COMPARAISON BETWEEN PID AND FUZZY PID CONTROL FOR DJI F450 QUADCOPTER STABILITY

[1]BENMOUIZA KHALIL, [2]OUBBATI YOUCEF, [3]SOUFFI ABDEL GHANI, [4]MAHDJOUB WAFIK MOHAMED, [5]BENMOUIZA ABDERRAHMANE, [6]RAHMANI ASMA

Department of Electotechnics , Faculty of Technology , Amar Telidji University, LSMF Laboratory, Laghout, Algeria
E-mail: k.benmouiza@lagh-univ.dz

Abstract - A quadcopter is a flying machine, which equipped with four motors to create lift and achieve a vertical flight, it could also stay stable in a hover position to make a determinate job as collecting data in a defined area, such mapping or taking areal phots or scanning earth topography. However, stability of quadcopters is an essential for better flying experiences. Hence, we propose in this paper, a comparative study between PID and fuzzy PID controller in order to test the stability of the movement of the quadcopter. This study was applied in the famous DJI F450 quadcopter frame. The results show an effective comparison with full review of both control schemes that helps for further implementation and stability of such kind of quadcopters.

Keywords - Quadcopters, PID, Fuzzy, Stability.

I. INTRODUCTION

Over the last decade, advances in technology and numerous potential applications have generated a growing interest in aerial robotics. UAV (Unmanned Aerial Vehicles) are autonomous flying machines whose lift and propulsion are ensured by the rotation of the motors. These aircraft are capable of following a trajectory, navigating space, using visual navigation, taking off, flying and landing vertically, performing near-stationary flights and low-level great maneuverability [1]. Interest in remote-controlled aerial drones seems to grow more and more particularly for military applications (demining for example) and intervention in hostile environments (radioactive environments). We can imagine a drone to explore a building or a contaminated tunnel and make a first observation before any intervention human. Research in the field of autonomous air vehicles is essentially multidisciplinary. Indeed, it involves a wide variety of areas such as aerodynamics, signal and image processing, automatic control, mechanical, composite materials, real-time computing [2]. Recently, the control of flying machines has attracted the attention of researchers in automatic control. Different approaches have been proposed to control planes, helicopters, rockets, satellites, mini helicopters, drones, etc. Each of these devices does not have a precise model describing his behavior [3,4] .

In this paper, we are particularly interested in air vehicles and more particularly to the quadcopters (micro helicopter with four propellers). The quadrotor drones are among the most complex of flying objects, because their flight dynamics is inherently nonlinear, and the variables are strongly coupled. The quadrotor has the ability to hover, which is required in some applications. The main objective of this work is to develop a dynamic model of the DJI F450 quadrotor that will serve as a basis for the stability control using two methods, namely PID and Fuzzy PID. These to regulators aims to control the position of equilibrium (hovering) and the stability of the quadcopter of the altitude and the pitch, roll and yaw angles. A Matlab/Simulink is used in order to simulate the dynamics of the proposed quadcopter as well as the results of the comparison between the two proposed controllers in order to test the stability of the system.

The rest of the paper is organized as follows; in section I , the mathematical modeling from kinematics to physics of the DJI F450 quadcopter is given. In section II , a brief overview of PID and fuzzy PID control schemes is explained. Section III, will show to the simulation results and discussion of the comparative study of PID and fuzzy PID controllers applied for the quadcopter. The last section will be devoted to the conclusion and some perspectives.

II. MATHEMATICAL MODLING OF QUADCOPTERS

The knowing of the mathematical modeling of the quadcopter is an essential part to control and stabilize its movement. The modeling consists of defining the structure of the quadcopter, modeling its kinematics, motors , forces , torques and its equations of movement [5,6,7,8] .

