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Adaptive PID Controller Based Control Algorithm For The Quadrotor UAV

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Abstract— Quad rotor vehicles are gaining prominence as Unmanned Aerial Vehicles (UAVs) owing to their simplicity in construction and ease of maintenance. They are being widely developed for applications relating to reconnaissance, security, mapping of terrains and buildings, etc. The control of the quad rotor is complicated due to tightly coupled dynamics. As a precursor to developing a model based design, the simulation of the mathematical model of the quad rotor is implemented. A Newton-Euler formulation is used to derive the mathematical model. An adaptive PID controller which control the vehicle's motion. The weights were obtained by genetic algorithm for improving the performance of controller and it was demonstrated. Effectiveness and robustness of the proposed adaptive control scheme is verified through simulation results.Software implementation is carried out using MATLAB Simulink. The proposed controller is an important step towards developing the next generation of agile autonomous aerial vehicles.

Index Terms—UAV, quadrotor, adaptive neuro PI, controller, genetic algorithm

I. INTRODUCTION

Now a days, unmanned aerial vehicles such as the quadrotor has wide applications in the field of research owing to its simple structure and a lot of advantages like hovering, vertical takeoff and landing capacity and high maneuverability. The possible capabilities of these aerial vehicles to carry out many tasks include mapping and surveillance, environmental monitoring, rescue and disaster relief operations, border patrol, fire detection and control…..However, the quadrotor dynamics is much more complicated since it is inherently unstable, thus a feedback controller is necessary to fly these type of vehicles.

The quad rotor is a helicopter with four rotors typically designed in a cross configuration, each rotor is directed upwards and mounted per corner with equal distance from the centre. The differential torque of these rotors provides different motions of quad rotor. The roll, pitch, yaw and the altitude are controlled by the changing thrust forces produced by the four rotors using pulse width modulation (PWM) to give desired degree of freedom.

The study of quad rotor is not a new concept, it become increasingly popular in the research platform due to its agility, which increases its application potential in a broad spectrum of scenarios.[1] [2]. Researchers have designed and implemented many quadrotor controllers such as PID and PI controllers, fuzzy, neuro fuzzy etc…[3].Fuzzy logic of controller is robustly and optimally good but it has no capability of handling the unmodeled parameters. In [4] a model reference adaptive control and LQR control for the quadrotor has been proposed adjust parametric uncertainities associated with the mass of the object. It is adaptively better in performance but it results an average tracking ability with no unmodeled parameter handling and less precision.

The author addressed the problem of quadrotor stabilization and trajectory tracking with the dynamic changes in its centre of gravity [5],which provides high maneuverability and agility, but the adaptive controller faces the problem of over parameterization, which causes no guarantee for the updated parameter results in instability. Robust backstepping control of a quadrotor using extended kalman bucky filter is another method of controlling of the quad rotor [6] to achieve stability by considering wind gust and sideslip of the model. But the backstepping control algorithm has the limitations such that it has a very low convergence response and the design is too much complicated. It only updated by manual tuning. Thereby, the regulation is not achieved. A direct self-repairing flight control system to eliminate the influence of the parameter uncertainties and external disturbance by an integrative method is proposed in [7] by combining fuzzy control, sliding mode control, and quantum information technique. A paper contribute a successful development of a robust chattering free backstepping sliding mode controller for quadrotor helicopter perturbed by external disturbances, but it is updated only by manual tuning and output is distorted due to large noises.[8].And also the backstepping make the system more complicated.

Based on the results an adaptive PID controller is implemented which can reduce the transient oscillations largely. The remainder sections of this paper are organized as follows. In section 2, the quadrotor dynamics is obtained by the Newton-Euler equation. Section 3 covers the adaptive PID control algorithm and the further sections presented the simulation results of the designed control scheme of the quadrotor.

II. QUADROTOR MODEL

There are four rotors whose rotational motions are used to maneuver the quadrotor. Each rotor produces both thrust and torque about its centre of rotation where the drag force acts opposite to the vehicle's direction of flight. A linear model of a quadrotor, as illustrated in fig:1.

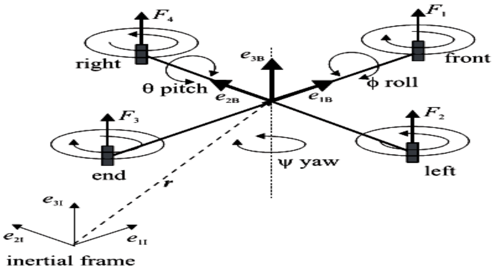

Fig 1: Quadrotor UAV schematic.

