MODELING THE EFFECTS OF EXTERNAL DISTURBANCES ON A QUADROTOR MINI-UAV

ZOARITSIHOARANA Fitiavana Avo Tongalafatra[1], RASTEFANO Elisée[2], HERINANTENAINA Edmond Fils[3]

[1] *PhD student, SE-I-MSDE, ED-STII, Antananarivo, Madagascar*
[2] *Thesis director and Laboratory Manager, SE-I-MSDE, ED-STII, Antananarivo, Madagascar*
[3] *Thesis co-director, SE-I-MSDE, ED-STII, Antananarivo, Madagascar*

ABSTRACT

With the progress of Technology, the use of Unmanned Aerial Vehicle called UAV is inescapable. Despite the fact that these machines are very useful, some problems can occur. There can be disturbances that can appears in different form. The main goals of this paper are to find the origin of some of the perturbations and to give solutions to avoid them. Indeed, when the UAV are in appropriate environment, they correctly receive the signals that are sent. So the UAV can carry out the required actions. However, if the environment contain disturbances, the UAV is affected. Therefore, it can't correctly receive the signals. These disturbances can be wind, rain, gravity or something else. In this article, some functioning principle of the quadrotor mini-UAV are explained. The analysis of the equation of movement is realized. The angles of Euler and the quaternions are therefore indispensable. In order to solve the problem of disturbances, we have to know something about it. Especially, we will see some information about how the wind comes about. So, we also give the effects of external perturbations like wind. We will see how it affects the UAV. Then, we will give some corrections to the effects of these external perturbations. All of that are possible thanks to the MATLAB software. As a matter of fact, an application is developed and written in M-files. The former equations are used in the programs. Graphic interfaces are built to facilitate the use of the application. The results are given as curves. These curves give first the operation of the UAV without perturbations. They also give the operation of the UAV with disturbances before and after the correction.

Keywords : - *Mini-UAV, quadrotor, gust wind*

1. INTRODUCTION

Drones perform movements according to equations with respect to different axes. For the case of quadrotors UAV, there are four motors. But the operation of these devices also depends on the environment in which they are and different conditions of this environment.

It is then necessary to make a study of different factors that may affect UAV. In this context, this paper will deal with the way some of these elements affect the behavior of a quadrotor mini-UAV by first passing through some operating parameters of the quadrotor mini-UAV.

2. EQUATIONS OF MOVEMENTS

The analysis of the movement of an object in space requires the definition of coordinates systems. Let $N(x_n; y_n; z_n)$ represent the coordinate system inertial such as unit vectors $(x_n; y_n; z_n)$ coincide respectively with the north, east and gravity directions.

The coordinate system attached to the object is represented by $B(x_b;\ y_b;\ z_b)$. The origin of this system is usually chosen from so that it coincides with the center of gravity of the object. The attitude of an object in space is expressed according to different representations whose choice depends directly from the intended application. [1]
Let $\vec{b}$ and $\vec{r}$ be the coordinates of a vector $\vec{x}$ expressed in *B* and *N* respectively. The vector $\vec{b}$ can be written in terms of the vector $\vec{r}$. Let $\vec{e}$= $[e_1\ e_2\ e_3]^T$ be a vector unitary collinear to the axis of rotation *L* around which *B* is turned from an angle so to coincide with *N*. As a result, $\vec{b}$ is obtained by:

$$\vec{b} = cos\beta\vec{r} + (1 - cos\beta)\vec{e}\,\vec{e}^T\,\vec{r} - sin\beta\vec{e} \times \vec{r} \tag{1}$$

We call simple rotation from B to N on movement of a coordinate system B compared to a coordinate system N, if there is a line L, called the axis of rotation, whose orientation with respect to B and N remains unchanged between the beginning and the end movement. The coordinates of $\vec{b}\ and\ \vec{r}$ are linked by the following transformation :

$$\vec{b} = C\vec{r} \tag{2}$$

The matrix C can be interpreted as an operator who takes a fixed vector $\vec{r}$ expressed in N and expresses it in B. From the expression, it follows:

$$C = \cos\beta I_3 + (1 + \cos\beta)\,\vec{e}\vec{e}^{\,T} - \sin[\vec{e}\times] \tag{3}$$