A. The frame

The absolute linear position of the quadcopter is defined in the inertial frame x,y,z-axes. The angular position, is defined in the inertial frame with three Euler angles η. Pitch angle θ determines the rotation of the quadcopter around the y-axis. Roll angle φ determines the rotation around the x-axis and yaw angle ψ around the z-axis. Vector q contains the linear and angular position vectors.

$$\varepsilon = \begin{bmatrix} x \\ y \\ z \end{bmatrix}, \quad \eta = \begin{bmatrix} \phi \\ \theta \\ \psi \end{bmatrix}, \qquad \mathrm{q} = \begin{bmatrix} \varepsilon \\ \eta \end{bmatrix} \qquad (1)$$

B. Kinematics

In the body frame, the linear velocities are determined by V_B and the angular velocities by ν.

$$V_B = \begin{bmatrix} v_x, B \\ v_y, B \\ v_z, B \end{bmatrix}$$

The angular velocities equal to dθ/dt . However, note that the angular velocity vector ν ≠dθ/dt. The angular velocity is a vector pointing along the axis of rotation, while linear velocities is just the time derivative of yaw, pitch and roll.

The transformation matrix for angular velocities from the inertial frame to the body frame is Wη , and from the body frame to the inertial frame is Wη−1 .

$$\dot{\eta} = w_n^{-1} \nu \quad , \quad \begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix} = \begin{bmatrix} 1 & S_\phi T_\theta & C_\phi T_\theta \\ 0 & C_\phi & -S_\phi \\ 0 & S_\phi / C_\theta & C_\phi / C_\theta \end{bmatrix} \begin{bmatrix} p \\ q \\ r \end{bmatrix} \quad (3)$$

$$\nu = w_n \dot{\eta} \quad , \quad \begin{bmatrix} p \\ q \\ r \end{bmatrix} = \begin{bmatrix} 1 & 0 & -S_\theta \\ 0 & C_\phi & C_\theta S_\phi \\ 0 & -S_\phi & C_\theta C_\phi \end{bmatrix} \begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix} \quad (4)$$

In which Tx = tan(x), Sx = sin(x) and Cx = cos(x). The matrix Wη is invertible if θ ≠(2k− 1) ϕ/2, (k ∈ Z).

C. Acceleration

In order to calculate the acceleration of the quadcopter, the Newton-Euler formalization is used. The angular accelerations in the inertial frame are then attracted from the body frame accelerations with the transformation matrix $W\eta^{-1}$.

$$\ddot{\eta} = \begin{bmatrix} 0 & \dot{\phi}C_\phi T_\theta + \dot{\theta}S_\phi / C_\theta^2 & -\dot{\phi}S_\phi C_\theta + \dot{\theta}C_\phi / C_\theta^2 \\ 0 & -\dot{\phi}S_\phi & -\dot{\phi}C_\phi \\ 0 & \dot{\phi}C_\phi / C_\theta + \dot{\phi}S_\phi T_\theta / C_\theta & -\dot{\phi}S_\phi / C_\theta + \dot{\theta}C_\phi T_\theta / C_\theta \end{bmatrix} \nu + W_n^{-1} \dot{\nu} \quad (5)$$

D. Physics

In order to properly model the dynamics of the quadcopter system, firstly we should understand its physical properties . At first stage , a quick description of the used motors on the quadcopter, as well as its power is introduced . We suppose that the four motors are identical, which means that we can analyze only one motor then apply it on the other three motors. The propeller are mounted on opposite sides ,where two are clockwise and other two are counter clockwise on the Quad X configuration.

The function of the produced torque is produced as follows;

$$\tau = k_t \left(I - I_0 \right) \quad (6)$$

Where, τ is the motor torque . I is the input current. $I_0$is no load current. k_t: is the Torque constant.

The voltage across the motor is given as follows,

$$V = IR_m + k_v \omega \quad (7)$$

(2) Where , V is the voltage drop across the motor. R_m is the motor resistance. ω is the angular velocity. k_v is the constant of RMF generated per RPM

We will assume that the motor resistance is negligible, the power of the motors is expressed in eq.(8);

$$P \approx \frac{k_\nu}{k_t} \tau \omega \quad (8)$$

E. Forces and Torques

In the quadcopter, we have to modelized the forces and torques of both the motor and the quadcopter frame. Hence, we will give in what follows the full modeling equations. Summing over all the motors, we find that the total thrust on the quadcopter (in the body frame) is given by,

$$T_B = \sum_{i=1}^{4} T_i = k \begin{bmatrix} 0 \\ 0 \\ \sum \omega_i^2 \end{bmatrix} \quad (9)$$