If all the rotors are spinning at the same angular velocity, with two rotors rotating clockwise and other two in counter clockwise, the net aerodynamic torque and hence the angular acceleration about the yaw axis is zero, thus the yaw stabilization of the quadrotor is achieved. Angular acceleration about the pitch and roll axis will be separately controlled without impacting the yaw axis. Since the yaw is induced by mismatching the balance in aerodynamic torque. Each pair of rotor blades rotating in the same direction controls one axis, either roll or pitch and increasing thrust for one rotor, while decreasing thrust for the other will maintain the torque balance needed for yaw stability and induce a torque about the roll or pitch axes. This way the fixed rotor blades can be made to maneuver the quadrotor in all dimensions.

1.1 MATHEMATICAL MODELLING

The mathematical model of the quadrotor is derived based on the Newton – Euler equation. Let $E = \{X_E, Y_E, Z_E\}$ denote an inertial frame and $B = \{X_B, Y_B, Z_B\}$ denote frame by a position vector (x, y, z) and three Euler angles(ϕ, θ, ψ) representing roll, pitch and yaw respectively. All equations are expressed in the inertial frame. The vehicle is assumed to be rigid and symmetrical The centre of mass, centre of gravity and origin of body axis are assumed to be coincident. The rotation matrix from the body frame to the inertial frame for the coordinate system is obtained as;

$$ {}_B^ER = {}_B^E\mathrm{R}_Z * {}_B^ER_Y * {}_B^ER_X \qquad (1)$$

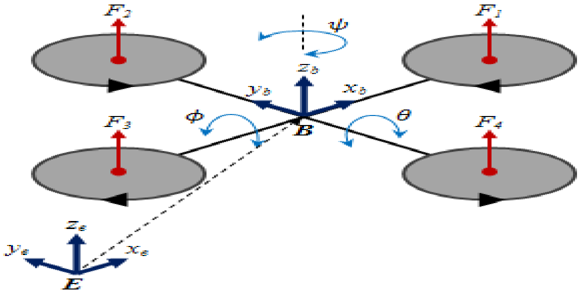

Fig 2: Coordinate system

$$ {}_B^ER = \begin{bmatrix} cos\psi & -sin\psi & 0 \\ sin\psi & cos\psi & 0 \\ 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} cos\theta & 0 & sin\theta \\ 0 & 1 & 0 \\ -sin\theta & 0 & cos\theta \end{bmatrix} * \begin{bmatrix} 1 & 0 & 0 \\ 0 & cos\phi & sin\phi \\ 0 & -sin\phi & cos\phi \end{bmatrix} $$

$$ {}_B^ER = \begin{bmatrix} cos\theta cos\phi & cos\phi sin\theta sin\psi - sin\phi cos\psi & cos\phi sin\theta cos\psi + sin\phi sin\psi \\ cos\phi sin\theta & sin\phi sin\theta sin\psi + cos\phi cos\psi & sin\phi sin\theta cos\psi - cos\phi sin\psi \\ -sin\theta & cos\theta sin\psi & cos\theta cos\psi \end{bmatrix} \quad (2)$$

The three matrices ${}_B^ER_X, {}_B^ER_Y, {}_B^ER_Z$ are generated by the rotations about X_B , Y_B and Z_B respectively. The rotors are paired such that the total moment induced is zero. By the experimental results, at low speed these moments are independent of the thrust forces produced by the four rotors. As the drags are negligible at low speed, the drag coefficients are assumed to be zero and the simplified form of the quadrotor model is presented as;

$\ddot{x}$=U_1(cosϕsinθcosψ-sinϕsinψ)
$\ddot{y}$=U_1(cosϕsinθsinψ+sinϕcosψ)
$\ddot{z}$=U_1(cosϕcosθ)-g
$\ddot{\phi}$=U_2l
$\ddot{\theta}$=U_3l
$\ddot{\psi}$=U_4 (3)

where the U_1,U_2,U_3 and U_4 are the input forces.

III CONTROLLER DESIGN

PID controller is one of the well known and mostly used controlling methods which is used for the past few years in many applications relating robotics and aerial vehicle design. In conventional PID controller, proportional gain produce a steady state error for any input signal but the integral action enables the controller to eliminate the offset. The derivative control mode gives a controller additional control action when the error changes consistently. It also makes the loop more stable (up to a point) which allows using a higher controller gain and a faster integral (shorter integral time or higher integral gain).These have the effect of reducing the maximum deviation of process variable from set point if the process receives and external disturbance.