In this equation, I_3 represents the matrix identity of dimension three and $[\vec{\xi}\times]$ represents an antisymmetric tensor associated with the vector $\vec{\xi}$:

$$[\vec{\xi}\times] = \begin{pmatrix} \xi_1 \\ \xi_2 \\ \xi_3 \end{pmatrix}^{\times} = \begin{pmatrix} 0 & \xi_3 & -\xi_2 \\ -\xi_3 & 0 & \xi_1 \\ \xi_2 & -\xi_1 & 0 \end{pmatrix} \tag{4}$$

3. DESCRIPTION WITH EULER ANGLES

The angles of Euler (ψ, θ, ϕ) allow to describe in a simple way a rotation in three-dimensional space. [2]
The passage of a coordinate system $N(x;\ y;\ z)$ to a coordinate system using 3 successive rotations :

- precession (name given to the gradual change of orientation of the axis of rotation of an object), around the axis O_z, move from O_{xyz} to the referential O_{uvz} ;
- nutation (nutation is a periodic swing of the axis of rotation), around the O_u axis, passes O_{uvz} from to $O_{uwZ'}$;
- the clean rotation around the axis O_{zo}, from O_{uvz} to the axis system linked to solid $O_{X'Y'Z'}$.

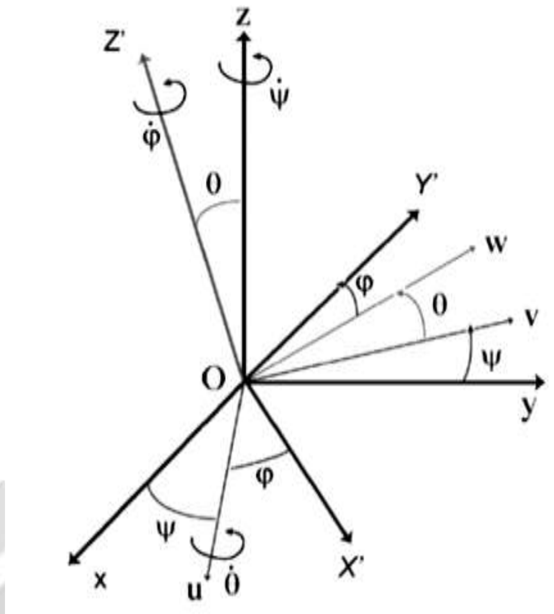

Fig -1 : *Angle of Euler*

4. QUATERNIONS

Another representation of the attitude is the unitary quaternion also called Euler parameter. Quaternion is a solution alternative to Euler's theorem, which states that a rotation in space can be made by a simple rotation around a rotation axis $\vec{e}$. [3]

The unitary quaternion is composed of a unit vector $\vec{e}$, named Euler axis and an angle of rotation around this axis. It is defined by:

$$q = \begin{pmatrix} \cos\frac{\beta}{2} \\ \vec{e}\sin\frac{\beta}{2} \end{pmatrix} = \begin{pmatrix} q_0 \\ \vec{q} \end{pmatrix} \in H \quad (5)$$

$$H = \left\{ q | q_0^2 + \vec{q^T}\vec{q} = 1, q = \left[q_0 \ \vec{q^T} \right]^T \right\}$$

$\vec{q} = [q_1 \ q_2 \ q_3]^T$ and q_0 are the part vector and the scalar part of the quaternion respectively.

The identity quaternion and the quaternion conjugate are defined by:

$$q_{id} = [1 \quad 0^T]^T \qquad \vec{q} = [q_0 - \vec{q}^T]^T \quad (6)$$

As the quaternion is unitary, $q^{-1} = \bar{q}$

5. GENERAL INFORMATION ON WIND GUSTS

5.1. Discrete Burst Function

The following relation describes the mathematical model of wind gusts.

$$V_{raf} = \frac{V_m}{2}(1 - \cos(\frac{\pi x}{L_u})t) \quad (7)$$

Where V_m represents the amplitude of the burst of wind (m/s), Lu represents the length of the gust (m) and x is the distance traveled (m). The length of the burst L_u is traditionally taken equal to 25 times the aerodynamic rope of the rotor blade principal of the drone $L_u = 25c_M$. [4], c_M is aerodynamic line of the UAV blade.

