrain and high levels according to the initial requirements. However, there are some limitations (not including the detail of the C legs section), the proposed techniques and methods have contributed to solving the difficulties in calculating and designing feasible.

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