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# Advance Robust Nonlinear Control Algorithm for Quadrotor Applications

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Abstract: One of the main challenges for quadrotor is desired trajectory tracking in presence of external disturbances. This paper addresses the quadrotor tracking control for external disturbances. Quadrotor dynamic modeling is taken by considering drag forces, aerodynamic friction and gyroscopic effects. So the new state space model is represented for the mathematical modeling of quadrotor. Two non linear controllers, sliding mode controller and backstepping controller are combined. The new sliding surface is designed using Lyapunov based adaptive law to compensate for the effect of external disturbances. The new law is asymptotically stable as tracking errors are reduced to zero. The controller algorithm is implemented using MATLAB simulations and compares with the nominal SMC with backstepping controller. And results shows new law is successfully compensate the external disturbances.

## *Index Terms*- Matlab, sliding mode control (SMC), Backstepping control (BSC)

### I. INTRODUCTION

The quadrotor is also known as quadcopter and it is characterized by a unique four rotor design. It has the ability to take off and land vertically even in a small place. Firstly these are developed mainly for military application purposes but because of its various advantages these are inevitable in many applications like agriculture, aerial photography etc. the critical aspect of the quadrotor is trajectory tracking which is an intense research area in recent years. Because of quadrotor nonlinear dynamics, controlling is a challenging task. In the presence of external disturbances it is difficult to achieve desired trajectory and stability of the system.

Mathematical modeling of the quadrotor is a difficult task, several quadrotor models like non linear model, quaternion model and near hover position model was discussed [1]. These mathematical models are represented in state space form. To implement the control techniques on dynamics of quadrotor state space modeling is easy [2]. Inertia, drag forces, aerodynamic friction and gyroscopic effects are considered for more effective modeling of the quadrotor [3].

Many linear and nonlinear control strategies were applied to the quadrotor Unmanned Aerial Vehicle (UAV), such as PD control, PID control, Trajectory Linearization Control (TLC), Sliding Mode Controller (SMC), Backstepping Controller (BSC) etc [24][25]. PID controller is a most popular controller but main disadvantage is tuning the controller gain which is a tedious process. Most of the PID controllers are focusing on tuning these controller gains. Two degrees of freedom PID controllers with tuning parameters individually without affecting the other parameters proposed [4]. Adaptive PID controller with particle swarm optimization used for automatic tuning based on strictly negative imaginary theory [5]. A nonlinear PID controller with Hurwitz stability theorem is used genetic algorithm is used for tuning the parameters [6]. Intelligent active force control integrated with PID controller is used to stabilize quadrotor and to compensate the external disturbances [7]. Backstepping control is well suited for stabilize nonlinear dynamic systems. It starts by defining a set of virtual control inputs then by using virtual control laws state variables are stabilized using recursive scheme. This paper proposed backstepping controller integrated with an auxiliary input saturation compensator, disturbance observer is employed and finite time stability is derived [8]. An adaptive neural tracking control law based back stepping control is designed which avoids singularity problem of virtual controls [9]. For quadrotor slung load, a nonlinear backstepping controller is used by introducing virtual thrust force for position control [10]. An adaptive backstepping controller is designed to overcome the problem of unknown input gains and improves tracking performance [11]. Robust backstepping control proposed the wind estimator is designed using neural networks levenberg marquart algorithm with back propagation [12]. Sliding mode controller, sliding surface is designed and controller is designed to derive the state trajectory onto the sliding surface and then maintain it there. It is a robust and nonlinear control technique and its main drawback is chattering problem. Both PID and sliding mode controller are designed by using iteration method coefficients are tuned [13]. Non singular fast terminal sliding mode control is proposed and to estimate the unknown external disturbances a nonlinear disturbance observer is designed for robust performance [14]. An adaptive fractional order nonsingular fast terminal sliding mode controller is designed for fast time convergence and reject uncertainties [15]. An adaptive sliding mode controller is proposed and these adaptive laws are used to detect actuator faults and improve the stability [16]. Sliding mode controller is integrated with neural network algorithm, which results in time varying sliding surfaces [17]. To estimate upper bounds of disturbance and physical parameters adaptive

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second order system based sliding mode controller is designed [18]. Sliding mode controller integrated with fuzzy network is proposed to compensate the external disturbances [19]. Appointed fixed time sliding mode controller is designed and its stability is verified using Lyapunov theorem [20]. Robust sliding mode controller with PID controller is designed observer estimate the disturbances and ensures exponential convergence [21]. Sliding mode controller is integrated with iterative learning control, this algorithm force the state trajectory on to the sliding surface without need of accurate dynamics of quadrotor [22]. A gain scheduling based SMC law is synthesized to compensate the presence of uncertainties in the system and it is integrated with nonlinear disturbance observer to reduce disturbances [23]. This paper presents sliding mode backstepping controller with new Lyapunov based adaptive law to compensate the external disturbances. This control strategy is effective for trajectory tracking of quadrotor as it combines the advantages of both sliding mode controller and back stepping controller. This approach offers robust and accurate trajectory tracking capabilities in the presence of external disturbances and complex dynamics. The main contribution of the paper is summarized as follows. i) The quadrotor model is developed by considering aerodynamic friction torques gyroscopic effects and drag forces. ii) The state space model is designed by considering all system nonlinearities. iii) Backstepping sliding mode controller is designed. iv) Lyapunov based new adaptive law is synthesized to compensate the disturbances. The rest of the paper is arranged as follows. Section II describes the modeling of the quadrotor. Section III describes the controller design and laws. Section IV presents simulation results of the proposed controller. Section V carries the conclusion.

#### **II. QUADROTOR DYNAMIC MODELLING:**

In this section we will discuss the mathematical model of a symmetrical rigid quadrotor based on Newton-Euler formulation. Quadrotor is equipped with four rotors that are directed upwards. It is an underactauted system with four inputs to control six degrees of freedom. Input thrust is generated by four propellers, which can be controlled. Six degrees of freedom in space includes translation motion x, y and z in three directions and rotational motion roll, pitch and yaw around three axes. For the quadrotor kinematic and dynamic equations are derived in both the inertial frame and the body fixed frame, assuming that the center of gravity of the quadrotor coincides with the origin of the body fixed frame. The transformation from the inertial reference frame to the body fixed reference frame of the quadrotor is given by a rotational matrix.

$$R_{i}^{b}(\phi,\theta,\psi) = \begin{pmatrix} c\theta c\psi & c\theta s\psi & -s\theta \\ s\phi s\theta c\psi - c\phi s\psi & s\phi s\theta s\psi + c\phi c\psi & s\phi c\theta \\ c\phi s\theta c\phi + s\phi s\psi & c\phi s\theta s\psi - s\phi c\psi & c\phi c\theta \end{pmatrix}$$
(1)

where  $c \triangleq cos$  and  $s \triangleq sin$ .

The position derivative vector P is in the inertial frame and the velocity vector V is in the body frame. They can be related to each other through a rotational matrix such as  $P = R_i^b(\phi, \theta, \psi) V$  where  $P = (\dot{x}, \dot{y}, \dot{z})^T$  and  $V = (u, v, w)^T$ , and the angular derivative vector  $R = (p, q, r)^T$  and angular velocity vector  $A = (\dot{\phi} \ \dot{\theta} \ \dot{\psi})^T$  are related by the equation

$$\begin{pmatrix} \phi \\ \dot{\theta} \\ \dot{\psi} \end{pmatrix} = \begin{pmatrix} 1 & s(\phi) t(\theta) & c(\phi) t(\theta) \\ 0 & c(\phi) & -s(\phi) \\ 0 & s(\phi) \sec(\theta) & c(\phi) \sec(\theta) \end{pmatrix} \begin{pmatrix} p \\ q \\ r \end{pmatrix}$$
(2)  
where  $s(.) = \sin(.), t(.) = \tan(.)$  and  $c(.) = \cos(.)$ 

Translational dynamic equations of the quadrotor can be written by using Newton's laws as below

$$\dot{V} = \begin{pmatrix} 0 & -r & q \\ r & 0 & -p \\ -q & p & 0 \end{pmatrix} V \tag{3}$$

Above matrix is skew symmetric matrix.

 $m\dot{P} = F_r + F_g + F_d$ 

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Where total mass of the quadrotor is represented by m,  $F_r$  is the resultant forces which are generated by the four rotors,  $F_g$  is the force of the gravity and  $F_d$  is the resultant drag forces along translation axis which are given as

$$F_r = \begin{pmatrix} c\phi s\theta c\phi + s\phi s\phi \\ c\phi s\theta s\psi - s\phi c\psi \\ c\phi c\theta \end{pmatrix} U_1$$
(5)

where  $c(.) = \cos(.)$  and  $s(.) = \sin(.)$  respectively

$$F_{g} = \begin{bmatrix} 0 & 0 & -Mg \end{bmatrix}$$

$$F_{d} = \begin{pmatrix} -K_{dx} & 0 & 0 \\ 0 & -K_{dy} & 0 \\ 0 & 0 & -K_{dz} \end{pmatrix} P$$
(6)
(7)

Such as  $K_{dx}$ ,  $K_{dy}$  and  $K_{dz}$  are the translation drag coefficients.