5.2. Function of the spectral density of PSD power

PSD (Power Spectral Density Functions) of a function x (t) is a real function which represents the average of the squares of values of the part of a given magnitude which goes through a narrow band filter of given center frequency ω, per unit of bandwidth when this width of band tends to zero and time to infinity [5].

$$\emptyset(\omega) = \lim_{\substack{\Delta\omega \to 0 \\ T \to \infty}} \int_0^T x^2(t, \omega, \Delta\omega) dt \quad (8)$$

$\emptyset(\omega)$ is the PSD of x. T is the duration in second. $x(t, \omega, \Delta\omega)$ is the component of x(t) which is in the band of frequency range $\omega \pm \frac{\Delta\omega}{2}$.

5.3. Representations of continuous bursts

There are two analytical representations about the PSD of the atmospheric disturbance that are used frequently in the control of flight systems. The first is the spectrum of Von Karman. It is the best spectrum obtained during tests under atmospheric disturbance but its use is less easy because it represents a complicated PSD function. It is defined by the equation:

$$\emptyset_{VK}(\Omega) = \frac{\sigma^2 L[1 + 8/3(1.339L\Omega)^2]}{[1 + (1.339L\Omega)^2]^{11/6}} \quad (9)$$

Where L is the length of the burst expressed in m, σ is the burst density in m / s.
The second is the spectrum of Dryden, used the most because it is simple and easy to implant:

$$\emptyset_{VK}(\Omega) = \frac{\sigma^2 L(1 + 3L^2\Omega^2)}{[1 + L^2\Omega^2]^2} \quad (10)$$

6. EFFECTS OF EXTERNAL DISTURBANCES ON THE MINI UAV

6.1. Effect of wind on the mini-drone

The goal is to integrate a wind model in the mini-UAV model. We use the discreet model of the gust of wind that one will program to impact the model of a mini-drone obeying equations of speed that follow [6].

$$V_x = t - a * cos(t) \quad (11)$$

$$V_y = b * t \quad (12)$$

$$V_z = t + a * cos(t) * sin(t) \quad (13)$$

The application in question allows to do simulations to get curves representing the operation of the UAV according to the coefficients of amplitude entered. And then corresponding curves when the mini drone is subject to wind gusts is given. We can also see simulations in 3D. **Fig -2** represents the first interface of the application.

Fig -2 : *First interface of the application under Matlab*

It contains several options including entry amplitude coefficients for the values of a and b, the input of the values of position vector for x, y and z. By default, standard values are assigned to each parameter and we can directly validate or give our own parameters.

Physically and concretely, the amplitude coefficients a and b have respectively the roles to amplify the sinusoidal movements on the x-axis and z, and to increase the speed with respect to time on the y-axis.

The initial parameters used such as amplitudes a and b correspond to :

$$\begin{cases} a = 15 \\ b = 1 \\ x = 0 \\ y = 0 \\ z = 1 \end{cases} \quad (14)$$

The application interface of these parameters is given in **Fig -3**.

Fig -3 : *Initial values of the parameters*

Fig -4 gives the curves representative interpreting the behavior of the mini-drone when it is not yet subject to disruptions.