In recent years, adaptive PID controller is proposed and is used in several applications and in this research; we use this controller in a specific form for controlling the flying quadrotor. Each of the controller's gains are multiplied in a ratio (w_1,w_2,w_3) and the controller's output is limited by Sigmund function.(6)

$$C=T(N) \tag{4}$$

$$N=(e*k_p*w_1)+(\int e*k_i*w_2)+\dot{e}*k_d*w_3 \tag{5}$$

where C is the control signal and the e is the error.

$$T(N)=\frac{1}{1+e^{-N}} \tag{6}$$

For updating w_1,w_2,w_3, it is trying to minimize an equation which describes the performance criterion of controlling system based error. It was used gradient values for updating these controller's coefficients in each step time by a recursive equation similar to the Steepest Descent Algorithm. Although controller's output is a value in a range of [0,1],we can adaptively change the controller's output in a custom range by multiplying with an arbitrary number.

$$F=\frac{1}{2}(D-Y)^2 \tag{7}$$

where D is the desired value of the plant,Y is the plant output and F is the performance criterion.The controller is adapted by means of parameter adaptation law.

$$W(t+1)=W(t)-\gamma\frac{\partial F}{\partial W} \tag{8}$$

For optimizing the adaptive PI controller coefficients (w_1,w_2,w_3), performance criterion should be minimized then using the adaptation law in each step, coefficients are updated.

IV. SIMULATION RESULTS AND DISCUSSIONS

The controller derived and presented in section 3 are simulated using MATLAB Simulink. The primary values for the weights w_1,w_2,w_3 are assumed to be zero. Initially,the controller gains k_p,k_i,k_d are considered as random values. Using trial and error 0.3 is considered for γ which is same for any change in w_1,w_2,w_3.

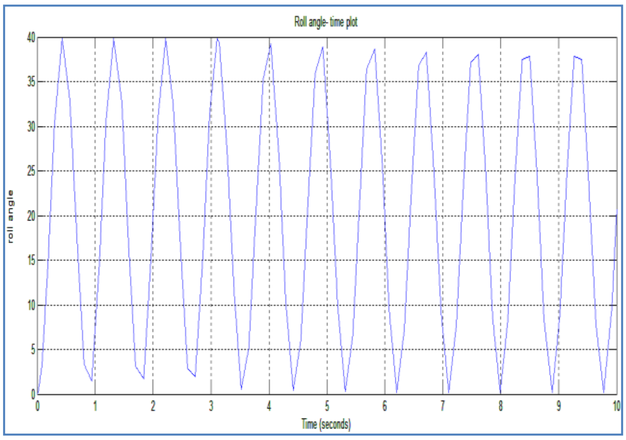

Fig 3:Variation of roll angle with time without controller.

The simulation result shows oscillations for an uncompensated system. Simulation is carried out with conventional PI and PID for comparing the performance of these controllers and to analyse the effect of controller gains on the quadrotor motion with zero input and 0.1 initial condition.The simulation using conventional PI controller is as shown in fig 4. The simulation results shows that the system oscillations are reduced to a small extend by the integral action. Like PI, PID also produce transient oscillations.(fig 5).