In addition to the thrust force, we have modelled the friction as a force proportional to the linear velocity in each direction. This is a highly simplified view of fluid friction, but will be sufficient for our modeling and simulation. Now that we have computed the forces on the quadcopter, we would also like to compute the torques. Each rotor contributes some torque about the body z axis. This torque is the torque required to keep the propeller spinning and providing thrust; it creates the instantaneous angular acceleration and overcomes the frictional drag forces. The torques in the body frame are,

$$\tau_B = \begin{bmatrix} Lk\left(\omega_1^2 - \omega_3^2\right) \\ Lk\left(\omega_2^2 - \omega_4^2\right) \\ b\left(\omega_1^2 - \omega_2^2 + \omega_3^2 - \omega_4^2\right) \end{bmatrix} \quad (10)$$

Where, L is the distance from the center of the quadcopter to any of the propellers and b is some appropriately dimensioned constant. Using the Euler-Lagrange equations, the forces and torques of the hall quadcopter

$$f = RT_B = m\ddot{\varepsilon} + mg \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} \quad (11)$$

And the torques are :

$$\tau = \tau_B = J\ddot{\eta} + \frac{d}{dt}(J)\dot{\eta} - \frac{1}{2}\frac{\partial}{\partial \eta}(\dot{\eta}^T J \dot{\eta}) = J\ddot{\eta} + C(\eta, \dot{\eta})\dot{\eta} \quad (12)$$

In which the matrix $C(\eta,\dot{\eta})$ is the Coriolis term, containing the gyroscopic and centripetal terms. $J(\eta)$ is Jacobian matrix from ν to $\dot{\eta}$.

F. Aerodynamical effects

The preceding model is a simplification of complex dynamic interactions. To enforce more realistically behavior of the quadcopter, drag force generated by the air resistance is included.

III. QUADCOPTER CONTROLLER

Quadcopters represents high dynamics nature. They are nonlinear and their modelling is related to different parameters. Several control algorithms have been proposed in last decade to stabilize the movement of the quadcopter, each control scheme has its advantages and disadvantages ranging from linear and non-linear controlled. In this paper, PID and fuzzy PID controller are used. A brief overview of the both controllers is given below,

A. PID controller

PID is the most applied controller in the industry, it is used widely in several applications. It has the advantages that it is simple to implement and its parameters can be adjusted easily,

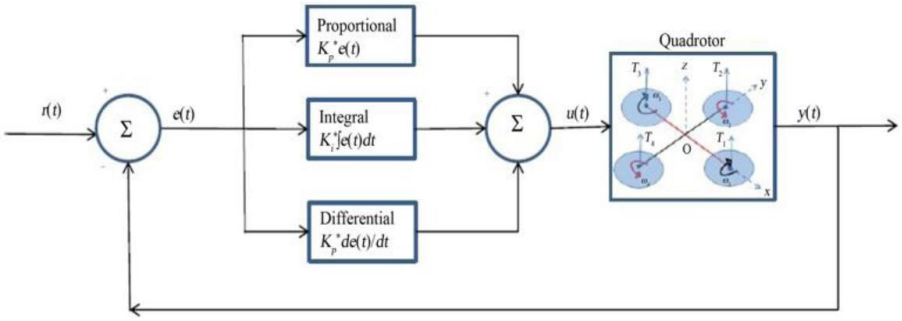


FIG. 1 Block Diagram of a PID Controller for the Quadrotor.

besides it has good robustness [9]. Fig. (1) shows the block diagram for the control of a quadcopter using a PID. Several researches have implemented PID to control and stabilize the quadcopter.

In [10] , PID is used for attitude control , while a dynamic surface control (DSC) was used for the altitude control. In [11], both position and orientation of the quadcopter have been controlled using PID The performance of the PID controller indicated relatively good attitude stabilization. The response time was good, with almost zero steady state error and with a slight overshoot. From literary review, we can see that PID controllers has been successfully applied to the quadrotor though with some limitations.