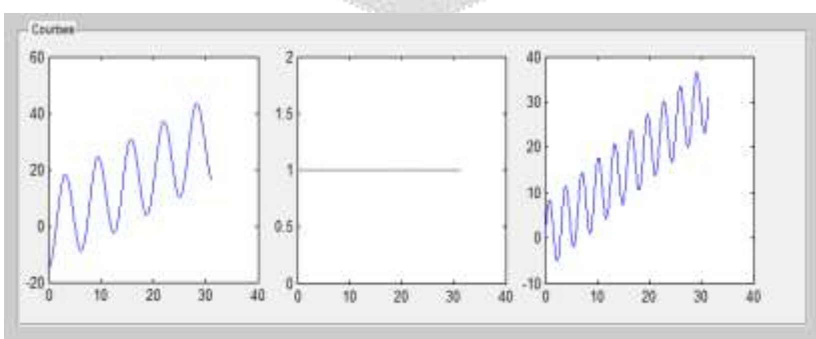

Fig -4 : *Curves whitout disturbance*

We see that the results are good in accordance with the initial equations. What means that the signals are correctly interpreted by the mini-UAV. We notice that in the second curve, we have a horizontal asymptote whose value is equal to 1. This is due to the coefficient of amplitude b which is equal to 1 at the input. In fact, the speed with respect to the y-axis corresponds to the value of b multiplied by the time.
When we will submit the mini-drone to effects of the wind, we will see that this one receives with difficulty the signals sent and therefore has difficulty in responding the equations.

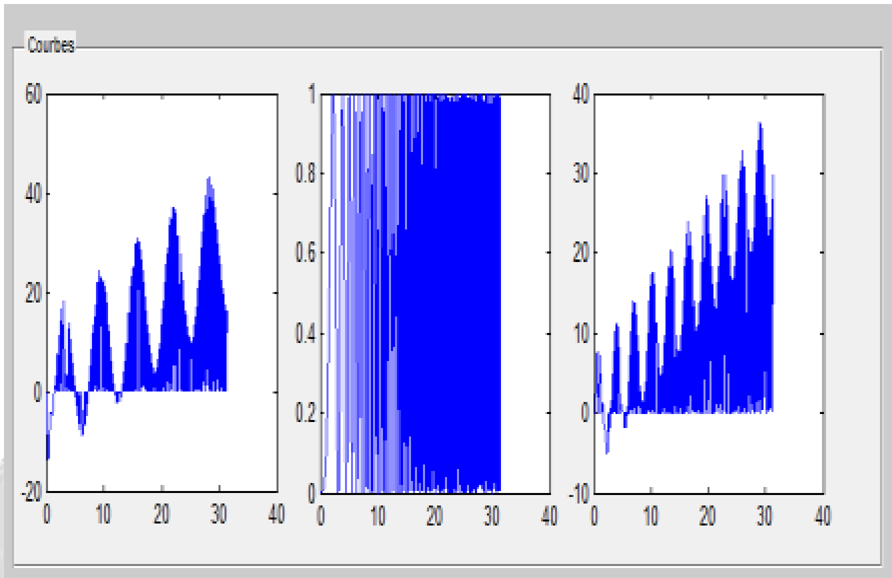

Fig -5 : *Curves with effect of the wind*

The superposition of the curves allows see this difference better. We observe that when the wind disturbs the mini-drone, the signals behave in such a way as to imitate the basic signals but that to get there, they go through various oscillations. That can deflect the mini-UAV from its target. Over several kilometers, this is likely to be fatal to the smooth running of missions assigned to it.

