Algerian Journal of Environmental Science and Technology
June edition. Vol. 9. Nº2. (2023)
ISSN : 2437-1114
www.aljest.org

Flaping wing mechanism and Remote monitoring of biomimetic micro robot.

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ARTICLE INFO

Article History:

Received **: 01/02/2021**
Accepted **: 04/09/2021**

***Key Words*:**

Biomimetic;
Micro-robot;
Remote-Monitoring;
Environnement;
Printable Material;
Mechanism;
Wing.

ABSTRACT/RESUME

Abstract: *The microrobot is suitable for the remote monitoring of forests fires°. In addition, it can give real-time alarm of saturated harmful gazes. The article describes typical biomimetic butterfly characteristics and compares them qualitatively with those found in biological counterpart. The article presents a biomemitic micro robot inspired by butterflies for remote monitoring. The flying micro robot is created based on 3D printable material of "Poly Lactic Acid" (PLA) and PolyDiMethileSeloxane (PDMS). The present paper underlines two independent and variable parameters; the constraint of the aerodynamic parameters on the flying micro robot and the remote monitoring scanned space. The chosen flying model represents in a logical and unified way many of the fundamental characteristics of the micro robot behavior. These characterisctics have been treated separately to acquire an optimal flight for maximum distance. As the experimental data are still limited, the model was simplified as much as possible and modeled by finite elements in COMSOL multiphysics CAD tool in order to provide a basic framework from which the boundary conditions and the flying characteristics are determined. The results of the flying mechanism, the wings and the remote monitoring are studied and discussed in order to assess the ability of the micro robot to fly. The observed and calculated results agree well, and they confirm the possibility of flying the biomimetic butterfly very similar to the naturel one.*

I. Introduction

Micro robots have many applications in environmental monitoring [1-2] including the monitoring of forests, climate, plantations or even research missions to help rescue teams. In this article, we propose a biomimetic micro robot for detecting and monitoring hazardous events in real time. Our research shows that it is possible to produce a wide range of micro robots inspired by nature with minimal environmental effects due to the use of biodegradable material [3]. The butterfly seems a strange insect for researchers to study and until recently no one knew how butterflies fly [4]. Furthermore, scientists have shown that butterflies have a valuable impact with their flying on the environment [5] with their air filtering capability. Certain characteristics such as the construction of the mechanism and the wings influence on small-scale processes. Others have much broader effects, such as surveillance cameras and sensors. Our results reveal a stable optimized micro robot capable of accomplishing different tasks.

II. Materials and methods

II.1. Mechanism Analyses

The choice of the flying mechanism underlines the performance compatibility between the micro robot and the butterfly. In this study, different models were considered. The first one was a common pattern in several patents and articles [6] designed only to mimic flight (fig.1). Figure 2 shows s our first idea of a flapping wing mechanism based on a spring fixed to the body from a side and to the wing on the other side. The wing side will be in contact with a pulley connected to the micro rotator. This contact will give us a wing beat. Then, figure 3 demonstrate the chosen model which is a refined and simplified ornithopter.