Rotational dynamic equations of the quadrotor can be derived by using Newton's laws as follows

$$A = -A \times J_b A + \tau_r - \tau_a - \tau_g$$
(8)  
where  $J_b$  is the matrix that represents quadrotor constant inertia in a symmetric manner
$$(I = 0, 0)$$

$$J_b = \begin{pmatrix} J_x & 0 & 0 \\ 0 & J_y & 0 \\ 0 & 0 & I_z \end{pmatrix}$$
(9)

Rotor torques developed by the quadrotor is denoted by  $\tau_r$  and it is expressed as follows

$$\tau_r = \begin{pmatrix} l U_2 \\ l U_3 \\ U_4 \end{pmatrix} \tag{10}$$

 $\tau_a$  is the aerodynamic frictions torques expressed as follows

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$\tau_{a} = \begin{pmatrix} K_{ax} & 0 & 0\\ 0 & K_{ay} & 0\\ 0 & 0 & K_{ay} \end{pmatrix} R^{2}$	(11)
$\begin{pmatrix} 0 & 0 & K_{az} \end{pmatrix}$	
$\tau_a$ is the resultant torque caused by the gyroscopic	
effects which is expressed as	
$\tau_g = \sum_{i=1}^4 R \times J_r (-1)^{i+1} \Omega$	(12)
$J_r$ is the rotor inertia and $\Omega$ is the rotor speed of the quadrotor expressed as $\Omega = \Omega_1 - \Omega_2 + \Omega_2 - \Omega_4$	(13)
The control inputs are derived using angular velocities as	()
$\begin{bmatrix} U_1 \\ \cdots \end{bmatrix} \begin{pmatrix} K_P & K_P & K_P & K_P \end{pmatrix} \begin{bmatrix} \Omega_1^2 \\ \Omega_2^2 \end{bmatrix}$	
$\begin{bmatrix} U_2 \\ U_2 \end{bmatrix} = \begin{bmatrix} -K_P & 0 & K_P & 0 \\ 0 & -K_P & 0 & K_P \end{bmatrix} \begin{bmatrix} \Omega_2^2 \\ \Omega_2^2 \end{bmatrix}$	(14)
$\begin{bmatrix} 0\\ U_4 \end{bmatrix}  \begin{pmatrix} 0 & H_F & 0 & H_F \\ K_d & -K_d & K_d & -K_d \end{pmatrix} \begin{bmatrix} \Omega_3\\ \Omega_1^2 \end{bmatrix}$	
where $K_P$ and $K_d$ are the thrust and drag coefficients respectively.	
Quadrotor uses four rotors powered by DC motors and the rotor model is expressed as $\Sigma^4$ , $\hat{c}_{12}$ , $c$	
$\sum_{i=1}^{T} \Omega_i = b \sum_{i=1}^{T} V_i - \beta_0 - \beta_1 \sum_{i=1}^{T} \Omega_i - \beta_2 \sum_{i=1}^{T} \Omega_i^T$	(15)
<b>III. CONTROLLER DESIGN</b> The above quadrotor mathematical model can be represented by the state space model as	
$\dot{X} = f(X, U)$	
The symbols X and U represent the state vector and control inputs, respectively	
$X = \begin{bmatrix} \phi & \phi & \theta & \psi & \psi & x & \dot{x} & \dot{y} & y & z & \dot{z} \end{bmatrix}^{T}$ $U = \begin{bmatrix} U_{1} & U_{2} & U_{2} & U_{4} \end{bmatrix}^{T}$	(16)
$\ddot{\phi} = \frac{(J_y - J_z)}{ar + l} ar + \frac{l}{2} U_2 - \frac{1}{2} (K_{zz} \dot{\phi}^2 - L_z \Omega \dot{\theta})$	(17)
$\ddot{\theta} = \frac{J_z - J_x}{J_x} m + \frac{L}{J_x} U = \frac{1}{J_x} \left( K \dot{\theta}^2 + L \dot{\theta} \dot{\theta} \right)$	(10)
$\ddot{U} = \frac{1}{J_y} p_1 + \frac{1}{J_y} U_3 = \frac{1}{J_y} (\Lambda_{ay} U + \frac{1}{J_r} 22\psi)$	(19)
$\psi = \frac{1}{J_z} pq + \frac{1}{J_z} o_4 - \frac{1}{J_z} \kappa_{az} \psi^2$ $\ddot{v} = (c \phi_z \rho_z c_h + z \phi_z c_h) \frac{u_1}{J_z} - \frac{\kappa_{dx}}{\kappa_{dx}} \dot{x}$	(20)
$\dot{x} = (c\phi s \delta c \phi + s\phi s \phi) \frac{1}{m} - \frac{1}{m} x$	(21)
$y = (c\varphi s\theta s\varphi - s\varphi c\varphi) \frac{1}{m} - \frac{1}{m} y$	(22)
$Z = (C\varphi C\theta) \frac{d}{m} - g - \frac{d}{m} Z$ This pop linear dynamic model can be represented in state space model with external disturbance	(23)
$\dot{\phi} = \dot{x}_1 = x_2$	(24)
$\ddot{\phi} = \dot{x}_2 = a_1 x_4 x_6 + a_2 x_2^2 + a_3 \Omega x_4 + b_1 U_2 + d_{\phi}$	(25)
$\dot{\theta} = \dot{x}_3 = x_4$	(26)
$\ddot{\theta} = \dot{x}_4 = a_4 x_2 x_6 + a_5 x_4^2 + a_6 \Omega x_2 + b_2 U_3 + d_\theta$	(27)
$\dot{\psi} = \dot{x}_5 = x_6$	(28)
$\ddot{\psi} = \dot{x}_6 = a_7 x_2 x_4 + a_8 x_6^2 + b_3 U_4 + d_{\psi}$	(29)
$\dot{x} = \dot{x}_7 = x_8$	(30)
$\ddot{x} = \dot{x}_8 = a_9 x_8 + \left( U_x * \frac{U_1}{m} \right) + d_x$	(31)
$\dot{y} = \dot{x}_9 = x_{10}$	(32)
$\ddot{y} = \dot{x}_{10} = a_{10}x_{10} + (U_y * \frac{U_1}{m}) + d_y$	(33)
$\dot{z} = \dot{x}_{11} = x_{12}$	(34)
$\ddot{z} = \dot{x}_{12} = a_{11}x_{12} + \left(U_1 * \frac{(Cx_1 * Cx_3)}{m}\right) - g + d_z$	(35)
where	
$a_1 = \frac{J_y - J_z}{J_x}, a_4 = \frac{J_z - J_x}{J_y}, a_7 = \frac{J_x - J_y}{J_z}$	(36)
$a_2 = \frac{-\kappa_{ax}}{J_x}, a_5 = \frac{-\kappa_{ay}}{J_y}, a_8 = \frac{-\kappa_{az}}{J_z}$	(37)
$a_3 = \frac{-J_r}{J_x}, \ a_6 = \frac{-J_r}{J_y}$	(38)

$$a_9 = \frac{-\kappa_{dx}}{m}, a_{10} = \frac{-\kappa_{dy}}{m}, a_{11} = \frac{-\kappa_{dz}}{m}$$
(39)

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$b_1 = \frac{l}{J_x}, b_2 = \frac{l}{J_y}, b_3 = \frac{1}{J_z}$	(40)
$U_x = Cx_1 * Sx_3 * Cx_5 + Sx_1 * Sx_5$	(41)
$U_y = Cx_1 * Sx_3 * Cx_5 - Sx_1 * Cx_5$	(42)

#### **Backstepping Sliding mode control:**

This section introduces the SMC technique combined with Back-Stepping control technique and introduces an adaptive reaching law to create a robust controller for position trajectory tracking. As it combines advantages of both SMC and Back-stepping controllers, the sliding mode control is an effective approach for addressing nonlinear tracking problems that involve model uncertainties and external disturbances and back-stepping controller offers precise tracking and stable performance for quadrotor. An adaptive reaching law is proposed which dynamically adjusts the control inputs while handling external disturbances to ensure robust performance and to guide a system to a desired trajectory.