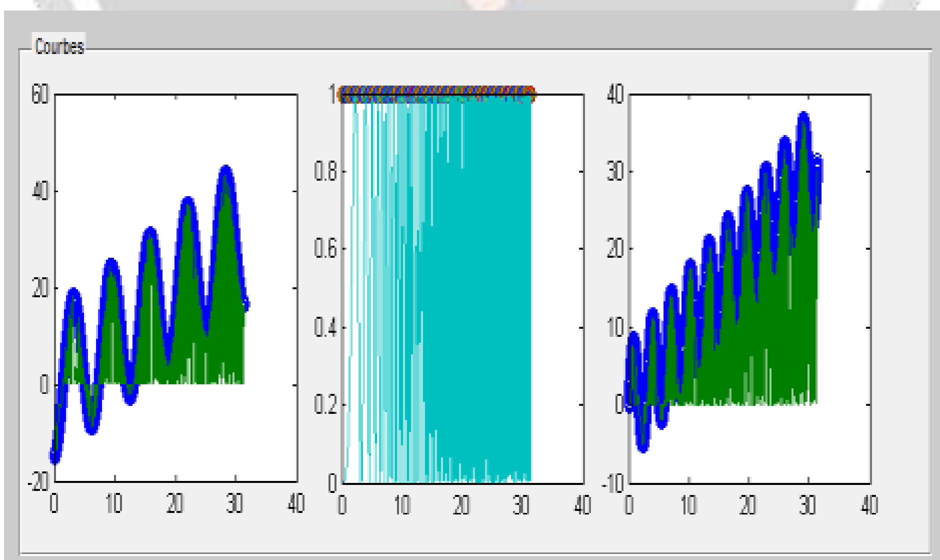

Fig -6 : *Superposed curves*

In the 3D model, the mini-UAV works best when is not subject to disturbances. When subjected to the wind, the mini-UAV fights against bursts and deviations in using all 4 motors.

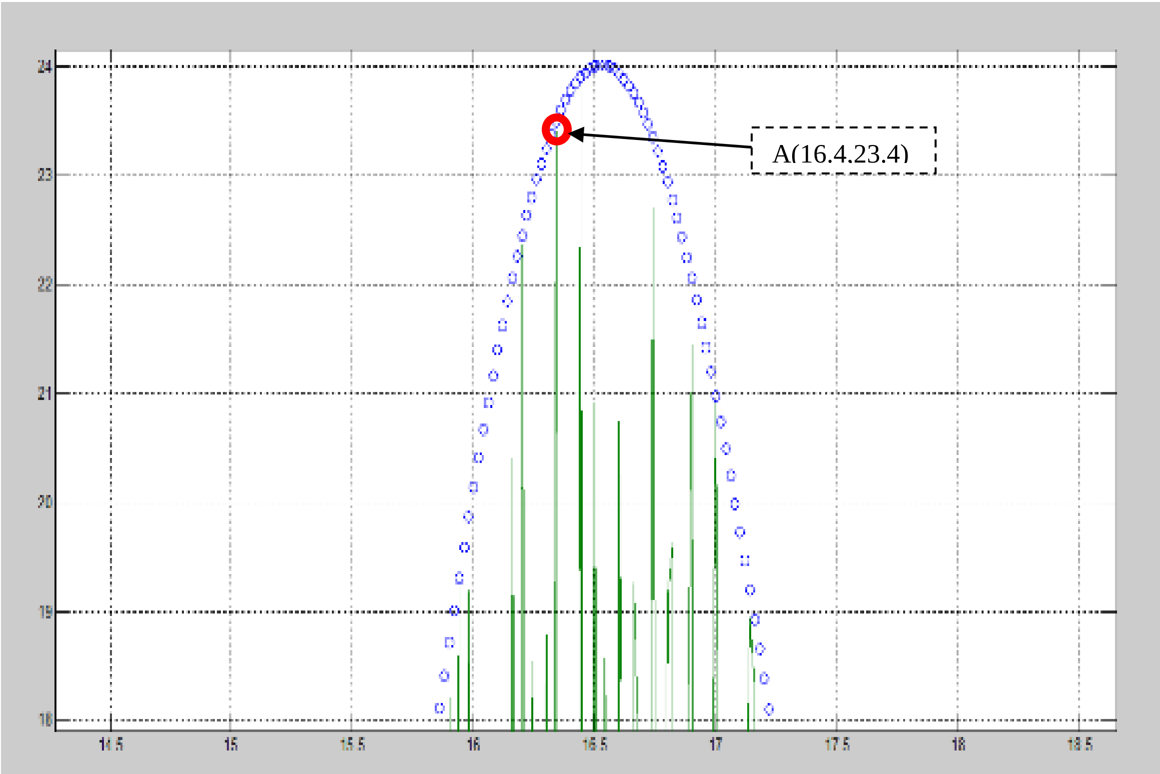

Fig -7 : *Zoom on the superposed curves*

As shown in the **Fig -7**, the signal is not correctly received when the UAV is under perturbation. However, some signals are still received like with the point A(16.4,23.4). That means that at 16.4 s, the perturbation can be supported by the UAV. That means that the wind is light. In the next paragraph, the first corrections will be brought.