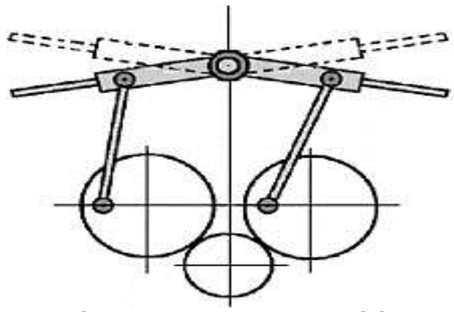

***Figure 1**. Flapping wing common model*

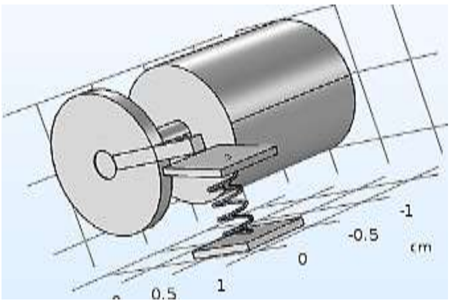

***Figure 2.** First designed model*

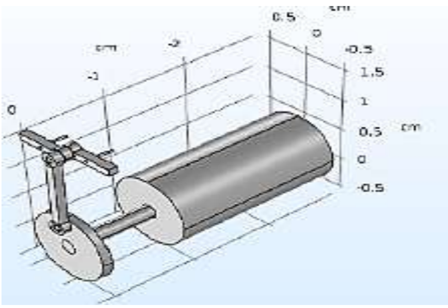

***Figure 3.** The chosen model*

The mechanism is modeled using the COMSOL Multiphysics CAD tool for the simulation of the stresses applied to the micro motor and the structure according to the appropriate thermal and physical conditions. Based on desired characteristics, we seek to find a match with our 3D printable materials and the behavior of the micro robot.

To determine the necessary conditions, we have chosen solid rotator physics. The following table indicates the initial choice of the micro motor according to a frequency comparison, the modeled structure, and to the circuit support.

***Table 1.** Micro robot characteristics*

	Butterfly	**Micro robot**
Weight (g)	0.5	49
Beat frequency (Hz)	1048	1080
Measurement (cm)	6-12	3

The influence of the structure carried on the micro rotator encourages a careful choice because several factors come into play such as the weight, the temperature, the material, and essentially the needed force for take-off.

The starting force is essential by the fact that the inertia and the friction contribute to a contrary forcewhich can be higher and blocks the takeoff. So, according to the first law of Newton "principle of inertia" and the second law the fundamental principle of the dynamics" by considering rate of force development (RFD)translation [7].

The choice of motors is based on their efficiency, defined by the number of revolutions that the motor can make in 1 minute and for 1 volt. This value is expressed in Kilo Volt noted KV. The larger the KV of a motor, the better its efficiency and therefore more energy efficient. Therefore, it is intimately linked from the first point to the choice of the battery. So, we are using a lipo lithium batterie of 3.74V and 1g of weight.

Therefore, in another hand the weight of the micro robot needs to be considered. Knowing that we are visualising a micro robot of 50g.

If we call ***dL*** the distance traveled in a small-time interval ***dt***, then we write:

$$S = \frac{dL}{dt} \quad (1)$$

Starting from the fact of acceleration we know that:

$$Acc = \frac{dS}{dt} \quad (2)$$

Or ***Acc*** is the acceleration, ***dS*** is the elementary speed traveled in a small-time interval *dt*.

Knowing that in a Galilean frame the body accelerates to a proportionality with the resultant force and another inverse to the mass of this first. In other words, this RFD is written:

$$\sum F = m.\frac{dS}{dt} \quad (3)$$

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Then, for a stable flight we need to procure a force that's higher than gravity, ie F_{flight} > gravitational force.

For a weight m = 50 (g), at flight height (Lift) of 1 m at displacement (Drag) of 1m/s of micro robot, the resultant of force then becomes:

$$F = m\,g \tag{4}$$
$$W = m\,g\,h \tag{5}$$

Where **m** the microrobot mass, **g** the gravity, h the height of the microrobot.

As a result, we use Newton's third law, the principle of reciprocal action, as a basis for energy counter-reaction. We do not need to overcome friction forces. As for angular velocity:

$$w = \frac{2\pi N}{60}\left(\frac{rd}{s}\right) \tag{6}$$

With ***w*** the angular speed of the rotator and ***N*** its rotational speed per minute. So, his acceleration becomes:

$$Acc = \frac{dw}{dt}\left(\frac{m}{s^2}\right) \tag{7}$$

And by applying the first law, the micro robot will continue to fly. In this regard, the rotator dynamics is involved following the physical laws to give an optimal beat to end up flying the micro robot is as follows:

$$J = \frac{1}{2}\,mr^2 \tag{8}$$

Where, ***J*** the inertia of the rotator, ***m*** its mass, and ***r*** its radius.

