International Journal of Engineering, Management, Humanities and Social Sciences Paradigms (IJEMHS)
(Volume 30, Issue: Special), April 2018
An Indexed and Referred Journal with Impact Factor: 2.75
ISSN (Online): 2347-601X
www.ijemhs.com

An Adaptive Integral Backstepping ControlApproach for UAV

Jitamitra Mohanty, Assistant Professor, Department of Electrical Engineering, Krupajal Engineering College, Bhubaneswar
Sangram Keshari Sahoo, Assistant Professor, Department of Electrical Engineering, NM Institute Of Engineering & Tech, Bhubaneswar
Saranjib Biswal, UG Student, Department of Electrical Engineering, Krupajal Engineering College, Bhubaneswar
Suryakanta Sahoo, UG Student, Department of Electrical Engineering, Krupajal Engineering College, Bhubaneswar

***Abstract*— An adaptive integral backstepping controller is designed for lateral track error control in an unmanned aerial vehicle.UAV's are a part of an unmanned aircraft system which consists of a ground based controller, a UAV and a system of communications between them. Backstepping is a recursive procedure where a nonlinear system is divided into several subsystems and a virtual control law is derived for each subsystem. Then, lyapunov function is derived for the entire system and it is proven to be asymptotically stable. The integral action will increase the system stability in the case of external disturbances and the adaptation law is used for the estimation of the modeling errors. Software implementation is executed with the help of MATLAB Simulink.**

Keywords—Adaptive Integral Backstepping; Lyapunov Function; Unmanned Aircraft System;

I. INTRODUCTION

UAV stands for unmanned aerial vehicle which is also known as drone is an aircraft without onboard human pilot. It is a part of an unmanned aircraft system that consists of a ground based controller, and unmanned aerial vehicle and a system of communications between the two. Mainly they are of two types of UAV autonomous and semi autonomous. In autonomous version computer software as well as electronic hardware acts as the vehicle's brain for accomplishing a desired mission. In semi-autonomous version a human pilot is controlling the aircraft using a remote controller. UAV's were originally used for missions that are too dangerous for humans or too dirty.

UAV innovations started in early 1900s and initially focused on training military personnel's by providing as practice targets. UAV's are currently used for many purposes such as they are employed for the simulation of enemy aircraft and missiles, used in dangerous situations and have attack capabilities, used for civil and commercial purposes, used for battlefield intelligent purposes etc.UAV has an excellent hovering capability so it can be widely used for surveillance and exploration in both indoor and outdoor environments. However, the high performance control of UAV is a difficult task because it is an underactuated system with strong nonlinear and coupling characteristics. Here the control of nonlinear model of a UAV is discussed. Our aim is to reduce the lateral track error as small as possible during its flight.

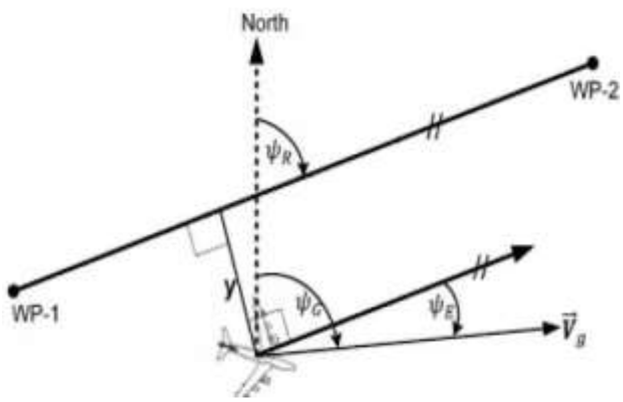
In the past few years ,different methods are used for the control of UAV due to its wide range of applications. It is a highly nonlinear system which is affected by aerodynamic disturbances and uncertainties. Linearizing the system will result in an incomplete model due to the cancelling of useful nonlinearities. To overcome the limitations of the conventional linear designs nonlinear designs are introduced.

In [1] a robust adaptive backstepping control law is proposed to solve the stabilization control problem of an inverted pendulum. The control algorithm exhibits a stable control performance in the presence of disturbances. The performance of the controller is tested against various external disturbances. Cao Lijia et.al [2] considers the problem of nonlinear system with lump uncertainties. It proposes a robust adaptive backstepping control method by using Lyapunov function techniques which is applied to the altitude control of an UAV. A command filtering approach is introduced in the design procedure to avoid the problem of explosion of complexity. Adaptive backstepping approach for the control of longitudinal dynamics of the aircraft is discussed in [3].A sliding surface adaptive backstepping controller approach is employed to control and stabilize an underactuated Quadrotor UAV system with unknown parameters in [4].A sliding surface is also incorporated in to the system to ensure better regulation.