6.2. First corrections made

Some corrections were found by relation to behavior with respect to wind. It's about playing on the coefficients of amplitude and the position vector. The goal is to improve behavior facing the wind and it is willingly adapted inappropriate behavior in the mini- drone when no disturbance is detected and so when the wind comes in, the UAV will behave in a normal way. These are the initial values of the parameters.

$$\begin{cases} a = 2 \\ b = 4 \\ x = 1 \\ y = 2 \\ z = 1 \end{cases} \tag{15}$$

Fig -8 shows an example of these parameter initializations.

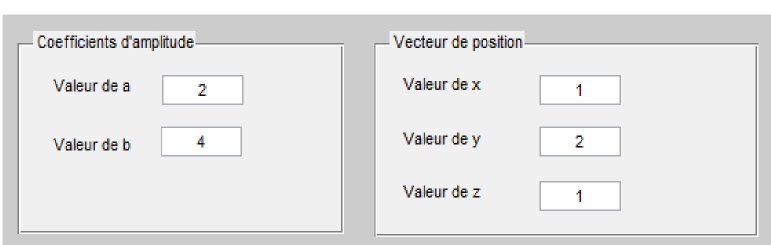

Fig -8 : *Initial values of coefficients and the vector of position*

The superimposed curves are shown in **Fig -9.** We notice that as in the previous case. For example, the signals are not the results of the equations except that this time this is done voluntarily.

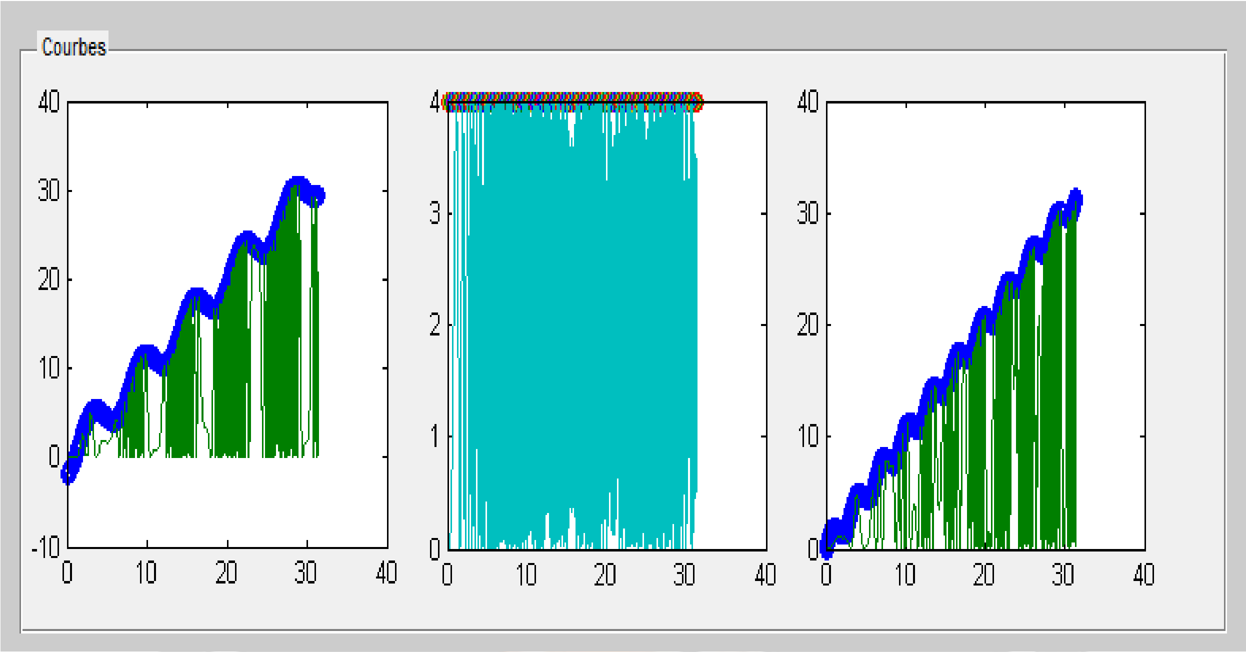

Fig -9: *Superposed curves of mini-UAV*

The superposed curves do not seem to an eye sight show the effectiveness of the method but when we simulate the 3D model, we notice that the mini-UAV will behave optimally when it is subject to the wind.