By now combining (7) and (8) the starting torque ***Cd*** then remains:

$$Cd = J.\frac{dw}{dt} \tag{8}$$

Finally, the resulting power of the micro rotator needed to lift the micro robot is:

$$P\,(Watt) = Cd.w \tag{9}$$

Then the effort provided by the micro rotator becomes:

$$P = C(m)w(m) = C(p)w(p) \tag{10}$$

Where ***C(m)*** the motor torque, ***w(m)*** motor angular rotation, ***C(p)*** beat torque, ***w(p)*** beat speed.

$$w(m) = \frac{C(p)w(p)}{C(m)} = \frac{P}{C(m)} \tag{11}$$

$$w(m) = \frac{224}{0.0143} = 15660.8\,rd/s$$

For our chosen reel monarch butterfly:
C(p) = 44.8
w(p) = 5 rd/s
For commercial micro motors.
C(m) = 0.014
Then, after conversion we need a 149549.6 RPM micro rotator to allow the robotic robot to fly as normally as possible.

The COMSOL Multiphysics software is used to determine the speed profile of the micro rotator on the structure. Based on the assumption that the final motor effects are neglected, a visual solution to the equation of motion can be obtained for the speed profile and determine its required power. The modified parameters include the radius of the rotating cylinder, the speed of rotation, and the kinematic energy of the micro-motor. For that we used multiphysics under COMSOL combining the structural mechanics and the dynamic rotation of solids in order to control the axes of rotations. The combination simulates the behavior of the rotor and its direction. This may include the beat frequencies, as well as the optimum rotational speed to avoid critical vibrations that can unbalance the contact between the structure and the micro motor. This study helps establish conditions within acceptable operating limits.

Figure 4. *Physics related to the mechanics of structures*

The approach imposes a rotation on the micro-motor, to identify the disturbance, then to test several speeds in order to find the point of equilibrium in a way to stabilize the operation. We will consider in our tests that we will impose a rotation of 150000RPM as concluded in the analytical part. The bottom of the micro motor is fixed with a zero-displacement condition. The force will be applied over a width of 1 m in a time interval of 60 s. Finally, we identify the

speed and maximum displacement that will allow us to quantify the resistance of our structure according to the 3D printable material.
According to the tests carried out for the selected micro-motor, we noticed a significant heat release influencing the 3D printable materials. The constraint is validated under COMSOL. The finite element analysis to reproduce the thermal profile obtained from the heating of the micro-motor instigates a heat transfer which modifies the resolution of the 3D printable structure. The materials used are Acrylonitrile Butadiene Styrene (ABS), Polylactic Acid (PLA), and Polydimethylsiloxane (PDMS). We then established an elasticity ratio which determines the suitable material. For this we compared some parameters differentiating the materials used.

Table 2. *Materials characteristics*

	ABS	PLA	PDMS
Young modulus (GPa)	2.1-2.4	2.7-16	0.2
Poisson Coefficient	0.35	0.34	0.5
Density (g/cm^3)	1.05	1.25	1.1-1.5
Temperature of degradation (°C)	70	175	280-350

This study also analyzes the thermal excitation of the structure of the micro rotator, in order to minimize it.

The combination of physics required to simulate our structure depends on several factors and may include boundary conditions, material properties, physical interfaces, and imposed effects of components.
Finally, the thickness of the structure can compromise the operation of the micro-butterfly since it allows adding additional weight. In this way, we make comparisons of the same material with different thicknesses.
To further develop and strengthen our research we have established a connection point between the PLA or ABS being rigid and the PDMS being flexible to have consistent printable structures in order to better adhere to the constraints and boundary conditions of our micro robot. To achieve this structure, it suffices to cover the ABS or the PLA with PDMS respecting the dimensions, therefore, without any modification of shape or size or weight. Indeed, we analyze the degradation of the structure due to the temperature released by the micro rotator.