II. SYSTEM MODELLING

Fig 1 Control problem definition

During the flight of a UAV the desired path is defined by using a no of waypoints. As in fig 1 WP-1 and WP-2 be the two waypoints that shows the desired flight path. Our aim is to reduce the lateral deviation from WP-1 to Wp-2 during a desired flight in the presence of external disturbances. Let V_g be the ground velocity. Ψ_R be the angle of the line WP-1 and WP-2 with respect to North. It is also known as desired heading angle. Ψ_G is the angle of ground velocity with respect to North. It is also known as velocity heading angle. The lateral track error is denoted by y. The intercept course or heading error $\Psi_E = \Psi_G - \Psi_R$ ie the difference between actual velocity heading angle and the desired heading angle. The main aim is to reduce lateral track error y as small as possible ie $\Psi_E \approx 0$ when $y \approx 0$.Acomponent of aerodynamic lift is



used by aerial vehicles so that lateral track error is reduced by generating lateral acceleration. Banking or rolling of vehicle helps to produce lateral acceleration.

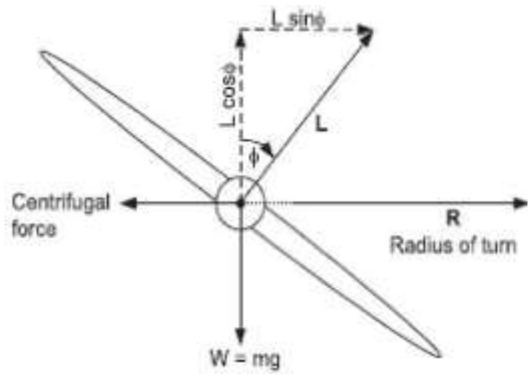


Fig 2 Component of lift during steady level flight

Taking only V for ground velocity and equating vertical component of ground velocity to rate of change of lateral distance y.

$$\dot{y} = V\sin\Psi_E \tag{1}$$

As shown in fig 2 the vertical component of lift is balanced by weight and the horizontal component of lift is balanced by centrifugal force.the aircraft is banked at an angle ϕ during a steady coordinated turn.

$$L\cos\phi = mg \tag{2}$$

$$L\sin\phi = mV^2/R \tag{3}$$

Where L is the lift, R is the radius of turn, g is the gravitational force, m is the mass of the vehicle, ϕ is the bank angle, V is the ground speed.

From (2) and (3)

$$\tan\phi = V^2/Rg \tag{4}$$

During a stedy turn relation between tangential and angular velocity is given by

$$V = R\Psi_G \tag{5}$$

$$\tan\phi = (V\,\dot{\Psi}_G)/g \tag{6}$$

Assuming outer control loop dynamics slower than the inner control loop dynamics $\phi \approx \phi_R$ and reference path course will not change quickly ie $\dot{\Psi}_R \approx 0$, $\dot{\Psi}_E \approx \dot{\Psi}_G$ then equation (6) becomes

$$\tan\phi_R = (V\,\dot{\Psi}_E)/g \tag{7}$$

Let u= tan ϕ_R be the control i/p

$$u = (V\,\dot{\Psi}_E)/g \tag{8}$$

Then the state equations are

$$\dot{Y} = V\sin\Psi_E \tag{9}$$

$$\dot{\Psi}_E = (g/V)u \tag{10}$$

III. ADAPTIVE INTEGRAL BACKSTEPING CONTROLLER DESIGN

A. Backstepping controller design

$$\dot{Y} = V\sin\Psi_E \tag{11}$$

$$\dot{\Psi}_E = (g/V)u \tag{12}$$

Let $x_1 = y$ and $x_3 = \Psi_E$

Therefore the state enqs are

$$\dot{x}_1 = x_2$$

$$\dot{x}_2 = gu\cos x_3$$

Let the lyapunov function be

$$V_1(x) = (1/2)\,x_1^2$$

$$\dot{V}_1(x) = x_1 x_2$$

$$x_2^{des} = -\,c_1 x_1$$

ie $\dot{V}_1(x) = -c_1 x_1^2 < 0$

Therefore the system is asymptotically stable since the first derivative of lyapunov function is negative definite. Let an error variable be defined as $z = x_2 - x_2^{des}$ for change of coordinates.