The PID parameter gains were chosen intuitively and the tuning of the PID controller could pose some challenges as this must be conducted around the equilibrium point, which is the hover point, to give good performance.

B. Fuzzy controller

Intelligent control algorithms apply several artificial intelligence approaches, some biologically-inspired, to control a system. Examples include fuzzy logic, neural networks, machine learning, and genetic algorithm. They typically involve considerable uncertainty and mathematical complexity. This complexity and abundant computational resources required are limitations to the use of intelligent systems. Intelligent control is not limited to fuzzy logic and neural networks but the two are the most widely used. Many other algorithms exist and continue to be formulated. Fuzzy logic algorithms deal with many-valued logic, not discrete levels of truth. An intelligent fuzzy controller was applied in [12] to control the position and orientation of a quadrotor with good response in simulation. However, a major limitation of this work was the trial and error approach for tuning of input variables. The block diagram of fuzzy logic controller used in our simulation is shown inFig.2.

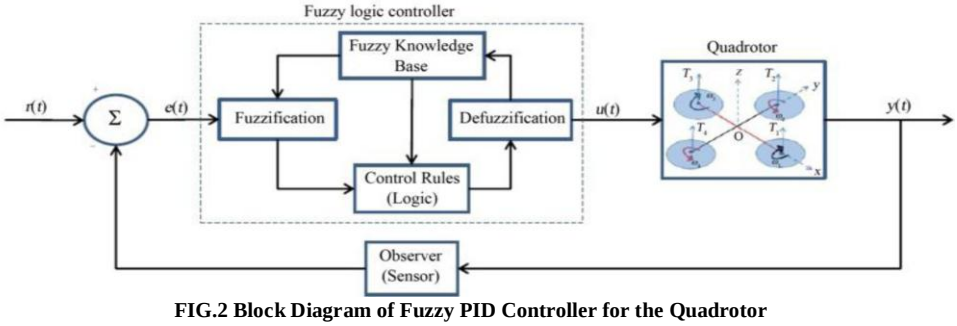


FIG.2 Block Diagram of Fuzzy PID Controller for the Quadrotor

IV. SIMULATION RESULTS AND DISCUSSIONS

In this part, the traditional PID controller and Fuzzy controllers are applied to stabilize, Altitude, Roll, Pitch and Yaw angles. The objective is to compare their performance in the quadcopter stability point of view. Several tuning parameters has been tested in order to know the range of the PID and fuzzy gains to be implemented in the real cases. A Matlab/ Simulink model was developed taking into consideration a real quadcopter components parameter. Beside, Solid work software was used to generate 3D file to be implemented in Simulink. The simulation model is shown in Fig.3.

