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A Tailless Coaxial Helicopter with Combination of Balancer and Gyroscope Mechanism

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ABSTRACT

Conventional helicopters endure of many disadvantages such as intensified weight and cost, restriction of aerodynamical structure, and displacement of center of gravity. This research work is focused on designing a tailless helicopter to overcome the mentioned disadvantages. Invention of this type of helicopter is currently registered as a patent in Iran. The flight mechanism of this kind of helicopter consists of three essential parts: a pair of two-bladed rotors which are rotated in opposed directions, balancer, and a gyroscope. In addition, a fuzzy controller is applied to combine the balancer and the gyroscope in a way that we have a much more stable helicopter without any vibration. The controller inputs are the two rotors' speed, and also wind speed. Moreover, to predict the behavior of the embedded controller, different angular speeds of balancer are simulated. Finally, in order to verify the helicopter performance, we made a small prototype, and tested in different conditions. The experimental results show good performances of this tailless helicopter with its fuzzy controller.

KEYWORDS: Coaxial helicopter, fuzzy controller, tailless

INTRODUCTION

The conventional helicopter is referring to any tailed helicopter. The tail system is an essential part for any conventional helicopter. The tail refers to the tail and its related parts in the helicopter body. The tail prevents vibration of the helicopter during a flight. The rotor helps the helicopter to change its direction during a flight [1]. The tail causes to intensified weight and cost, restriction of aero-dynamical structure, and displacement of gravity center [2]. Also in some of the coaxial helicopters, the physiccal shape of tail is still necessary [3]. However, there are rare references and resources about tailless helicopters. If the tail could be removed, it may cause to reduction energy consumption [11].

Thus it is essential to find a new structure of a tailless helicopter in which the disadvantages of conventional helicopters is taken away.

In this paper, a tailless helicopter is proposed. This invention is currently registered as a patent in Iran [4]. This helicopter is consisted of two rotors, a balancer, and gyroscope mechanism. Thus the scientific contributions of this paper can be summarized as follows:

1. A new stable, tailless helicopter without any vibration during flight is proposed.
2. An effective controller to coordinate the operation of the balancer and the gyroscope is proposed.
3. The helicopter is modeled using multi-body dynamic approach.

The rest of this paper is organized as follows: In section 1, the main components of the proposed structure for the helicopter are descried. In section 2, the helicopter is modeled using multi-body dynamic approaches. In section 3, the fuzzy controller to coordinate the balancer and gyroscope is proposed and designed. In section 4, by using the developed model in section 3, we can predict the behavior of the controller, and then some simulations are carried out. In section 4, to verify the proposed helicopter platform and controller, we assembled a prototype with implementing some experiments. Then, we presented the vibration in term of all components of helicopter with using a controller and without using a controller. Finally, in section 5, we presented the conclusion.

PROPOSED STRUCTURE

In the following section, the three essential parts of helicopter is considered. They are: a pair of two-bladed rotors which are rotated in opposed directions, balancer, and a gyroscope.

A. Main Body

The main body is designed as an aerodynamic fuselage body as seen in Fig 1. Since the proposed helicopter is consider as remote piloted, any space for the pilot is not considered.

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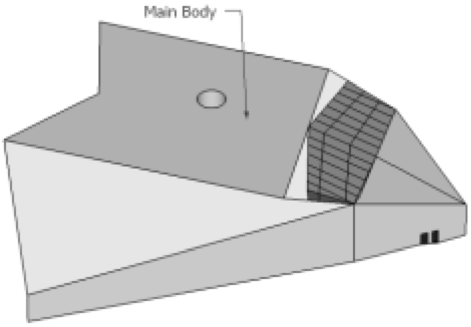

Fig. 1. The fuselage main body

B. Rotating Rotors

In conventional helicopters, there is only a rotor. But, by elimination of the tail, the helicopter with a rotor becomes unstable. Thus, to ensure the stability two rotors are considered which are rotating in opposite directions. These rotors are entitled as upper and lower rotors, as seen in Fig. 2.