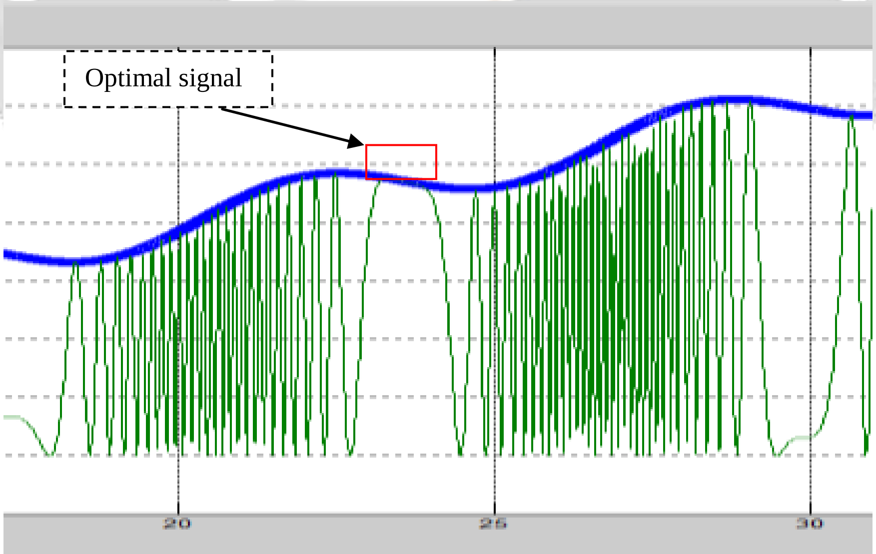

Fig -10 : *Zoom on the superposed curves with corrections*

After the corrections, we can see that at many points, the perturbed signal can reach the initial signals. For example, between 25 s and 28 s, we have many oscillations but the signal is reached many times. Between 23 s and 24 s the perturbed signal is exactly the same as the initial signal. We can call it an optimal signal.

7. CONCLUSION

The operation of the quadrotor mini-UAV can be disturbed when the UAV is subject to external disturbances like the wind. The designed application allowed to have representative curves behaviors of the mini-UAV with and without wind effect. In this model, we have performed MATLAB programs and designed an application for simulation.
Some corrections have also been brought. That is a first step towards an objective that aims to bring the maximum correction on the mini-UAV.

8. REFERENCES

[1]. E.F. Herinantenaina, *« Contribution à la conception d'un système drone utilisant un minidrone quadrirotor à énergie solaire-application à la protection de l'environnement »*, Doctoral Thesis, Embedded Systems Laboratory, Ecole Supérieure Polytechnique d'Antananarivo, 2014.
[2]. P. Michel, *« Commande d'un minidrone à hélice carénée : de la stabilisation dans le vent à la navigation autonome »*, april 2006.
[3]. A. Jordan, C. Wossler, M. Beekman. *« A scientific note on the drone flight time of Apis mellifera capensis and A. m. scutellata »*, january 2018.
[4]. M. Adnan, G. Abba, *« Modélisation et commande de vol d'un hélicoptère drone soumis à une rafale de vent »*, France, 2008.
[5]. A. Walid. *« Bounded error estimation and design of guidance and control laws for small UAV's in presence of atmospheric perturbations »*, february 2018.
[6]. J. Coelho, *« Heat transfer and body temperature in honey bee (Hymenoptera: Apidae) drones and workers »*, december 2017.