1. Roll Control: Poll Error is defined as	
Roll Effort is defined as $a = x$	(12)
$e_1 - x_{1d} - x_1$ where a is error x is desired roll and x is actual roll	(43)
Differentiating the roll error	
$\dot{\rho}_{i} = \dot{\gamma}_{i} = \dot{\gamma}_{i}$	(44)
$x_1 - x_{1d} - x_1$ Substituting from equation no 24	(++)
$\dot{\rho}_1 = \dot{\chi}_{1,1} - \chi_2$	(45)
The sliding surface $S_{A}$ is defined and $v_{A}$ is virtual control	(15)
$e_2 = S_0 = x_2 - v_1$	(46)
$x_2 = S_0 - v_1$	(47)
$\dot{e}_1 = \dot{x}_{1d} - S_0 + v_1$	(48)
The Lyapunov candidate chosen for this is	(10)
$V_{\rm c} = \frac{1}{2} \rho^2$	(49)
$V_1 = {}_2 V_1$	(+))
$\dot{V} = a \dot{a}$	(50)
$\dot{V}_1 = e_1 e_1$	(50)
$V_1 = e_1 \left( x_{1d} + v_1 - S_0 \right)$	(51)
The virtual control $v_1$ is designed to stabilize Lyapunov function as	(50)
$\dot{v}_1 = -x_{1d} - c_1 e_1$	(52)
$v_1 = e_1(-c_1e_1 - S_0)$	(53)
$V_1 = -c_1 e_1^2 - e_1 S_{\emptyset} < 0$	(54)
where $c_1$ is positive constant, and the subsystem is asymptotically stable.	
I he sliding surface time derivative is	
$e_2 = S_{\emptyset} = v_1 + x_2$	(55)
Lyapunov candidate chosen for this system is	
$V_2(e_1, S_{\emptyset}) = \frac{1}{2}(e_1^2 + S_{\emptyset}^2)$	(56)
Time derivative of the Lyapunov function is	
$\dot{V}_2(e_1, S_{\emptyset}) = e_1 \dot{e}_1 + S_{\emptyset} \dot{S}_{\emptyset}$	(57)
Necessary sliding condition required to stabilize is	
$\dot{S}_{\phi} = -q_1 sign(S_{\phi}) - k_1 S_{\phi}$	(58)
$\dot{V}_2(e_1, S_{\emptyset}) = -c_1 e_1^2 - e_1 S_{\emptyset} + S_{\emptyset}(-q_1 sign(S_{\emptyset}) - k_1 S_{\emptyset})$	(59)
$\dot{V}_2(e_1, S_{\emptyset}) = -c_1 e_1^2 - e_1 S_{\emptyset} - q_1 sign(S_{\emptyset}) S_{\emptyset} - k_1 S_{\emptyset}^2$	(60)
$\dot{V}_2(e_1, S_{\phi}) = -c_1 e_1^2 - e_1 S_{\phi} - q_1 sign(S_{\phi}) S_{\phi} - k_1 S_{\phi}^2 < 0$	(61)
System is asymptotically stable and control input can be obtained by	
$\dot{S}_{\phi} = -q_1 sign(S_{\phi}) - k_1 S_{\phi}$	(62)
$\dot{S}_{0} = -\ddot{x}_{1d} - c_{1}\dot{e}_{1} + \dot{x}_{2}$	(63)
$-a_1 sign(S_{\phi}) - k_1 S_{\phi} = -\ddot{x}_{1,d} - c_1 \dot{e}_1 + a_1 x_4 x_c + a_2 x_2^2 + a_2 \Omega x_4 + b_1 U_2$	(64)
$H = \frac{1}{2} \left( -a \operatorname{sign}(S_1) - k S_1 + \ddot{x}_1 + c \dot{a}_2 - a x x_1 - a x^2 - a \Omega x_1 \right)$	(65)
$b_{2} = b_{1} (-q_{1}s_{1}g_{1}(s_{0}) - \kappa_{1}s_{0} + \kappa_{1}d + c_{1}c_{1} - u_{1}\kappa_{4}\kappa_{6} - u_{2}\kappa_{2} - u_{3}s_{2}\kappa_{4})$	(03)
In this control input an adaptive control law which is proposed to compensate the external disturbances.	
$q_1 = k_{bar1} *  S_{\phi} $	(66)
where $k_{bar1}$ is a controller gain and $q_1$ is a state variable whose value changes.	
2. Pitch Control:	
Find the first defined as $a = x + x$	(67)
$\sigma_3 = \lambda_{3d} = \lambda_3$ Where $\rho_{13}$ is error $x_{13}$ is desired nitch and $x_{13}$ is actual nitch	(07)
Differentiating the nitch error	
$\dot{e}_{2} = \dot{x}_{2,2} - \dot{x}_{2}$	(68)
Substituting from equation no.26	(00)
$\dot{e}_3 = \dot{x}_{3d} - x_4$	(69)