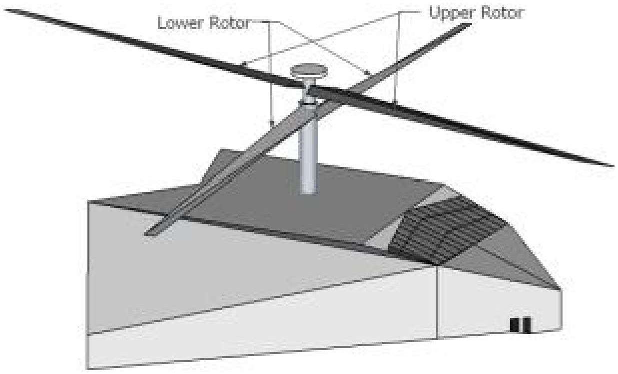

Fig. 2. The fuselage main body

As shown in figure 3, the upper and lower rotor are connected to two coaxial rotors which are denoted as upper and lower rotors axis', respectively.

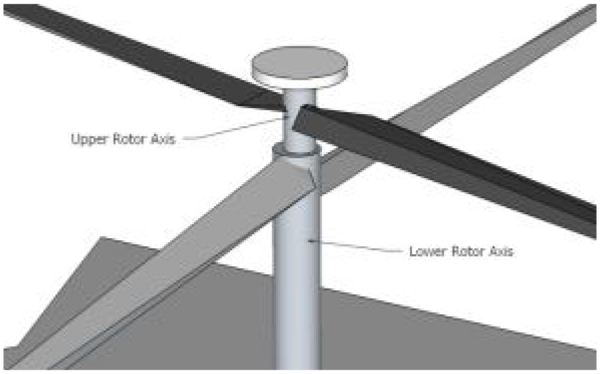

Fig. 3. The axis's of the upper and downer rotors

The acting torque on the main body by these rotors cancel each other, causing a near zero torque on the main body. Thus, the main body remains stable without any tend to rotation. Two brushless electrical motors rotate the upper and lower rotor using two gear-boxes, which are positioned inside the main body.

C. Balancer

The rotors cannot completely cancel each other, which is mainly due to the aerodynamic turbulence between them and the slight difference between their angular speeds. Thus, to stabilize the main body, a balancer is considered. This balancer consists of two mass which are fixed at the ends of a bar. The balancer is connected to the upper rotor axis, as shown in Fig. 4.

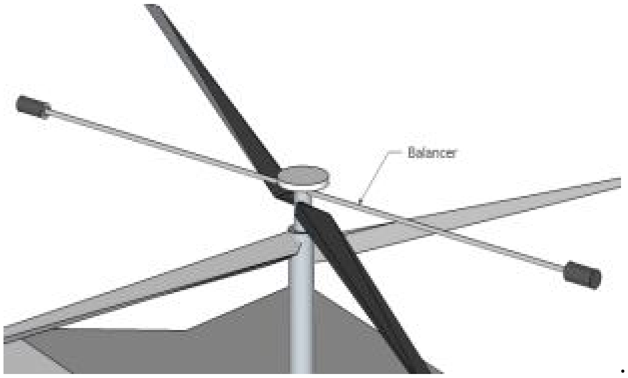

Fig. 4. The balancer which is connected to the upper rotor axis.

The complete helicopter with the rotors and balancer is shown in Fig. 5.

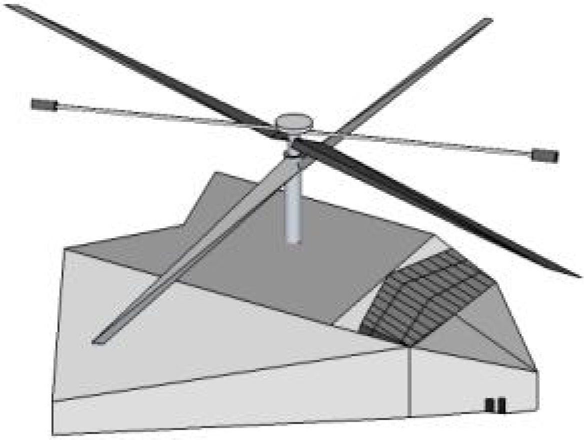

Fig.5. The assembled view of the proposed tailless helicopter.