II.2. Surveillance Analyses

For the surveillance analysis, we are going to study the following elements:

- Finite element modeling where we study the space occupied according to different characteristics.
- The development of the communication circuit between the basestation and the artificial butterfly

The head of the butterfly micro robot will consist of two light CMOS image sensors. The first is thermal imager and the second gives a high definition 360 ° view. To model the distance occupied a WiFi or radio frequency transmission or satellite transmission is used to define the perimeter monitored by the micro robot. The following figure shows the multiphysics model used in COMSOL.

Modeling can be established around two axes: one on the distance traveled and the other on the camera characteristics. The flying microrobot can be used for injecting products, collect measures and store the or analyze environmental information.
Knowing that the micro robot can lift up to 50g at most, the choice of imagers and sensors must match this condition. The following table shows the various components and their characteristics.

Table 3. *Camera characteristics*

Weight (g)	12
Power supply (V)	3.7
Current (A)	0.28
Temperature resistance (C°	-30 to +70
Resolution	Full HD 1920 x 1200
Application	Capture - record
Power consumption (W)	0.66 -0.92
Model	e-CAM217_CUMI0234_MOD
Transmission mode	WiFi – IR – RF - Bluetooth

Table 4. *Thermal camera characteristics*

Weight (g)	9
Power supply (V)	3.7 - 5
Current (A)	0.2 - 0.3
Temperature resistance (C°	30 to 70
Resolution	Full HD
Application	Waterproof - night
Power consumption (W)	0.5 - 1
Model	IP 67 Compact IR
Transmission mode	WiFi – IR – RF

In this part, we will demonstrate the capacity of the micro robot to circulate in different places controlled remotely by using finite element modeling.
The idea is to integrate the imagers' transmission system in the entennas integrated in the head of the flying micro robot.Next step is to evaluate the distance acuried for flying under specific voltage. Then, the frequency transmission needed for remote monitoring and estimate the relation between this distance and the micro robot weight. As known before we start the evaluation with a weight of 50g, 3.7V, with neglected inertia.

III. Results and discussion

III.1. Flying Mecanism results

Through the results obtained analytically and those by finite elements, one can discover the necessary

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rotations to use for an optimal flight according to the conditions that can help design and refine a micro engine. In addition, one can use the model to evaluate the simulation results and further improve the designs.

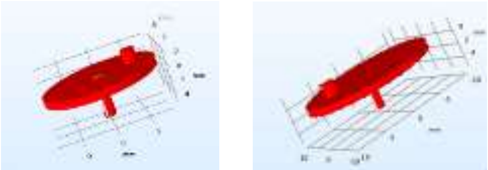

Figure 8. *Mechanism profile as function as Velocity: (b) 65000 Rpm (a) 150000 Rpm*

Fig 8 shows the speed profiles of the micro motor with different rotations from a COMSOL Multiphysics solution of a 3D model in which an inner cylinder (micro motor) rotates inside an outer cylinder (pulley) suitable to its movement. The rotation frequency fully develops after going through the time interval. The analytical solution for the case where the speed profile depends on the power of the structure corresponds well to those of the finite elements. A slight loss of rotation control and degradation forces us to choose the speed at 65000 RPM.

Regarding the influence of heat on the contructing materials, the results of finite element modeling allow to certify that the choice of material gives a better appearance when designing the micro robot mechanism. There is a deformation on the ABS particularly at the point of contact with the micro motor. However, PLA does not degrade at the same temperature unlikethe PDMS that comes off quickly because of its flexibility. It can also be seen that the temperature gradient increases with the speed of rotation. As a result, a spatially modified structure (size, weight) will exhibit a variation in behavior with respect to the circuit, which implies thermal excitation. To determine the combination that meets our structural modeling needs, all three factors require further study. Rotation determines contact disturbances, temperature and weight reduce performance. To sum up the mechanism that is supposed to fly is not stable.