The sliding surface  $S_{\theta}$  is defined and  $v_3$  is virtual control

$\begin{aligned} \mathbf{q}_{1} = \mathbf{b}_{1} = \mathbf{r}_{1} \\ \mathbf{q}_{2} = \mathbf{c}_{2} \\ \mathbf{q}_{1} = \mathbf{c}_{2} \\ \mathbf{q}_{2} \\ \mathbf{q}_{2} = \mathbf{c}_{1} \\ \mathbf{q}_{2} \\ \mathbf{q}_{2$	© 2023 JETIR November 2023, Volume 10, Issue 11	www.jetir.org (ISSN-2349-5162)
$\begin{aligned} x_1 = x_0 - x_0 + x_1 & (71) \\ (x_1 = x_0 + x_0 + x_0 + x_0 & (72) \\ The Lyapunov candidate chosen for this is \\ V_1 = x_0 + x_0 & (73) \\ The Lyapunov candidate chosen for this is \\ V_1 = x_0 + x_0 & (73) \\ The Lyapunov candidate chosen for this is \\ V_1 = x_0 + x_0 & (74) & (73) \\ The Lyapunov candidate of stabilize Lyapunov function as \\ V_1 = x_0 + x_0 & (74) & (75) \\ The Lyapunov candidate of stabilize Lyapunov function as \\ V_1 = x_0 + x_0 & (74) & (75) \\ V_1 = x_0 + x_0 + x_0 & (76) & (75) & (75) \\ V_1 = x_0 + x_0 + x_0 & (76) & (77) & (77) \\ V_2 = x_0 + x_0 + x_0 & (79) & (79) & (79) \\ V_1 = x_0 + x_0 & (79) & (79$	$\overline{e_4} = S_{\theta} = x_4 - v_3$	(70)
$\begin{aligned} c_1 = z_k - z_k - z_k + z_k \\ The L_1 appance candidate chosen for this is  V_k = z_k^2 - z_k^2 + z_k \\ (3) \\ Derivative of V_k$ is $\begin{aligned} V_k = z_k - z_k - z_k + z_k \\ (4) \\ V_k = z_k - (z_k - z_k - z_k) \\ (5) \\ Virtual control V_k$ is designed to stabilize Lyapunov function as $\begin{aligned} v_k = z_k - (z_k - z_k - z_k) \\ (5) \\ v_k = z_k - (z_k - z_k) \\ (5) \\ v_k = z_k - (z_k - z_k) \\ (5) \\ v_k = z_k - (z_k - z_k) \\ (5) \\ (5) \\ v_k = z_k - (z_k - z_k) \\ (5) \\ (5) \\ v_k = z_k - (z_k - z_k) \\ (5) \\ (5) \\ v_k = z_k - (z_k - z_k) \\ (5) \\ (5) \\ v_k = z_k - (z_k - z_k) \\ (5) \\ (5) \\ v_k = z_k - (z_k - z_k) \\ (5) \\ (5) \\ v_k = z_k - (z_k - z_k) \\ (5) \\ (5) \\ v_k = z_k - (z_k - z_k) \\ (5) \\ (5) \\ v_k = z_k - (z_k - z_k) \\ (5) \\ (5) \\ v_k = z_k - (z_k - z_k) \\ (5) \\ (5) \\ v_k = z_k - (z_k - z_k) \\ (5) \\ (5) \\ v_k = z_k - (z_k - z_k) \\ (5) \\ v_k = z_k - (z_k - z_k) \\ (5) \\ v_k = z_k - (z_k - z_k) \\ (5) \\ v_k = z_k - (z_k - z_k) \\ (5) \\ v_k = z_k - (z_k - z_k) \\ (5) \\ v_k = z_k - (z_k - z_k) \\ (5) \\ v_k = z_k - (z_k - z_k) \\ (5) \\ v_k = z_k - (z_k - z_k) \\ (5) \\ v_k = z_k - (z_k - z_k) \\ (5) \\ v_k = z_k - (z_k - z_k) \\ (5) \\ v_k = z_k - (z_k - z_k) \\ (5) \\ v_k = z_k - (z_k - z_k) \\ (5) \\ v_k = z_k - (z_k - z_k) \\ (5) \\ v_k = z_k - (z_k - z_k) \\ (6) \\ v_k = z_k - (z_k - z_k) \\ (6) \\ v_k = z_k - (z_k - z_k) \\ (6) \\ v_k = z_k - (z_k - z_k) \\ (6) \\ v_k = z_k - (z_k - z_k) \\ (6) \\ v_k = z_k - (z_k - z_k) \\ (6) \\ v_k = z_k - (z_k - z_k) \\ (6) \\ v_k = z_k - (z_k - z_k) \\ (6) \\ v_k = z_k - (z_k - z_k) \\ (6) \\ v_k = z_k - (z_k - z_k) \\ (6) \\ v_k = z_k - (z_k - z_k) \\ (6) \\ v_k = z_k - (z_k - z_k) \\ (6) \\ v_k = z_k - (z_k - z_k) \\ (6) \\ v_k = z_k - (z_k - z_k) \\ (6) \\ v_k = z_k - (z_k - z_k) \\ (6) \\ v_k = z_k - (z_k - z_k) \\ (7) \\ v_k = z_k - (z_k - z_k) \\ (9) \\ v_{1111} \\ v_k = z_k - (z_k - z_k) \\ (9) \\ v_{1111} \\ v_k = z_k - (z_k - z_k) \\ (9) \\ v_{1111} \\ v_k = z_k - (z_k - z_k) \\ (9) \\ v_{1111} \\ v_k = z_k - (z_k - z_k) \\ (9) \\ v_{1111} \\ v_k = z_k - (z_k - z_k) \\ (9) \\ v_{1111} \\ v_k = z_k - (z_k - z_k) \\ (10) \\ v_k = z_k - (z_k - $	$x_4 = S_{\theta} - v_3$	(71)
The L spaquace and date, chosen for this is $V_1 = \frac{1}{2}e_1^2$ (7) Derivative of $V_2$ is $V_1 = e_1e_1^2$ , $v_1 = 5_0^2$ (7) $V_1 = e_1e_1^2$ , $v_1 = 10^{-1}$ (8) $V_1 = e_1e_1^2$ , $v_1 = 10^{-1}$ (9) $V_1 = V_1 = V_1 = V_1^2$ , $v_1 = 10^{-1}$ (9) $V_1 = V_1 = V_1 = V_1^2$ , $v_1 = 10^{-1}$ (9) $V_1 = V_1 = V_1 = V_1^2$ , $v_1 = 10^{-1}$ (9) $V_1 = V_1 = V_1 = V_1^2$ , $v_1 = 10^{-1}$ (9) $V_1 = V_1 = V_1 = V_1^2$ , $v_1 = 10^{-1}$ (9) $V_1 = V_1 = V_1 = V_1^2$ , $v_1 = V_1^2$ (9) $V_1 = V_1 = V_1 = V_1^2$ , $v_1 = V_1^2$ (9) $V_1 = V_1$	$\dot{e}_3 = \dot{x}_{3d} - S_\theta + v_3$	(72)
$\begin{aligned} y_{q} = \frac{1}{2} e_{q}^{2} & (73) \\ \text{Derivative of } Y_{q} \text{ is } e_{q} e_{q} & (74) \\ Y_{q} = e_{q} (X_{q_{q}} + Y_{q} - S_{q}) & (75) \\ \text{Virtual control } v_{q} \text{ is designed to stabilize Lyapunov function as} & (75) \\ Y_{q} = e_{q} e_{q}^{2} & (76) \\ Y_{q} = e_{q} e_{q}^{2} - e_{q}^{2} - e_{q} S_{q} < 0 & (77) \\ Y_{q} = e_{q} e_{q}^{2} - e_{q}^{2} - e_{q} S_{q} < 0 & (73) \\ C_{q} = S_{q} e_{q}^{2} - e_{q}^{2} - e_{q} S_{q} < 0 & (73) \\ C_{q} = S_{q} e_{q}^{2} + e_{q}^{2} & (73) \\ C_{q} = S_{q} e_{q}^{2} + e_{q}^{2} & (73) \\ C_{q} = S_{q} e_{q}^{2} + e_{q}^{2} & (73) \\ C_{q} = S_{q} e_{q}^{2} + e_{q}^{2} & (73) \\ C_{q} = S_{q} e_{q}^{2} + e_{q}^{2} & (73) \\ C_{q} = S_{q}^{2} - e_{q}^{2} + e_{q}^{2} & (73) \\ C_{q} = S_{q}^{2} - e_{q}^{2} + e_{q}^{2} & (73) \\ C_{q} = S_{q}^{2} - e_{q}^{2} + e_{q}^{2} & (73) \\ C_{q} = S_{q}^{2} - e_{q}^{2} + e_{q}^{2} & (73) \\ C_{q} = S_{q}^{2} - e_{q}^{2} + e_{q}^{2} & (73) \\ C_{q} = S_{q}^{2} - e_{q}^{2} + e_{q}^{2} & (73) \\ C_{q} = S_{q}^{2} - e_{q}^{2} + e_{q}^{2} & (73) \\ C_{q} = S_{q}^{2} - e_{q}^{2} + e_{q}^{2} & (73) \\ C_{q} = S_{q}^{2} - C_{q}^{2} + S_{q}^{2} & (74) \\ C_{q} = S_{q}^{2} - C_{q}^{2} + S_{q}^{2} & (74) \\ C_{q} = S_{q}^{2} - C_{q}^{2} + S_{q}^{2} & (75) \\ C_{q} = S_{q}^{2} - S_{q}^{2} $	The Lyapunov candidate chosen for this is	