D. Gyro System

The gyro is a crucial component in helicopters to have a stable flight. The gyro is usually used to control unwanted movements on the yaw axis. The gyro sense any unwanted rotation around the yaw axis, correcting the orientation of the helicopter. With no gyro, helicopter eventually tend to drift and rotate. The gyroscope senses any change in yaw, correcting it using a controller [5].

MODELING OF THE HELICOPTER

To develop an algorithm for satiability of robot performance as well as prediction of its dynamic performance, a multi-body approach is used.

The helicopter is considered as seven bodies including the main body, right and left blades of the lower and upper rotors, and right and left arms of the balancer. It should be noted that because the shaft of each rotor is fixed to its shaft, both the rotor and shaft is considered as a body. The join type between the rotors and main boy is revolute type. In the Fig. 6, all the seven bodies and the corresponding coordinates and the reference coordinate are shown.

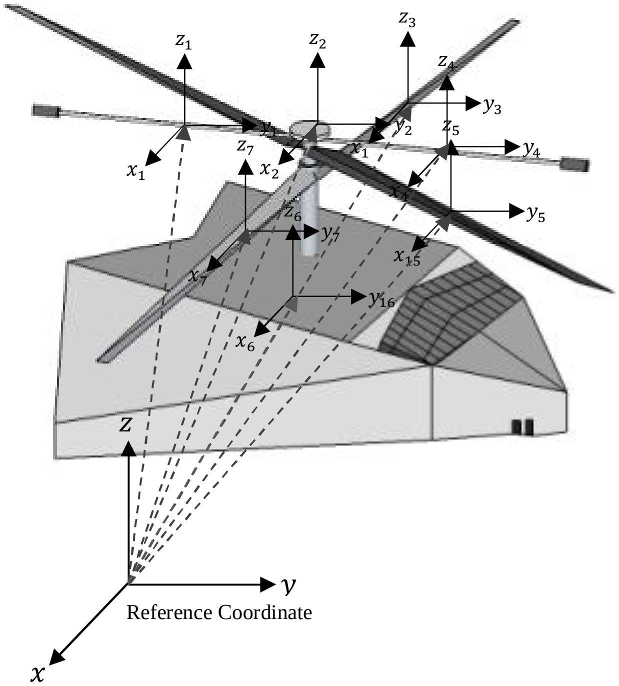

Fig. 6. The seven bodies and corresponding Cartesian Coordinates.

The configuration of each body in the space can be uniquely expressed by six coordinates; three coordinates have for its location in the space and three Cartesian coordinate for its angular position using EULER parameters [6]. Thus, configuration of body of i is presented with configuration vector of q_i:

$$q_i = \begin{bmatrix} r_i \\ p_i \end{bmatrix} \qquad (1)$$

where, $r_i = [x_i, y_i, z_i]$ is location vector in Cartesian, and p_i is the Euler parameters vector. Thus translational and acceleration vectors of body of i respectively are:

$$\dot{q}_\iota = \begin{bmatrix} \dot{r}_\iota \\ \dot{\omega}_\iota \end{bmatrix} \qquad (2)$$

$$\ddot{q}_\iota = \begin{bmatrix} \ddot{i} \\ \ddot{\omega}_\iota \end{bmatrix} \qquad (3)$$

The equation of motion of each multi body system with its dynamic constraints, which is result of connection of bodies together, is described as:

$$\Phi = \Phi(q) = 0 \qquad (4)$$

where Φ is the body movement constraint, and q is the vector of body configuration including n_c numbers of equations:

$$q = \begin{bmatrix} q_1 \\ q_2 \\ \vdots \\ q_n \end{bmatrix} \qquad (5)$$

By derivation of equation (4), the velocity constraint can be expressed as:

$$\dot{\Phi} = D\dot{q} = 0 \qquad (6)$$

The second derivative provides acceleration constraint:

$$\ddot{\Phi} = D\ddot{q} + D\dot{q} = 0 \xrightarrow{yields} D\ddot{q} = -D\dot{q} \qquad (7)$$

where D is the Jacobean Matrix of body.
For simplicity, we express the $-D\dot{q}$ value by γ thus, equation (7) can be written as:

$$D\ddot{q} = \gamma \qquad (8)$$

By solving the motion equation with its body constraint based on the Newton laws, the motion of robot bodies can be predicted.
Because the acted force on a system may include external, internal and inertia forces, motion equation with its constraint is expressed as:

$$\boldsymbol{M}\ddot{q} = g + g_c \qquad (9)$$

where $\ddot{q}$ includes $6 \times n$ number of transnational and angular accelerations corresponding to the n number of bodies.