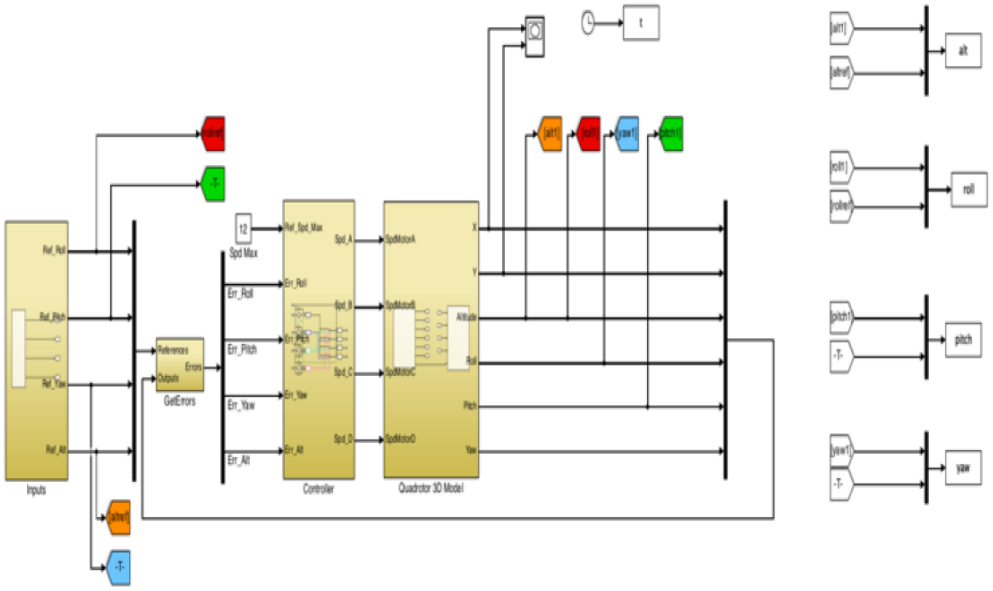


Fig.3 Simulink Block Diagram of the Proposed Controlled Quadcopter.

The used fuzzy logic controller is shown in Fig.4

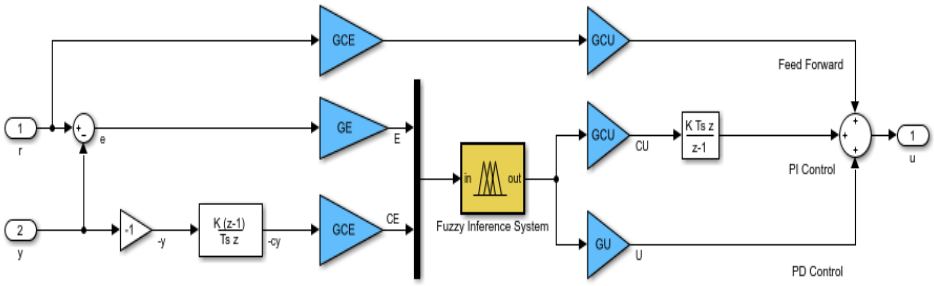


Fig.4 Simulink Block Diagram of the Used PID Fuzzy Controller.

In the simulation , a given scenario is used in order to track altitude , pitch , roll and yaw and test their stability as well as the response time. Different values of P, I and D , as well as different normalization gains of fuzzy logic controller were tested. The simulation results are given in Fig.5 The red dot line represents the given reference scenario. The yellow line is the PID controller response and the blue one is the response of Fuzzy logic.

Determine scaling factors GE, GCE, GCU, and GU from the Kp, Ki, and Kd gains of by the conventional PID controller. Comparing the expressions of the traditional PID and the linear fuzzy PID, the variables are related as follows, taking a variable value of GE we have;

GCE = GE*(Kp-sqrt(Kp^2-4*Ki*Kd))/2/Ki;
GCU = Ki/GE;
GU = Kd/GCE;

A. Discussion

P regulator determines how hard the flight controller works to correct error and achieve the desired flight path with sensitivity and responsiveness setting. Higher P gain means sharper control while low P gain means softer control. If P is too high, the quadcopter becomes too sensitive and tends to over-correct, eventually it will cause overshoots, and you will have high frequency oscillations. Lower P is used to reduce the oscillations, but reduce it too much and the quadcopter will start to feel sloppy.

D gain works as a damper and reduces the over-correcting and overshoots caused by P term. Like a shock absorber stops the suspension from being bouncy, adding D gain can “soften” and counteract the oscillations caused by excessive P gain, as well as minimizing propellers wash oscillations.

When D is too low, the quadcopter will have bad bounce-backs at the end of a flip or roll, and felling the worst experience of propellers wash oscillations in vertical descents. Increasing D gain can improve these problems; however, an excessive D value can introduce vibration in the quadcopter because it amplifies the noise in the system. Eventually this will lead to motor overheat and quad oscillation. Another side effect of excessive D term is the decrease in the quad’s response, this effect is often described as “mushy”.