Derivative of $V_1$ is $V_1 = e_2(e_2 + v_1 - S_0)$ (74) $V_1 = e_2(e_2 + v_2 - S_0)$ (75) $V_1 = -e_2(e_2 - e_2)$ (76) $V_1 = e_2(e_2 + e_2)$ (76) $V_1 = e_2(e_2 - e_2)$ (77) $V_1 = -e_2(e_2 - e_2)$ (78) $V_1 = e_2(e_2 - e_2)$ (78) $V_1 = e_2(e_2 - e_2)$ (79) $V_1 = e_2(e_2 - e_2)$ (79) $V_1 = e_2(e_1 - e_2)$ (70) $V_1 = e_2(e_1 - e_2)$ (70) $V_2 = e_2(e_1 - e_2)$ (71) $V_2 = e_2(e_1 - e_2)$ (72) $V_2 = e_2(e_1 - e_2)$ (73) $V_2 = e_2(e_1 - e_2)$ (74) $V_2 = e_2(e_1 - e_2)$ (74) $V_2 = e_2(e_1 - e_2)$ (75) $V_2 = e_2(e_1 - e_2)$ (75) $V_2 = e_2(e_1 - e_2)$ (75) $V_2 = e_2(e_1 - e_2)$ (76) $V_2 = e_2(e_1 - e_2)$ (77) $V_2 = e_2(e_1 - e_2)$ (78) $V_2 = e_2(e_1 - e_2)$ (79) $V_2 = e_2(e_1 - e_2)$ (70) $V_2 = e_2(e_1 - e_2)$ (70) $V_2 =$	$V_3 = \frac{1}{2}e_3^2$	(73)
$\begin{aligned} \frac{1}{Y_{q}} &= \frac{1}{2} \left( \frac{1}{2} \left( \frac{1}{2} \left( \frac{1}{2} \right) + \frac{1}{2} \left( \frac{1}{2} \right) \right) \\ \frac{1}{Y_{q}} &= \frac{1}{2} \left( \frac{1}{2} \left( \frac{1}{2} \right) + \frac{1}{2} \right) \\ \frac{1}{Y_{q}} &= \frac{1}{2} \left( \frac{1}{2} \left( \frac{1}{2} \right) + \frac{1}{2} \right) \\ \frac{1}{Y_{q}} &= \frac{1}{2} \left( \frac{1}{2} \left( \frac{1}{2} \right) + \frac{1}{2} \right) \\ \frac{1}{Y_{q}} &= \frac{1}{2} \left( \frac{1}{2} \left( \frac{1}{2} \right) + \frac{1}{2} \right) \\ \frac{1}{Y_{q}} &= \frac{1}{2} \left( \frac{1}{2} \left( \frac{1}{2} \right) + \frac{1}{2} \right) \\ \frac{1}{Y_{q}} &= \frac{1}{2} \left( \frac{1}{2} \left( \frac{1}{2} \right) + \frac{1}{2} \right) \\ \frac{1}{Y_{q}} &= \frac{1}{2} \left( \frac{1}{2} \left( \frac{1}{2} \right) + \frac{1}{2} \right) \\ \frac{1}{Y_{q}} &= \frac{1}{2} \left( \frac{1}{2} \left( \frac{1}{2} \right) + \frac{1}{2} \right) \\ \frac{1}{Y_{q}} &= \frac{1}{2} \left( \frac{1}{2} \left( \frac{1}{2} \right) + \frac{1}{2} \right) \\ \frac{1}{Y_{q}} &= \frac{1}{2} \left( \frac{1}{2} \left( \frac{1}{2} \right) + \frac{1}{2} \right) \\ \frac{1}{Y_{q}} &= \frac{1}{2} \left( \frac{1}{2} \left( \frac{1}{2} \right) + \frac{1}{2} \right) \\ \frac{1}{Y_{q}} &= \frac{1}{2} \left( \frac{1}{2} \left( \frac{1}{2} \right) + \frac{1}{2} \right) \\ \frac{1}{Y_{q}} &= \frac{1}{2} \left( \frac{1}{2} \left( \frac{1}{2} \right) + \frac{1}{2} \right) \\ \frac{1}{Y_{q}} &= \frac{1}{2} \left( \frac{1}{2} \left( \frac{1}{2} \right) + \frac{1}{2} \right) \\ \frac{1}{Y_{q}} &= \frac{1}{2} \left( \frac{1}{2} \left( \frac{1}{2} \right) + \frac{1}{2} \right) \\ \frac{1}{Y_{q}} &= \frac{1}{2} \left( \frac{1}{2} \left( \frac{1}{2} \right) + \frac{1}{2} \right) \\ \frac{1}{Y_{q}} &= \frac{1}{2} \left( \frac{1}{2} \left( \frac{1}{2} \right) + \frac{1}{2} \right) \\ \frac{1}{Y_{q}} &= \frac{1}{2} \left( \frac{1}{2} \left( \frac{1}{2} \right) + \frac{1}{2} \left( \frac{1}{2} \left( \frac{1}{2} \right) \right) \\ \frac{1}{Y_{q}} &= \frac{1}{2} \left( \frac{1}{2} \left( \frac{1}{2} \right) + \frac{1}{2} \left( \frac{1}{2} \left( \frac{1}{2} \right) \right) \\ \frac{1}{Y_{q}} &= \frac{1}{2} \left( \frac{1}{2} \left( \frac{1}{2} \right) + \frac{1}{2} \left( \frac{1}{2} \left( \frac{1}{2} \right) \right) \\ \frac{1}{Y_{q}} &= \frac{1}{2} \left( \frac{1}{2} \left( \frac{1}{2} \right) \right) \\ \frac{1}{Y_{q}} &= \frac{1}{2} \left( \frac{1}{2} \left( \frac{1}{2} \right) \right) \\ \frac{1}{Y_{q}} &= \frac{1}{2} \left( \frac{1}{2} \left( \frac{1}{2} \right) \right) \\ \frac{1}{Y_{q}} &= \frac{1}{2} \left( \frac{1}{2} \left( \frac{1}{2} \right) \right) \\ \frac{1}{Y_{q}} &= \frac{1}{2} \left( \frac{1}{2} \left( \frac{1}{2} \right) \\ \frac{1}{Y_{q}} &= \frac{1}{2} \left( \frac{1}{2} \right) \\ \frac{1}{Y_{q}} &= \frac{1}{2} \left( \frac{1}{2} \left( \frac{1}{2} \right) \\ \frac{1}{Y_{q}} &= \frac{1}{2} \left( \frac{1}{2} \left( \frac{1}{2} \right) \right) \\ \frac{1}{Y_{q}} &= \frac{1}{2} \left( \frac{1}{2} \left( \frac{1}{2} \right) \right) \\ \frac{1}{Y_{q}} &= \frac{1}{2} \left( \frac{1}{2} \left( \frac{1}{2} \right) \\ \frac{1}{Y_{q}} &= \frac{1}{2} \left( \frac{1}{2} \left( \frac{1}{2} \right) \\ \frac{1}{Y_{q}} &= \frac{1}{2} \left( \frac{1}{2} \left( \frac{1}{2} \right) \right) \\ \frac{1}{Y_{q$	Derivative of $V_2$ is	
$\begin{aligned} \dot{q}_{2}^{2} = \frac{1}{2} \langle \dot{q}_{2} \neq \psi_{2} - \psi_{3} \rangle \\ \forall rund correl \psi_{3} is designed to stabilize Lyapunov function as\psi_{3} - x_{3} - z_{3} \langle \dot{q}_{2} = \psi_{3} \langle \dot{q}_{2} = \psi_{3} \rangle \\ \langle f_{3} = c_{3} \langle \dot{q}_{2} = c_{3} \rangle \\ \langle f_{3} = c_{3} \langle \dot{q}_{2} = c_{3} \rangle \\ \langle f_{3} = c_{3} \langle \dot{q}_{2} = c_{3} \rangle \\ \langle f_{3} = c_{3} \langle \dot{q}_{2} = c_{3} \rangle \\ \langle f_{3} = c_{3} \langle \dot{q}_{2} = c_{3} \rangle \\ \langle f_{3} = c_{3} \langle \dot{q}_{2} = c_{3} \rangle \\ \langle f_{3} = c_{3} \rangle \\ \langle f_{4} = c_{4} \rangle \\ \langle f_{5} = c_{5} \rangle \\ $	$\dot{V}_{0} = \rho_{0}\dot{\rho}_{0}$	(74)
Virtual control is is designed to stabilize Lyapunov function as $v_3 = -x_{AI} - c_5 v_1$ (70) $v_3 = -c_5 c_1^2 - e_5 v_6 < 0$ (71) $v_3 = -c_5 c_1^2 - e_5 v_6 < 0$ (72) $v_3 = -c_5 c_1^2 - e_5 v_6 < 0$ (73) $c_1 = c_5 v_6 + c_5 v_6 < 0$ (74) $v_4 = c_6 v_6 + s_5 v_6 < 0$ (75) $v_4 = c_6 v_6 + s_5 v_6 < 0$ (70) $v_4 = c_6 v_6 + s_5 v_6 < 0$ (70) $v_4 = c_6 v_6 + s_5 v_6 < 0$ (80) Time derivative of the Lyapunov function is $v_4 (e_5 v_5) = -c_5 v_6 + s_5 v_6 < 0$ (81) Necessary shifting conflicton required to stabilize is $s_6 = -a_1 s_1 s_0 (x_6 v_5) = -c_5 v_6 + s_5 v_6 < 0$ (82) $v_4 (e_5 v_5) = -c_5 v_6 - e_5 v_6 + s_6 v_6 v_6 = 0$ (83) $v_4 (e_5 v_5) = -c_5 v_6 - e_5 v_6 + s_6 v_6 v_6 = 0$ (84) $v_4 (e_5 v_5) = -c_5 v_6 - e_5 v_6 + s_6 v_6 v_6 = 0$ (84) $v_4 (e_5 v_6) = -c_5 v_6 - e_5 v_6 + s_6 v_6 v_6 = 0$ (85) System is asymptotically stable and control input can be obtained by $v_6 = -a_2 s_1 g_0 (x_6) - v_6 v_5 v_6 + x_6 v_6 v_6 v_6 v_6 v_6 v_6 v_6 v_6 v_6 v$	$\dot{V}_{0} = \rho_{0} (\dot{x}_{0,1} + v_{0} - S_{0})$	(75)