Also, g_c and g_c include the external and internal forces, respectively:

$$g = \begin{bmatrix} g_1 \\ g_2 \\ \vdots \\ g_n \end{bmatrix} \qquad (10)$$

where g_i is:

$$g_i = \begin{bmatrix} f_i \\ {n_i}^* \end{bmatrix} \qquad (11)$$

where f_i is a vector which includes the actuator, damper, spring, and weight forces:

$$f_i = {f_i}^a + {f_i}^s + {f_i}^d + {f_i}^g = {f_i}^a u + k(d - d_0)u0 + c\dot{d}u + \begin{bmatrix} 0 \\ 0 \\ -gm_i \end{bmatrix} \qquad (12)$$

Where, $\boldsymbol{u}$ is a unity vector between each two bodies:

$$\boldsymbol{u} = \frac{d}{d} \qquad (13)$$

$$d = r_i + s_i - (r_j + s_j),\ d = \sqrt{d^T d} \qquad (14)$$

Using the Lagrange coefficient principle, it can be shown that the three internal forces are result of body interactions which can be expressed as:

$$\boldsymbol{g_c} = \boldsymbol{D^T}\gamma \qquad (15)$$

Thus, using equation (15), equation (9) can be rewritten as:

$$\boldsymbol{M}\ddot{q} + \boldsymbol{D}^T\gamma = \boldsymbol{g} \qquad (16)$$

The expanded form of equation (16) is:

$$\begin{bmatrix} M & -q^T \\ D & O \end{bmatrix} \begin{bmatrix} q \\ \lambda \end{bmatrix} = \begin{bmatrix} g \\ r \end{bmatrix} \qquad (17)$$

Where, M is the mass matrix includes mass and inertia tensors of the bodies:

$$M = [M_1, M_2, \dots, M_n] \qquad (18)$$

Where M_i is:

$$M_i = \begin{bmatrix} M_i I & O \\ O & j_i \end{bmatrix} \qquad (19)$$

THE PROPOSED CONTROLLER

To obtained stability and avoid vibration, we utilized two method of fuzzy and neural network [7-8]. But, due to novelty of this helicopter to have a high stability in the flight, we prefer to apply a fuzzy based control mechanism to match up the gyro and balancer operations. This controller accepts the rotors angular speeds and wind data as high and, medium, and low levels, and control balancer angular speed results in a significant stability of the controller is shown in Fig. 8.for the helicopter without any vibration. The control scheme

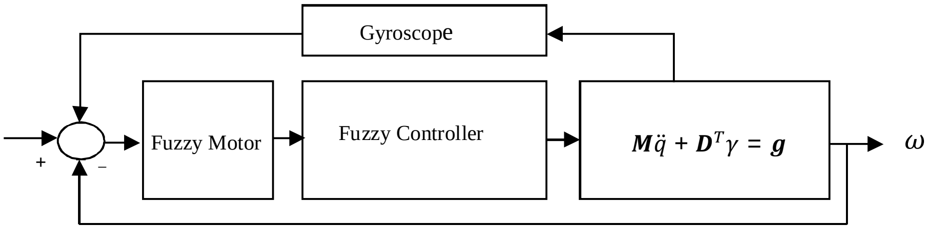

Fig. 7. Control scheme of the Fuzzy based controller.

FUZZIFICATION

The accepted wind pressure data for fuzzy controller should be fuzzifide as five levels of very low, low, medium, high, and very high. This fuzzification is being carried out using a fuzzy motor based on the defined fuzzy rules which are summarized in Table I.