I term determines how hard the flight controllers works to hold the drone’s attitude against external forces, such as wind and off-centered center of gravity. When I is too low , we might to correct the quad’s flying path a lot more with remote control sticks, especially when the throttle is active. When I gain gets too high, the quadcopter will be overly constrained by this, and start to feel unresponsive. It’s similar to having a slower reaction and a decreased P gain. Excessive I gain in extreme cases can create a low frequency oscillation. In the real world, no two ESC’s, motors or propellers are identical, which provide different levels of thrust even when spinning in the same air. When we do a punch out and immediately lower the throttle, one motor might increase and decrease RPM faster than the others, this will cause an unwanted dip movement. We increase I gain to “fix” these details in the flight performance. To avoid bringing in undesired “stiffness” to our quads with high I gain

Based on the previous simulations we found that the three gains should be tested with different values in order to compensate the drawback of each individual controller. As previously, different values of P, I and D are tested

From these results, we can conclude that PID controllers gives the best results compared to single P , PI and PD ones. However, high gains of P, I and D together leads to a stable system but with high oscillations. In the other side, low values of P, I and D gains instable systems. As a conclusion of this, optimal values should be chosen carefully for optimal response with good stability and low oscillations .

In general, to achieve a good tune, we want to use as much P as possible without introducing oscillations. In a sense P is proportional to the amount of control you have over an axis. Less P is less positive control. More P is more positive control. The problem is that if P gets too high, it will start to overshoot the intended end state. This causes it to constantly overcorrect; hence, oscillations. High quality ESCs and faster PID loop times help with this as well by allowing the flight controller to make corrections more quickly and effectively. I and D are only there to pick up the leftover bits of error that P can’t handle:

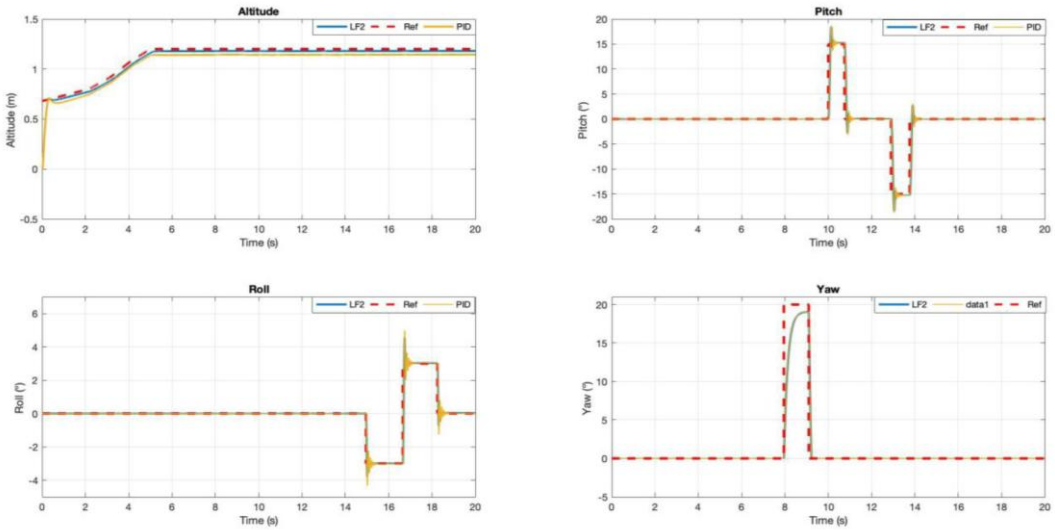


Fig.5 Simulation Results of PID and Fuzzy PID Controllers for Altitude and Pitch , Roll and Yaw Angles

If looks back at accumulated error (drift) that P was unable to correct for at the time, and then adjusts for it. That’s why adding I might correct when the Pitch of the quadcopter changes unintentionally after throttle changes. However, we need to try adding P first. If P is too low, then I has too much of a job to do because P has never quite done enough...)

D looks forward to see if the axis is reaching its intended value too quickly. If we give the quadcopter a command to stop a roll very quickly, a high P value (just like we want) might tend to overshoot just a little bit and then "bounce back".