$\begin{aligned} \mathbf{v}_{2} = -\mathbf{x}_{24} - (-\mathbf{x}_{25}^{2} - (\mathbf{x}_{25}^{2} - \mathbf{x}_{5}^{2}) & (7) \\ \mathbf{v}_{2}^{2} = \mathbf{c}_{2}(-\mathbf{x}_{25}^{2} - \mathbf{c}_{5}) & (7) \\ \mathbf{v}_{3}^{2} = -\mathbf{c}_{4}(-\mathbf{x}_{25}^{2} - \mathbf{c}_{5}) & (7) \\ \mathbf{v}_{4}^{2} = \mathbf{c}_{5}(-\mathbf{x}_{25}^{2} - \mathbf{c}_{5}) & (7) \\ \mathbf{v}_{5}^{2} = -\mathbf{c}_{5}\mathbf{c}_{5}^{2} + \mathbf{x}_{4} & (7) \\ \mathbf{v}_{5}^{2} = \mathbf{v}_{5}\mathbf{c}_{5}^{2} + \mathbf{x}_{4} & (7) \\ \mathbf{v}_{5}^{2} = \mathbf{v}_{5}\mathbf{c}_{5}^{2} + \mathbf{x}_{4} & (7) \\ \mathbf{v}_{5}^{2} = \mathbf{v}_{5}\mathbf{c}_{5}^{2} + \mathbf{x}_{5}^{2} & (8) \\ \mathbf{v}_{1}^{2} = \mathbf{v}_{5}\mathbf{c}_{5}^{2} + \mathbf{x}_{5}^{2} & (8) \\ \mathbf{v}_{1}^{2} = \mathbf{v}_{5}\mathbf{c}_{5}^{2} + \mathbf{x}_{5}^{2} & (8) \\ \mathbf{v}_{1}^{2} = \mathbf{v}_{5}\mathbf{c}_{5}^{2} - \mathbf{v}_{5}\mathbf{c}_{5}^{2} + \mathbf{x}_{5}\mathbf{c}_{5}^{2} & (8) \\ \mathbf{v}_{1}^{2} = \mathbf{v}_{5}\mathbf{c}_{5}^{2} - \mathbf{v}_{5}\mathbf{c}_{5}^{2} + \mathbf{x}_{5}\mathbf{c}_{5}^{2} & (8) \\ \mathbf{v}_{1}^{2} = \mathbf{v}_{5}\mathbf{c}_{5}^{2} - \mathbf{v}_{5}\mathbf{c}_{5}^{2} + \mathbf{x}_{5}\mathbf{c}_{5}^{2} & (8) \\ \mathbf{v}_{1}^{2} = \mathbf{v}_{5}\mathbf{c}_{5}^{2} - \mathbf{v}_{5}\mathbf{c}_{5}^{2} - \mathbf{v}_{5}\mathbf{c}_{6}^{2} - \mathbf{v}_{5}\mathbf{c}_{6}^{2} - \mathbf{v}_{5}\mathbf{c}_{6}^{2} & (\mathbf{v}_{5}^{2} - \mathbf{v}_{5}^{2} - \mathbf{v}_{5}\mathbf{c}_{5}^{2} - \mathbf{v}_{5}\mathbf{c}_{5}^{2} & (8) \\ \mathbf{v}_{1}^{2} = \mathbf{v}_{5}\mathbf{c}_{5}^{2} - \mathbf{v}_{5}\mathbf{c}_{5}^{2} - \mathbf{v}_{5}\mathbf{c}_{5}^{2} - \mathbf{v}_{5}\mathbf{c}_{5}^{2} & (8) \\ \mathbf{v}_{1}^{2} = \mathbf{v}_{5}\mathbf{c}_{5}^{2} - \mathbf{v}_{5}\mathbf{c}_{5}^{2} - \mathbf{v}_{5}\mathbf{c}_{5}\mathbf{c}_{5}^{2} & (8) \\ \mathbf{v}_{1}^{2} = \mathbf{v}_{5}\mathbf{c}_{5}^{2} - \mathbf{v}_{5}\mathbf{c}_{5}^{2} - \mathbf{v}_{5}\mathbf{c}_{5}^{2} & (8) \\ \mathbf{v}_{5}^{2} = -\mathbf{v}_{5}\mathbf{c}_{5}^{2} - \mathbf{v}_{5}\mathbf{c}_{5}^{2} - \mathbf{v}_{5}\mathbf{c}_{5}^{2} & (8) \\ \mathbf{v}_{5}^{2} = -\mathbf{v}_{5}\mathbf{c}_{5}^{2} - \mathbf{v}_{5}\mathbf{c}_{5}^{2} + \mathbf{v}_{5}\mathbf{c}_{5}^{2} & (\mathbf{v}_{5}\mathbf{c}_{5}^{2} - \mathbf{v}_{5}\mathbf{c}_{5}^{2} & (\mathbf{v}_{5}\mathbf{c}_{5}^{2} + \mathbf{v}_{5}\mathbf{c}_{5}^{2} & (\mathbf{v}_{5}\mathbf{c}_{5}^{2} + \mathbf{v}_{5}\mathbf{c}_{5}^{2} & (\mathbf{v}_{5}\mathbf{c}_{5}^{2} + \mathbf{v}_{5}\mathbf{c}_{5}^{2} & (\mathbf{v}_{5}\mathbf{c}_{5}^{2} & (v$	Virtual control $v_2$ is designed to stabilize Lyapunov function as	(10)
$\begin{aligned} \dot{r}_{2} = e_{1} \left( -e_{2} e_{1} - e_{3} \right)_{2} \\ (7) \\ \dot{r}_{1} = e_{2} e_{1}^{2} - e_{3} \delta_{1} < 0 \\ (7) \\ \dot{r}_{2} = e_{3} e_{1}^{2} - e_{3} \delta_{1} < 0 \\ (7) \\ \dot{r}_{3} = c_{3} e_{1}^{2} - e_{3} \delta_{1} < 0 \\ (7) \\ \dot{r}_{4} = \delta_{4} = \frac{1}{2} + \frac{1}{2} + \frac{1}{2} \\ \dot{r}_{4} = \delta_{4} = \frac{1}{2} + \frac{1}{2} + \frac{1}{2} \\ \dot{r}_{4} = \delta_{3} = \frac{1}{2} + \frac{1}{2} + \frac{1}{2} \\ \dot{r}_{4} = \delta_{3} = \frac{1}{2} + \frac{1}{2} + \frac{1}{2} \\ \dot{r}_{4} = \delta_{3} = \frac{1}{2} + \frac{1}{2} + \frac{1}{2} \\ \dot{r}_{4} = \delta_{3} = \frac{1}{2} + \frac{1}{2} + \frac{1}{2} \\ \dot{r}_{4} = \delta_{3} = \frac{1}{2} + \frac{1}{2} + \frac{1}{2} \\ \dot{r}_{4} = \delta_{3} = \frac{1}{2} + \frac{1}{2} + \frac{1}{2} \\ \dot{r}_{4} = \delta_{3} = \frac{1}{2} + \frac{1}{2} + \frac{1}{2} \\ \dot{r}_{4} = \delta_{3} = \frac{1}{2} + \frac{1}{2} + \frac{1}{2} \\ \dot{r}_{4} = e_{3} + \frac{1}{2} + \frac{1}{2} + \frac{1}{2} \\ \dot{r}_{4} = \delta_{3} = \frac{1}{2} + \frac{1}{2} + \frac{1}{2} + \frac{1}{2} + \frac{1}{2} + \frac{1}{2} \\ \dot{r}_{4} = \delta_{3} = \frac{1}{2} + \frac{1}{2} + \frac{1}{2} + \frac{1}{2} + \frac{1}{2} + \frac{1}{2} \\ \dot{r}_{4} = \delta_{3} = \frac{1}{2} + \frac{1}{2} + \frac{1}{2} + \frac{1}{2} + \frac{1}{2} + \frac{1}{2} \\ \dot{r}_{4} = \delta_{3} = \frac{1}{2} + \frac{1}{2} + \frac{1}{2} + \frac{1}{2} + \frac{1}{2} + \frac{1}{2} + \frac{1}{2} \\ \dot{r}_{4} = \delta_{3} = \frac{1}{2} + \frac{1}{2} \\ \dot{r}_{4} = \delta_{3} = \frac{1}{2} + \frac{1}{2} \\ \dot{r}_{4} = \delta_{3} = \frac{1}{2} + \frac{1}{2} \\ \dot{r}_{4} = \delta_{4} = \frac{1}{2} \\ \dot{r}_{4} = \delta_{4} = \frac{1}{2} + \frac{1}{2} + \frac{1}{2} \\ \dot{r}_{4} = \delta_{4} = \frac{1}{2} + \frac{1}{2} + \frac{1}{2} \\ \dot{r}_{4} = \delta_{4} = \frac{1}{2} + \frac{1}{2} + \frac{1}{2} \\ \dot{r}_{4} = \delta_{4} = \frac{1}{2} + \frac{1}{2} + \frac{1}{2} \\ \dot{r}_{5} = \delta_{4} = \frac{1}{2} \\ \dot{r}_{5} = \delta_{4} = \frac{1}{2} \\ \dot{r}_{5} = \delta_{5} = \delta_{5} = 0 \\ \dot{r}_{5} = \delta_{5} = \delta_{5} = 0 \\ \dot{r}_{5} = \delta_{5} = 0 \\ \dot{r}_{5} = \delta_{5} = \delta_{5} = 0 \\ \dot{r}_{5} = \delta_{5} = 0 \\ \dot{r}_{5} = \delta_{5} = \delta_{5} \\ \dot{r}_{5} = \delta_{5} = 0 \\ \dot{r}_{5} = \delta_{5} = \delta_{5} \\ \dot{r}_{5} = 0 \\ \dot{r}_{5} = \delta_{5} = \delta_{5} \\ \dot{r}_{5} = 0 \\ \dot{r}_{5} = \delta_{5} = 0 \\ \dot{r}_{5} = \delta_{5}$	$v_3 = -\dot{x}_{3d} - c_3 e_3$	(76)