TABLE I
THE DEFINED FUZZY RULES FOR FUZZY CONTROLLER

E/V	**Very- low**	**Low**	**Medium**	**High**	**Very high**
Low	Low	Low	Medium	Medium	High
Medium	Medium	Medium	Medium	High	High
High	Medium	High	High	High	High

Also, the membership function is with distribution is shown in Figure 8.

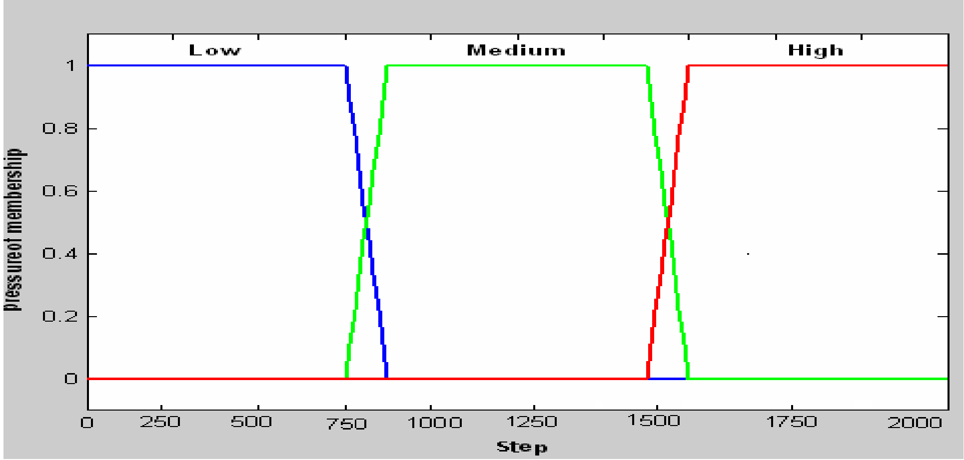

Fig. 8.The membership function

SIMULATION

In order to verify the proposed helicopter topology as well as the designed control schemes in the previous section, the balancer angular speed simulations are carried out. For simplicity of simulation, only three conditions including low, medium, and high pressure are considered. The performance of the controller in controlling the angular speed of balancer in each of these conditions is simulated as following.

E. I. Lowe Pressure

In wind loads acted on the helicopter with low pressure, the controller controls the balancer speed so that with a liner trend reach its set points as shown in Fig.9.

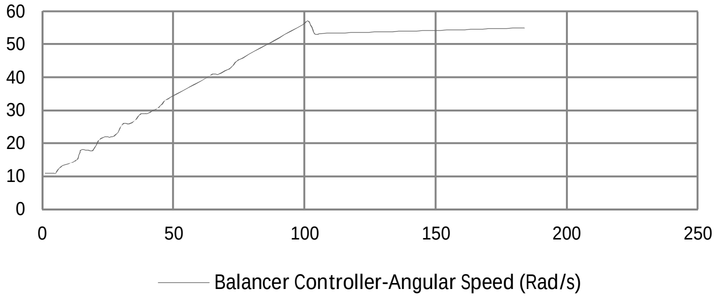

Fig. 9. The angular speed of balancer controller with proposed controller is measured using measurement procedure proposed in [9]

F. Medium Pressure

In medium pressures, the simulation show the balancer speed increase in linear trend, but a small overshoot can be seen in Fig. 10. The overshoot magnitude is not exceeds the sent point value.

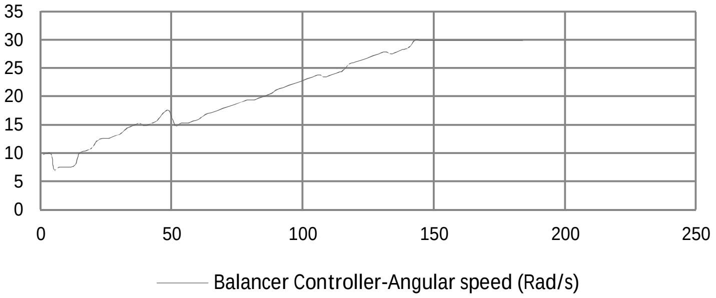

Fig. 10. The angular speed of balancer controller with proposed controller is measured using measurement procedure proposed in [9]

G. High Pressure

In high pressure wind loads, simulation shows a slight oscillation at the first ten seconds. But, similarly, the balancer speed increase in linear trend, without any over shoot to reach the set point as shown in Fig. 11.