Considering subsystem 2 ,Let the lyapunov function be

$$V_2(x) = (1/2)x_1^2 + (1/2)\,z^2$$

$$\dot{V}_2(x) = -c_1 x_1^2 + z\dot{z}$$

Sub $\dot{z} = gu\cos x_3 + c_1 x_2$ in $\dot{V}_2(x)$

$$\dot{V}_2(x) = -c_1 x_1^2 + z[gu\cos x_3 + c_1 x_2]$$

To make $\dot{V}_2(x)$ negative definite globally stabilizing control law is

$$u = (1/g\cos x_3)(-c_1 x_2 - c_2 z) \tag{13}$$

Sub in $\dot{V}_2(x) = -\,c_1 x_1^2 - c_2 z^2 < 0$

So the system ensures asymptotic stability in the design phase itself.

B. Adaptive integral backstepping controller design

The state equations are

$$\dot{x}_1 = x_2 \tag{14}$$

$$\dot{x}_2 = \phi u\cos x_3 \tag{15}$$

where ϕ is an unknown constant parameter and is taken as

$$\phi = g\cos x_3 \tag{16}$$

Considering subsystem 1, Let the lyapunov function be

$$V_1(x) = (1/2)\,x_1^2$$

$$\dot{V}_1(x) = x_1 x_2$$

$$x_2^{des} = -\,c_1 x_1$$

ie $\dot{V}_1(x) = -c_1 x_1^2 < 0$

Therefore the system is asymptotically stable since the first derivative of lyapunov function is negative definite. Let an error variable be defined as $z = x_2 - x_2^{des}$ for change of coordinates.

$$\dot{z} = \dot{x}_2 - \dot{x}_2^{des}$$

$$\dot{z} = \phi u + c_1 x_2$$

Considering subsystem 2 ,Let the lyapunov function be

$$V_2(X) = \frac{1}{2}X_1^2 + \frac{1}{2}Z^2 + \frac{1}{2\gamma}\tilde{\phi}^2$$

Where

$$\tilde{\phi} = \phi - \hat{\phi}$$

$$\dot{V}_2(x) = -c_1 x_1^2 + z\dot{z} + \frac{1}{\gamma_1}\tilde{\phi}\dot{\tilde{\phi}}$$

Sub $\dot{z}$ in $\dot{V}_2(x)$ then the control law is obtained as

$$u = (1/\hat{\phi}\cos x_3)[-c_1 x_2 - c_2 z] \tag{17}$$

The parameter adaptation law is obtained as

$$\dot{\hat{\phi}} = z\gamma u \cos x_3 \tag{18}$$

Then the derivative

$$\dot{V}_2(x) = -c_1 x_1^2 - c_2 z^2 < 0$$

Eqn (17) and eqn (18) will ensure asymptotic stability of the system.

IV. SIMULATION RESULTS AND DISCUSSIONS

In this section the performance of adaptive integral backstepping controller for the lateral track error control is discussed. Table 1 show the values of parameters which are used for the simulation.

TABLE 1 Simulation Parameter Values

Parameter	Description	Values	Units
m	Aircraft Mass	10	Kg
Q	Dynamic Pressure	80.05	
S	Wing Area	0.2712	m^2
I_x	Moment of inertia around X-axis	0.14641	Kg. m^2
I_Y	Moment of inertia around Y-axis	0.11995	Kg. m^2
I_z	Moment of inertia around Z-axis	0.26547	Kg. m^2
g	Acceleration due to gravity	9.8	m/s^2
m_a	Empty Weight	0.0568	Kg
AR	Aspect Ratio	2.42	
γ	Adaptation Gain	0.2	
V_a	Aircraft Velocity	11.432	m/s