If we see a lot of this, we might want to increase D just a bit. Adding D term can also help with the small oscillations that come right after a quick change in direction or low throttle drop (prop-wash). Very important to not use too much D. Use only as much as necessary because too much D causes noise. noise that

reaches the motors may cause them to heat up and possibly burn. Moreover, from the simulation results of fuzzy control, we can conclude that fuzzy PID controller gives the best results compared to the classic PID controller. To achieve a good tuning, the objective is to decrease the response time with less oscillation and to guarantee the stability of the system. In the case of altitude, low GE value leads to an increasing of response time. Beside to, higher GE value conduct to decreasing in the response time. However, in this case we notice a higher pick. In the case of pitch, roll and yaw, higher GE value leads to an increasing of response time, with few oscillations, and lower GE value decrease the response time with the occurrence of oscillation. Hence, we have to find the optimum GE in order to enhance the overall system performance.

V. CONCLUSION

In this paper, we presented a comparison study between two control schemes to stabilize the quadcopters. namely, PID and fuzzy controllers, they are implemented in the simulation considering the full model of the proposed quadcopter. A Matlab/Simulink model is developed and different PID values and fuzzy logic gains are tested. The simulation results performed on a quadrotor model show that PID control technique gives good results in terms of tracking with relatively small errors. As it has advantages, that is simple and fast to implement. However, it presents some oscillation. Fuzzy logic controller gives better results in the term of low oscillation however, its response time is sometimes low that the PID one. Future works can focus on some hybrid method that can take the advantages of both PID and fuzzy PID controller in order to enhance the overall quadcopter response and performances.

REFERENCES

[1] S. Lee , Y. Choi, “Reviews of unmanned aerial vehicle (drone) technology trends and its applications in the mining industry,” Geosystem Engineering, vol. 19, Issue 4 pp: 197- 204, 2016.

[2] A. AL-Kaff, D. Martín, F. García ,A. Escalera and J M. Armingol, “Survey of computer vision algorithms and applications for unmanned aerial vehicles,” Expert Systems with Applications. vol. 92, pp: 447-463, February 2018.

[3] A. Zulu, S. John. “A Review of Control Algorithms for Autonomous Quadrotors,” Open Journal of Applied Sciences, vol.4, pp: 547-556, 2014.

[4] H. Huang, H. Stanford, “ Test bed of autonomous rotorcraft for multi-agent control,” In IEEE/RSJ International Conference on Intelligent Robots and Systems, pp. 404–405, 2009.

[5] M HOANG, T. W. POON, ‘’Design, Implementation, and Testing of a UAV Quadcopter” ,Univrsity of Manitoba, March 28, 2013.

[6] R. Mahony, P. Pounds, and P. Corke, ‘’Modelling and control of a quad- rotor robot,” In the Proceedings of the Australasian Conference on Robotics and Automation. Auckland, New Zealand, September2012.

[7] G. M. Hoffmann, H. Huang, S. L. Waslander, and C. J. Tomlin, “Quadrotor helicopter flight dynamics and control: Theory and experiment,” Proceedings of the AIAA Guidance, Navigation and Control Conference and Exhibit, Aug. 2007.

[8] K. M. Zemalache, L. Beji, and H. Marref, “Control of an under-actuated system: Applica- tion to a four rotors rotorcraft,” IEEE International Conference on Robotic and Biomimet- ics, pp. 404–409, 2005.

[9] S.John,”Artificial Intelligent-Based Feedforward Optimized PID Wheel Slip Controller”. AFRICON, Pointe-Aux-Piments, 1-6. 12 September 2013

[10] K.U.Lee, H.S Kim, J.-B.Park and Y.H. Choi, “Hovering Control of a Quadroto,” 12th International Confe- rence on Control, Automation and Systems (ICCAS),162-167. 17-21 October 2012

[11] J.Li, Y. Li, “Dynamic Analysis and PID Control for a Quadrotor,”. International Conference on Mechatronics and Automation (ICMA), 573-578. 7-10 August 2011

[12] T. Madani, A. Benallegue, “ Backstepping Control for a Quadrotor Helicopter,” Proceedings of the 2006 IEEE/RSJ International Conference on Intelligent Robots and Systems, Beijing, pp:3255-3260. 9-15 October 2006.

★★★