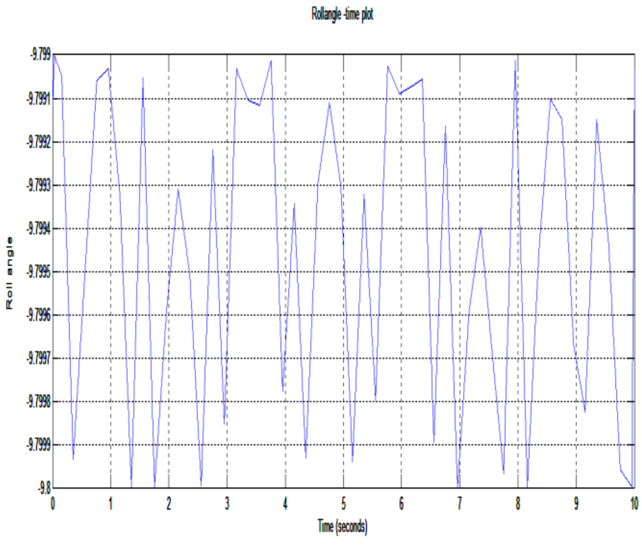

Fig 5: Variation of roll angle with time with conventional PI controller

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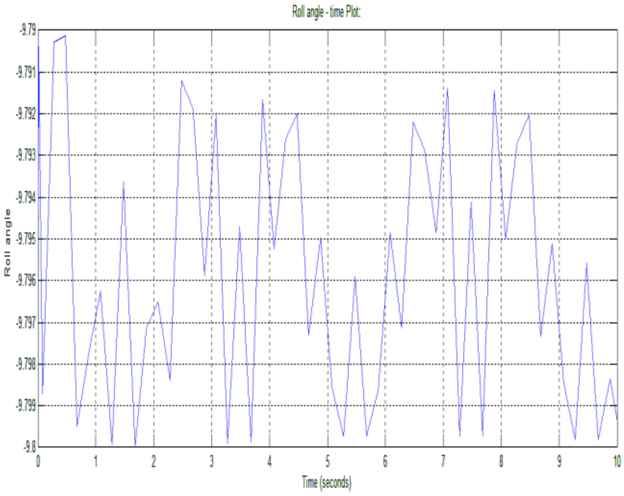

Fig 5: Variation of roll angle with time with conventional PID controller

By adding the adaptive part to the controller design, the simulation results are shown in fig 6 and fig 7 and we solve the regulation problem with atmost 80% reduced transient oscillations. The proposed algorithm thereby succeeds in the eliminations of oscillations and hence improved performance.

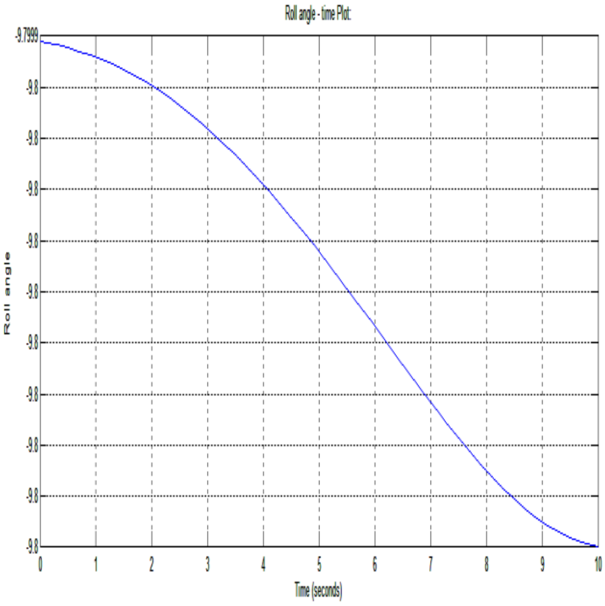

Fig 6: Variation of roll angle with time with adaptive PI controller

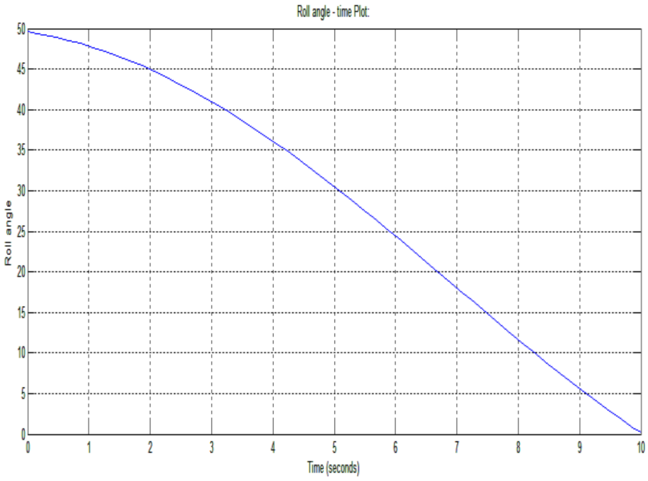

Fig 7: Variation of roll angle with time with adaptive PID controller.

V CONCLUSIONS

A linear quadrotor system with unstable dynamics was under consideration with a constant coefficient of drag. Conventional PID suffers a lot of disadvantages in terms of performance specifications and stability. It even fails in parameter adaptation, since the system is highly non linear and full of uncertainities. Therefore an adaptive strategy is incorporated along with a PID controller, which helps in reducing the transient oscillations. According to the simulations, this combination helps in reducing transient oscillations.

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