$\begin{aligned} \vec{Y}_{2} = -c_{2}c_{2}^{2}\vec{z}_{1} = c_{2}c_{3}^{2}\vec{z}_{1} = 0 \\ (73) \\ \vec{c}_{1} \text{ by other constant and the subsystem is asymptotically stable. \\ The stilding surface time derivative is \\ \vec{e}_{4} = \hat{S}_{0} = \vec{v}_{5} + X_{4} \\ (79) \\ Lyapanov candidate chosen for this system is \\ V_{1}(e_{2}, S_{3}) = \frac{1}{2}(e_{1}^{2} + S_{3}^{2}) \\ (80) \\ Thm derivative of the Lyapanov function is \\ V_{1}(e_{2}, S_{3}) = -c_{2}\dot{a}_{1} + S_{3}\dot{b}_{3} \\ (81) \\ Necessary stilding condition required to stabilize is \\ S_{p} = -q_{2}sigm(S_{p}) - k_{p}S_{p} \\ (e_{2}, S_{3}) = -c_{2}\dot{a}_{1}^{2} - e_{3}S_{p} - q_{2}sigm(S_{p}) \\ (e_{2}, S_{3}) = -c_{4}\dot{a}_{1}^{2} - e_{3}S_{p} - q_{2}sigm(S_{p}) \\ (e_{2}, S_{3}) = -c_{4}\dot{a}_{1}^{2} - e_{3}S_{p} - q_{2}sigm(S_{p}) \\ (e_{2}, S_{3}) = -c_{4}\dot{a}_{1}^{2} - e_{3}S_{p} - q_{2}sigm(S_{p}) \\ (e_{2}, S_{3}) = -c_{4}\dot{a}_{1}^{2} - e_{3}S_{p} - q_{2}sigm(S_{p}) \\ (e_{2}, S_{3}) = -c_{4}\dot{a}_{1}^{2} - e_{3}S_{p} - q_{2}sigm(S_{p}) \\ (e_{2}, S_{3}) = -c_{4}\dot{a}_{1}^{2} - e_{3}S_{p} - q_{2}sigm(S_{p}) \\ (e_{2}, S_{3}) = -c_{4}\dot{a}_{1}^{2} - e_{3}S_{p} - q_{2}sigm(S_{p}) \\ (e_{2}, S_{3}) = -c_{4}\dot{a}_{1}^{2} - e_{3}S_{p} - q_{2}sigm(S_{p}) \\ (e_{2}, S_{3}) = -c_{4}\dot{a}_{1}^{2} - e_{3}S_{p} - q_{2}sigm(S_{p}) \\ (e_{2}, S_{3}) = -c_{4}\dot{a}_{1}^{2} - e_{3}S_{p} - q_{2}sigm(S_{p}) \\ (e_{2}, S_{3}) = -c_{4}\dot{a}_{1}^{2} - e_{3}S_{p} + a_{3} + a_{4}x_{3}\dot{a} + a_{4}x_{3}\dot{a} + a_{4}\Omega_{3}x_{2} + b_{5}U_{3} \\ (S) \\ S_{9} = -q_{8}sigm(S_{9}) - k_{5}S_{9} \\ (S) \\ S_{9} = -q_{8}sigm(S_{9}) - k_{5}S_{9} \\ (S) \\ (F_{9} = -S_{9} - (F_{9} + S_{9}) \\ (S) \\ (H) \\ (here k_{hore} z \ k a controller gain and q_{2} is a state variable whose value changes. \\ (S) \\ (H) \\ (H$	$\dot{V}_3 = e_3 (-c_3 e_3 - S_{\theta})$	(77)
$\begin{aligned} c_{n}^{-1} \text{ spontrive constant and the subsystem is asymptotically stable. \\ The sliding surface time derivative is  \begin{aligned} e_{4} = S_{0} = \psi_{x} + x_{x} & (79) \\ \text{Lyapunov candidate chosen for this system is  \begin{aligned} v_{1}(e_{3}, S_{3}) = \frac{1}{2}(e_{3}^{2} + S_{3}^{2}) & (80) \\ \text{Time derivative of the Lyapunov function is  \begin{aligned} v_{1}(e_{3}, S_{3}) = e_{3}e_{2}^{2} + S_{5}G^{-0} & (81) \\ \text{Neccessary sliding condition required to sublize is  \begin{aligned} S_{6} = -q_{6}s(gn(S_{0}) - k_{2}S_{9} & (81) \\ v_{1}(e_{n}, S_{3}) = -c_{6}e_{1}^{2} - e_{5}S_{n} - q_{2}s(gn(S_{0}) - k_{2}S_{0}^{2}) & (81) \\ v_{1}(e_{n}, S_{3}) = -c_{6}e_{1}^{2} - e_{5}S_{n} - q_{2}s(gn(S_{0}) S_{9} - k_{2}S_{0}^{2} & (81) \\ v_{1}(e_{n}, S_{3}) = -c_{6}e_{1}^{2} - e_{5}S_{n} - q_{2}s(gn(S_{0}) S_{9} - k_{2}S_{0}^{2} & (81) \\ v_{1}(e_{n}, S_{3}) = -c_{6}e_{1}^{2} - e_{5}S_{n} - q_{2}s(gn(S_{0}) S_{9} - k_{2}S_{0}^{2} & (81) \\ v_{1}(e_{n}, S_{3}) = -c_{6}e_{1}^{2} - e_{5}S_{n} - q_{2}s(gn(S_{0}) S_{9} - k_{2}S_{0}^{2} & (81) \\ v_{2}(e_{n}, S_{3}) = -c_{6}e_{1}^{2} - e_{5}S_{n} - q_{2}s(gn(S_{0}) S_{9} - k_{2}S_{0}^{2} & (81) \\ v_{3}(e_{n}, C_{3}) = -c_{6}e_{1}^{2} - e_{5}S_{n} - q_{2}s(gn(S_{0}) S_{9} - k_{2}S_{0}^{2} & (81) \\ v_{3}(e_{n}, C_{3}) = -c_{6}e_{1}^{2} - e_{5}S_{n} - q_{2}e_{5}(gn(S_{0}) S_{9} - k_{2}S_{0}^{2} & (81) \\ v_{3}(e_{n}, C_{3}) = -c_{6}e_{1}^{2} - e_{5}S_{n} - q_{2}e_{5}(gn(S_{0}) S_{9} - k_{2}S_{0}^{2} & (81) \\ v_{3}(e_{n}, C_{3}) = -c_{5}e_{1}^{2} - e_{5}S_{0} + x_{3} + e_{6}e_{n} - a_{4}x_{3}x_{n} - a_{6}x_{1}^{2} - a_{6}(2x_{2}) & (89) \\ v_{1} = c_{6}e_{1}s(gn(S_{0}) - k_{2}S_{9} + x_{3} + e_{6}e_{n} - a_{4}x_{3}x_{n} - a_{6}x_{1}^{2} - a_{6}(2x_{2}) \\ v_{1} = c_{1}e_{1}(gn(S_{0}) - k_{2}S_{9} + x_{3} + e_{6}e_{n} - a_{6}x_{1}x_{n} - a_{6}x_{1}^{2} - a_{6}(2x_{1}^{2} - a_{6}(2x_{1}$	$\dot{V}_3 = -c_3 e_3^2 - e_3 S_{\theta} < 0$	(78)
The skiding surface time derivative is $ \begin{aligned} \\ \begin{aligned} e_s = \delta_s = y_s = y_s + \lambda_s, \\ (79) \end{aligned} \\ \begin{aligned} \\ \begin{aligned} Lyupunov candidate chosen for this system is \\ \end{aligned} \\ \end{aligned} \\ \end{aligned} \\ \end{aligned} \\ \end{aligned} \\ \begin{aligned} \begin{aligned} \begin{aligned} \begin{aligned} \begin{aligned} \\ \begin{aligned} \\ \\ \\ \\$	$c_3$ is positive constant and the subsystem is asymptotically stable.	
$\begin{aligned} e_s = \delta_s = v_s + x_s & (79) \\ \text{Lyppuro candidate chosen for this system is } \\ V_1(e_3, S_g) = \frac{1}{2}(e_s^2 + S_g^2) & (80) \\ \text{Time derivative of the Lyppunov function is } \\ V_1(e_3, S_g) = e_s^2 + S_s S_g & (81) \\ \text{Neccessary sliding condition required to stabilize is } \\ S_g = -q_s S_g(n(S_g) - k_s S_g) & (82) \\ V_1(e_3, S_g) = -c_s e_s^2 - e_s S_g + S_g(-q_s)(gn(S_g) - k_s S_g^2) & (83) \\ V_1(e_3, S_g) = -c_s e_s^2 - e_s S_g - q_s S_g(gn(S_g) ) S_g - k_s S_g^2 & (0) \\ S_g = -q_s S_g(n(S_g) - k_s S_g) & (83) \\ V_1(e_3, S_g) = -c_s e_s^2 - e_s S_g - q_s S_g(gn(S_g) ) S_g - k_s S_g^2 & (0) \\ S_g = -q_{s,s}(gn(S_g) - k_s S_g) & (83) \\ V_1(e_3, S_g) = -c_s e_s^2 - e_s S_g - q_{s,s}(gn(S_g) ) S_g - k_s S_g^2 & (0) \\ S_g = -x_{s,s}(-c_s S_g) - q_{s,s}(gn(S_g) ) S_g - k_s S_g^2 & (0) \\ S_g = -x_{s,s}(-c_s S_g) - q_{s,s}(gn(S_g) - k_s S_g) & (s, S_g) \\ S_g = -x_{s,s}(-c_s S_g) - q_{s,s}(gn(S_g) - k_s S_g) & (s, S_g) \\ S_g = -x_{s,s}(-c_s S_g) + x_{s,s}(-c_s S_g + a_s X_s + a_s X_s + a_s X_s^2 + a_s \Omega X_s) & (83) \\ H & \text{th cortol input an adaptive control law which is proposed to compensate the external disturbances. \\ q_2 = k_{hora} +  S_g  & (9) \\ \text{Where } k_{hora} is a controller gain and q_s is a state variable whose value changes. \\ 3. Xaw Control: \\ Yaw error is defined as \\ e_g = x_{s,a} - x_g & (9) \\ S_g = -x_{s,a} - x_g & (9) \\ \text{Where } k_s = -x_s & (9) \\ \text{Where } k_s = -x_s & (9) \\ \text{Where } k_s = -x_s & (9) \\ \text{The slufting the yaw error \\ e_g = x_{s,a} - x_g & (9) \\ \text{Where } k_s = -x_s & (9) \\ \text{The slufting the yaw error \\ e_g = x_{s,a} - x_s & (9) \\ \text{Where } k_s = -x_s & (9) \\ \text{Where } k_s$	The sliding surface time derivative is	