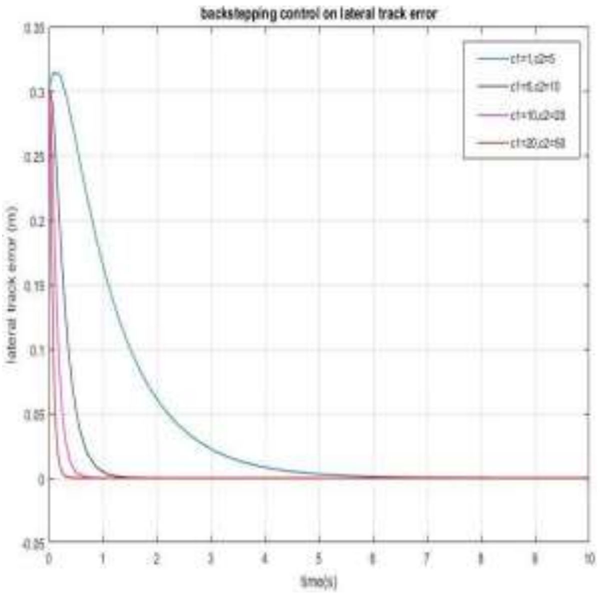


Fig 3 Variation of lateral track error w.r.t time.

Fig 3 shows the variation of lateral track error when backstepping controller is applied to the system with an initial condition 0.3.When c1=1 and c2=5 small overshoot is obtained and settling time is about nearly 6 sec. As c1and c2 is increased the settling time is reduced. At c1=20 and c2=50 the settling time is about 0. 5sec which shows that the regulation holds good for high values of gain.

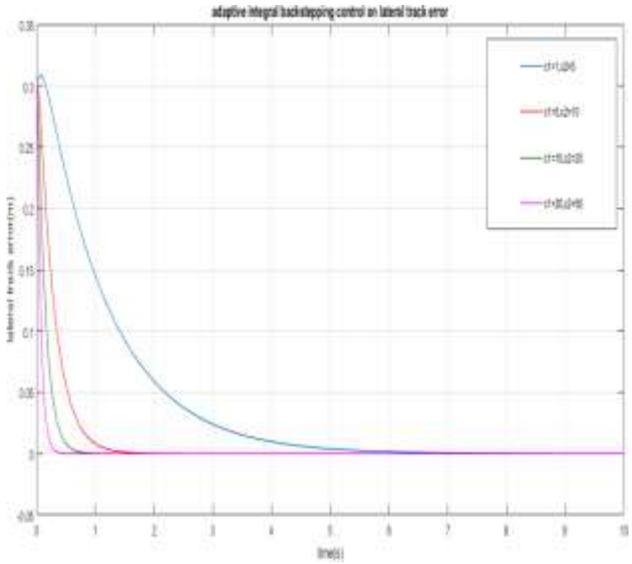


Fig 4 Variation of lateral track error w.r.t time (AIBC)

Fig 4 shows the variation of lateral track error when adaptive integral backstepping controller is applied to the system with an initial condition 0.3.When c1=1 and c2=5 small overshoot is obtained and settling time is about nearly 6.2 sec. As c1and c2 is increased the settling time is reduced. At c1=20 and c2=50 the settling time is about 0. 6 sec. From the simulation results, we can say that the system converges to zero. i.e. regulation holds good. And we can obtain better performance while increasing the gain values.

V. CONCLUSION

The UAV is a highly coupled, nonlinear system which is stabilized by using the adaptive integral backstepping controller. The lateral track error is minimized even in the presence of external disturbances and uncertainties. Simulation results show that the proposed controller performs well than the backstepping controller. Even though settling time is slightly increased in an adaptive integral backstepping controller because there are unknown parameters in its design so that system takes time to find out these parameters and regulate but all the errors will be regulated to zero ie the system converges to zero in the presence of external disturbances and uncertainties. Proposed controller ensures better regulation.

REFERENCES

[1] Shubhobrata Rudra And Ranjith Kumar Barai ,"Robust Adaptive Backstepping Control Of Inverted Pendulum On Cart System "International journal of control and automation Vol.5, No.1, March 2012.

[2] Cao Lijia,Hu Xiaoxiang and Guo Yang, "Robust Adaptive Backstepping Control Of Uav With Lumped Uncertainties" 2014 international conference on mechatronics and control, july 3-5 ,2014.

[3] Aiswarya Raj & Ashima C R, "Adaptive Backstepping Approach For Longitudinal Control Of Aircraft Unmanned Aerial Vehicles." IARJSET Vol.3, August 2016

[4] Athulya R S & Ashima C R, "Adaptive Backstepping control of quadrotor unmanned aerial vehicles" IARJSET Vol.3, August 2016.

[5] Tushar Kanti Roy, "Robust Adaptive Backstepping Controller Design For Rejecting External Wing Gust Effect In An Uav" European scientific journal vol 11,no.36,December 2015.