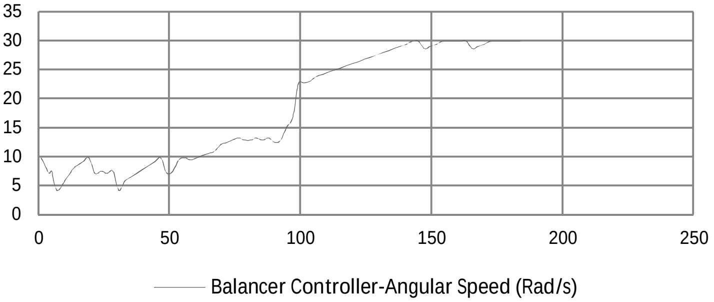

Fig. 11. The angular speed of balancer controller with proposed controller is measured using measurement procedure proposed in [9]

EXPERIMENTS

To validate the feasibility of the proposed topology and effectiveness of the control scheme a prototype is constructed. This prototype is shown in Fig. 11.

Fig. 12 Various constructed prototypes of the tailless helicopter

The output signals of gyroscope which show the orientation of the main body in the space continually are sending using a transmitter. The gyroscope data include variation of each components of x,y, and z of the main body. To evaluate performance of the proposed control scheme two experiments are considered. The first experiment is assessment of the main body vibration in all the three directions of x, y, and z of main body of helicopter without any controller. The results of this experiment are recorded in Figures 13, 14, and 15.

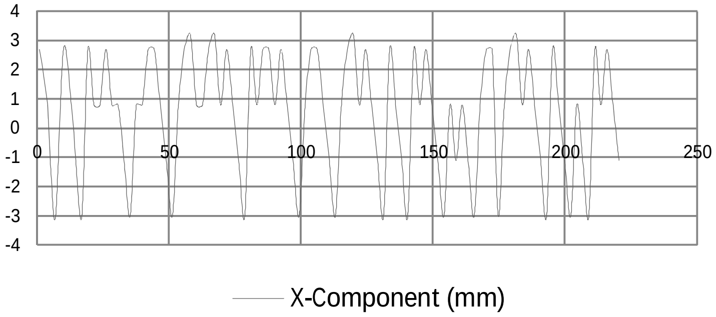

Fig. 13.Variation of x amplitude during flight of the uncontrolled helicopter [10].

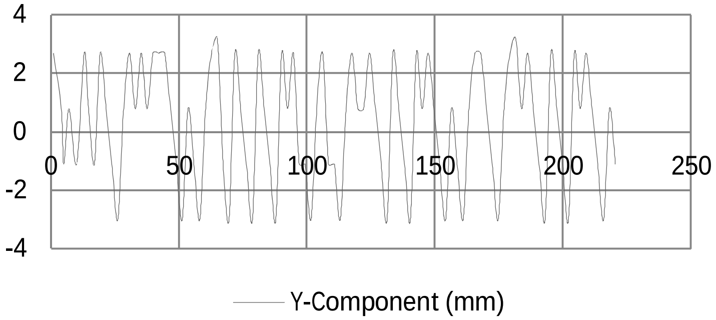

Fig. 14.Variation of y amplitude during flight of the uncontrolled helicopter [10].

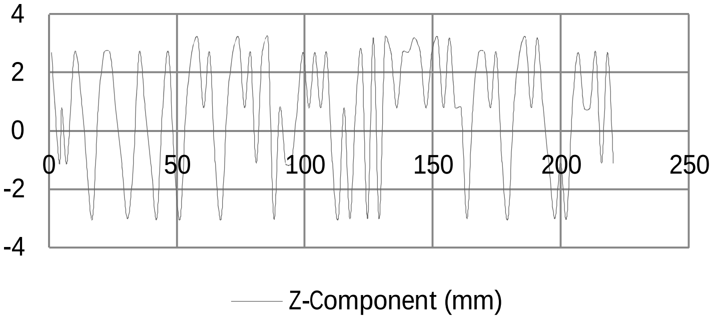

Fig. 15.Variation of z amplitude during flight of the uncontrolled helicopter [10].