The results are indicated on the following tabel illustrating the impact of heat and form to the behavior of the structure according to the material used.

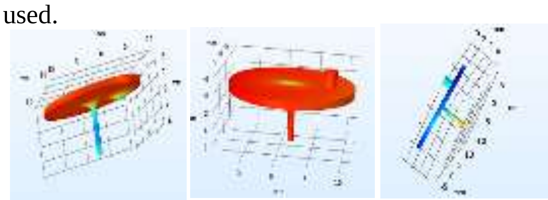

Figure 9. *3D Deformation profile: (a) ABS, (b) PLA, (c) PDMS*

The solution to these above-mentioned issues is suggested by mixing the rigid PLA with the flexible PDMS.

We went further into the study to see the influence of thickness on the flying mechanism. and we have found that the gear should not exceed 2mm, since the micro-rotator finds difficulty to operate due to the weight of the mechanism (Fig 10).

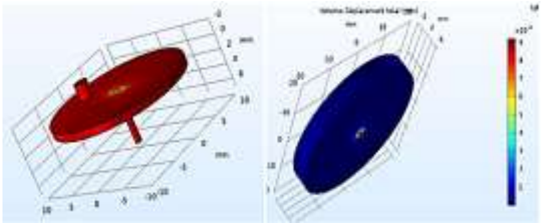

Figure 10. *Size thickness effect (a) 2 mm (b) 5 mm.*

III.2. Surveillance results

III.2.1 Suveillance connection

The modeled micro robot is inspired from monarch butterfly as commen pattents model and has several control and protection circuits. The guidance and remote monitoring system will be inserted in the head as shown in the following figures.

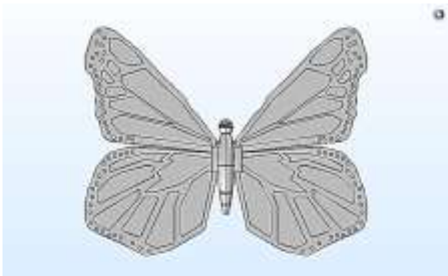

Figure 11. *Micro robot final modeling*

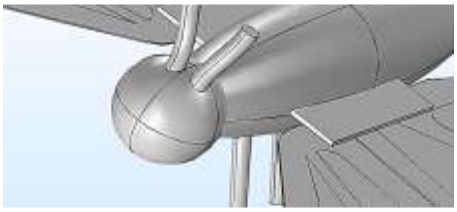

Figure 12. *Butterfly microrobot head*

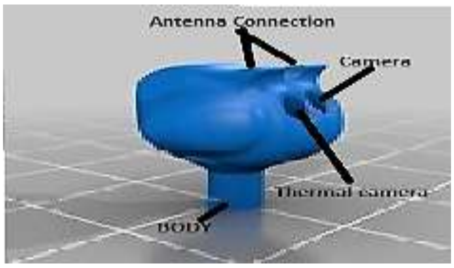

Figure 13. *Monitoring system connection.*

III.2.1 Perimeter and transmission

According to figure 14.b, for an initial speed of 1 m/s and a lifting load of 50g, the power voltage must be no less than 3.7 V. The results below show that the micro robot can move in a radius of 600 m

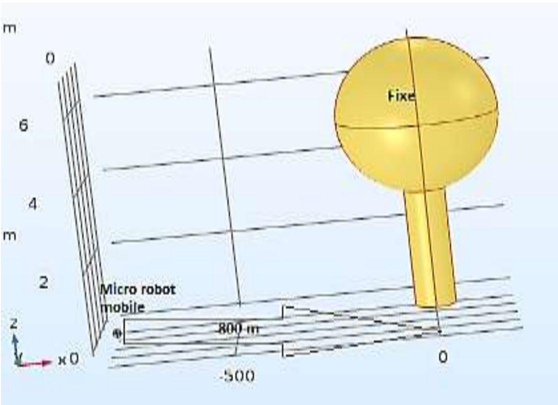

Figure 14. a. *Initial state of the micro robot*

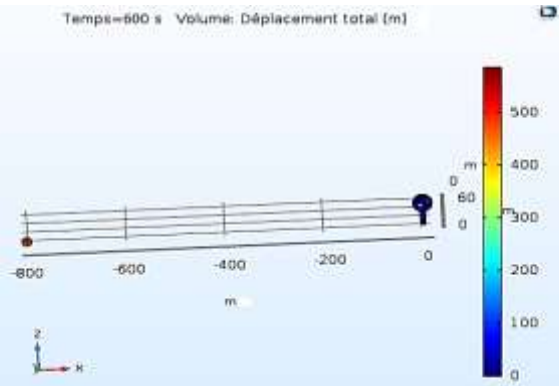

Figure 14. b. *Final position according to initiale conditions*

The lighter the load is, the farther is the displacement is. In this sense we have reduced the load and see how far the flying micro robot can travel. The following graph explains the relationship between the load and the travelled distance.

of transmission module, gas sensors and imagers can be supported by the microrobot as long as its weight does not exceed 50 grams. The next step is the assembly and testing of the microrobot for a multitude of monitoring tasks.

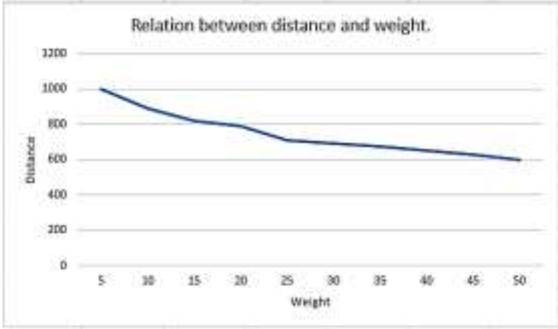

Figure 15. *Relaion between distance and weight.*

Therefore, we can say that the distance traveled is proportional to the energy consumed and inversely proportional to the load lifted.

Figure 15 shows the RF transmission frequency that can be exploited in the event of an obstacle, such as innodations, dimolings, earthquike etc…

This requires a minimum transmission RF sensor of 1.69 GHz for a distance of 6m between the transmitter and the receiver.

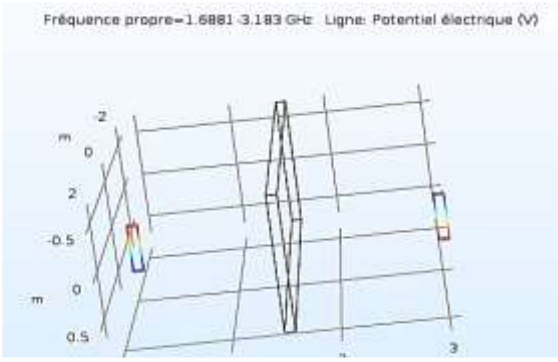

Figure 16. *RF Transmission frequency*

So, knowing that WiFi and Satelite are better than the RF transmitter we can deduce that the micro robot could send the information for more than 6m.

IV. Conclusion

In this work, we proposed a concept of a microrobot for environmental monitoring, where, the wing's architecture combined with 3D printablematerials that produce long distance flights, helping to monitor a large space. For the design study, we used the finite element method under multiphysics comsol. The microrobot flying mechanism and shape studied taking into account the weight of the sensors that can allow monitoring of the environment. The addition

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Please cite this Article as:
Kromba I., Soulimane S., Saffih F., Flaping wing mechanism and Remote monitoring of biomimetic micro robot, ***Algerian J. Env. Sc. Technology***, **9:2 (2023) 3086-3092**