The second experiment is assessment of the main body vibration in all the three directions of x, y, and z of main body of helicopter with the proposed controller. The results of this experiment are recorded in Fig. 16, 17, and 18.

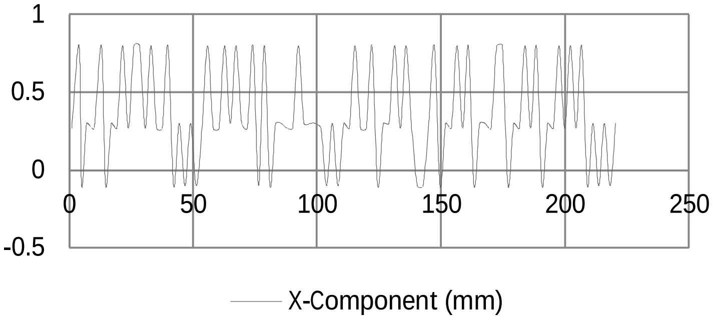

Fig. 16.Variation of x amplitude during flight of the controlled helicopter [10].

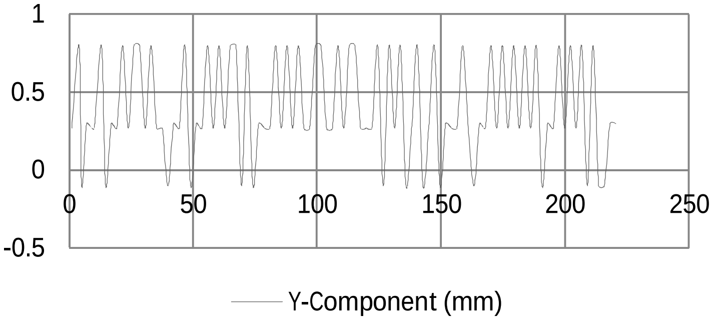

Fig. 17.Variation of y amplitude during flight of the controlled helicopter [10].

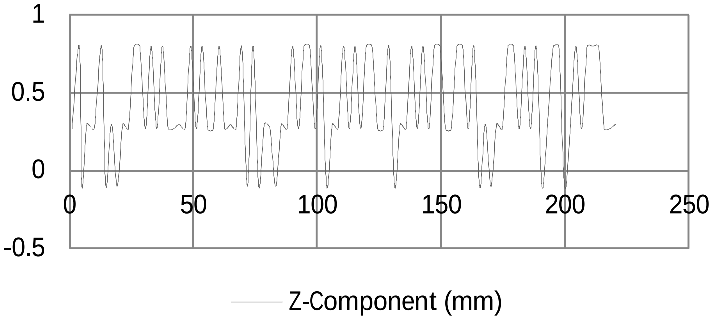

Fig. 18.Variation of z amplitude during flight of the controlled helicopter [10].

To evaluate the effect of the controller on the flight vibration, we defined a vibration index. This index is express as:

$$RMS = \sqrt{\frac{1}{t_2-t_1}\int_{t_1}^{t_2} x^2 + y^2 + z^2 dt} \qquad (1)$$

Thus, RMS Values f x, y, z components are computed over 65 seconds, for both the Controlled and uncontrolled Helicopters, and are summarized in Table. II.

TABLE II.RMS Values f x, y, z Components Are Computed for both the Controlled and Uncontrolled Helicopters

Component	**RMS Value Without any Controller**	**RMS Value With the Controller**
x	2.3mm	0.12 mm
y	43 mm	0.17 mm
z	162 mm	0.26 mm

CONCLUSION

The paper outlines a novel tailless helicopter topology. The main components of the proposed helicopter were described. A fuzzy based controller scheme to coordinate the balancer and the gyroscope performance for higher stability and avoiding vibration of the helicopter is proposed. Moreover, to predict the performance of the helicopter with the controller, we simulated the plant with a balancer angular speed. To verify the proposed helicopter topology and the fuzzy controller a small prototype was manufactured and tested. Obtained experimental data demonstrate the effectiveness of the proposed helicopter topology as well as its fuzzy controller.

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