Lyapunov candidate chosen for this system is $V_{4}(e_{3}, S_{0}) = \frac{1}{2}(e_{3}^{2} + S_{3}^{2})$ (80) Time derivative of the Lyapunov function is $V_{4}(e_{3}, S_{3}) = e_{4}e_{3} + S_{5}S_{5}$ (81) Necessary situation required to stabilize is $S_{9} = -q_{2}sign(S_{9}) - k_{5}S_{9}$ (82) $V_{4}(e_{3}, S_{3}) = -c_{3}e_{3}^{2} - e_{3}S_{9} - 4_{2}(q_{2}sign(S_{9}) - k_{5}S_{9}^{2})$ (83) $V_{4}(e_{3}, S_{3}) = -c_{3}e_{3}^{2} - e_{3}S_{9} - q_{2}sign(S_{9}) S_{9} - k_{5}S_{9}^{2} < 0$ (85) System is asymptotically stable and control input can be obtained by $S_{9} = -q_{2}sign(S_{9}) - k_{5}S_{9} = -S_{3,4} - c_{2}e_{3} + a_{4}x_{2}x_{6} + a_{5}x_{4}^{2} + a_{6}\Omega x_{2} + b_{7}U_{3}$ (86) $S_{9} = -q_{5,2}gn(S_{9}) - k_{5}S_{9} = -S_{3,4} - c_{2}e_{3} + a_{4}x_{2}x_{6} + a_{5}x_{4}^{2} + a_{6}\Omega x_{2} + b_{7}U_{3}$ (87) $-q_{2}sign(S_{9}) - k_{5}S_{9} = -s_{3,4} - c_{2}e_{3} + a_{4}x_{2}x_{6} + a_{5}x_{4}^{2} - a_{6}\Omega x_{2}$ (89) In this control input an adaptive control law which is proposed to compensate the external disturbances. $q_{2} = k_{nac} - 1S_{6}$ (90) where $k_{barz}$ is a controller gain and $q_{2}$ is a state variable whose value changes. 3 Awa Control: Yaw error is defined as $e_{5} = x_{5a} - x_{5}$ (91) Where $e_{5}$ is error, $x_{a4}$ is desired yaw and $x_{5}$ is actual yaw Differentiating the yaw error $e_{5} = x_{5a} - x_{5}$ (92) Substituting from equation no.28 (92) Substituting from equation no.28 (93) $e_{5} = x_{5a} - S_{4} + v_{5}$ (96) The Lyapunov candidate chosen for this is $V_{5} = e_{5}(e_{3} + V_{5} - S_{9})$ (91) $V_{5} = e_{5}(e_{5} + V_{5} - S_{9})$ (92) Virtual control $v_{5}$ is defined and $v_{5}$ is virtual control $v_{5} = x_{5a} - S_{4} + v_{5} - S_{9}$ ) (93) $V_{5} = e_{5}(e_{5} + V_{5} - S_{9})$ (94) $V_{5} = e_{5}(e_{5} + V_{5} - S_{9})$ (95) $V_{5} = e_{5}(e_{5} + V_{5} - S_{9})$ (96) The Lyapunov candidate chosen for this is yterm is $v_{5} = -e_{5}e_{7} + S_{5}$ (97) Dorivative of $V_{5}$ is $e_{5} + e_{5} < S_{9}$ (103) Ly	$\dot{e}_4 = \dot{S}_\theta = \dot{v}_3 + \dot{x}_4$	(79)
$\begin{aligned} V_{q}(e_{2},S_{2}) &= \frac{1}{4}(e_{2}^{2} + S_{2}^{2}) \\ \text{Time derivative of the Lyapunov function is} \\ V_{q}(e_{2},S_{2}) &= e_{3}e_{3} + S_{3}S_{3} \\ \text{Neccesary shifting condition required to stabilize is} \\ S_{9} &= -q_{2}sign(S_{9}) - k_{2}S_{9} \\ -k_{2}S_{9} \\ -k_{2}S_{9}$	Lyapunov candidate chosen for this system is	
Time derivative of the Lyapunov function is $V_q(a_3, S_q) = a_3 + S_q S_q^*$ (81) Necessary shifting condition required to stabilize is $S_q = -q_{2S}(gn(S_q) - k_S S_q)$ (82) $V_q(a_2, S_q) = -c_q S_q^* - e_S S_q - q_{S}(gn(S_q)) S_q - k_S S_q^*$ (83) $V_q(a_2, S_q) = -c_q S_q^* - e_S S_q - q_{S}(gn(S_q)) S_q - k_S S_q^*$ (84) $V_q(a_2, S_q) = -c_q S_q^* - e_S S_q - q_{S}(gn(S_q)) S_q - k_S S_q^*$ (84) $V_q(a_2, S_q) = -c_q S_q^* - e_S S_q - q_{S}(gn(S_q)) S_q - k_S S_q^*$ (85) $S_q = -q_{S}(gn(S_q)) - k_S S_q$ (86) $S_q = -q_{S}(gn(S_q)) - k_S S_q$ (87) $S_q = -q_{S}(gn(S_q)) - k_S S_q$ (87) $V_q = (a_g S_qn(S_q)) - k_S S_q - c_q S_q + a_A x_S x_h + a_S x_h^2 + a_G \Omega x_2 + b_2 U_3$ (88) $U_3 = \frac{1}{b_q} (-q_S)(gn(S_q)) - k_S S_q + x_{3d} + c_S S_q^2 - a_A x_X x_h - a_S x_h^2 - a_G \Omega x_2)$ (90) In this control input adaptive control law which is proposed to compensate the external disturbances. $q_2 = k_{nac} - s_{q_2} +  S_q $ (91) Where $k_{0arc2}$ is a controller gain and $q_2$ is a state variable whose value changes. 3. Yaw Corn to ide dinued as $e_q = x_{a_q} - x_q$ (92) Substituting from equation on .28 (92) Substituting from equation on .28 (93) The shifting surface $S_q$ is defined and $v_5$ is virtual control $e_q = S_q - x_q - (e_g S_q - (e_g S_g - (e_g S$	$V_4(e_3, S_\theta) = \frac{1}{2}(e_3^2 + S_\theta^2)$	(80)
$\begin{aligned} \hat{\psi}_{q}(e_{2}, \xi_{q}) &= e_{2}e_{1} + \xi_{q} \hat{\xi}_{q}^{b} \end{aligned} \tag{81} \\ \text{Necessary sliding condition required to stabilize is } \\ \hat{\xi}_{q} &= -q_{2}sign(\xi_{q}) - k_{2}\xi_{q} \end{aligned} \tag{82} \\ \hat{\psi}_{q}(e_{2}, \xi_{q}) &= -c_{q}e_{1}^{b} - e_{q}\xi_{q} - e_{q}\xi_{q} = q_{2}sign(\xi_{q}) \end{aligned} \tag{82} \\ \hat{\psi}_{q}(e_{2}, \xi_{q}) &= -c_{q}e_{1}^{b} - e_{q}\xi_{q} - e_{q}\xi_{q} = q_{2}sign(\xi_{q}) &= -k_{2}\xi_{q}^{b} \end{aligned} \tag{83} \\ \hat{\psi}_{q}(e_{2}, \xi_{q}) &= -c_{q}e_{1}^{b} - e_{q}\xi_{q} - e_{q}\xi_{q} = q_{2}sign(\xi_{q}) &= -k_{2}\xi_{q}^{b} \end{aligned} \tag{84} \\ \hat{\psi}_{q}(e_{2}, \xi_{q}) &= -c_{q}e_{1}^{b} - e_{q}\xi_{q} - e_{q}\xi_{q} = q_{2}sign(\xi_{q}) - k_{2}\xi_{q}^{b} &= 0 \end{aligned} \tag{85} \\ System is symptotically stable and control input can be obtained by \\ \hat{\xi}_{q} &= -q_{2}sign(\xi_{q}) - k_{2}\xi_{q} &= -k_{4}x_{2}x_{h} + a_{q}x_{4}^{2} + a_{q}\Omega_{2}x_{2} + b_{p}U_{1} \end{aligned} \tag{86} \\ \hat{\xi}_{q} &= -q_{q}e_{1}e_{q}(e_{1}e_{1}e_{1}e_{1}e_{1}e_{2}e_{1}e_{1}e_{1}e_{2}e_{3}e_{1}e_{4}x_{2}x_{h} + a_{q}x_{4}^{2} + a_{q}\Omega_{2}x_{2} + b_{p}U_{1} \end{aligned} \tag{88} \\ H_{1} &= \frac{h}{h_{c}}(-q_{2}sign(\xi_{q}) - k_{2}\xi_{q} + a_{4}x_{2}x_{h} - a_{4}x_{2}x_{h} - a_{4}x_{2}- a_{6}\lambda x_{2}) \end{aligned} \tag{89} \\ \text{In this control input an adaptic control law which is proposed to compensate the external disturbances.} \\ d_{2} &= k_{aor} *  \xi_{q}  \end{aligned} \tag{90} \\ \text{where } k_{bar2} \text{ is a controller gain and } q_{2} \text{ is a state variable whose value changes.} \end{aligned}$	Time derivative of the Lyapunov function is	
Necessary sliding condition required to stabilize is $\delta_0 = -q_2 sign(S_0) - k_2 S_0$ (82) $V_1(e_2, S_0) = -c_2 e_1^2 - e_2 S_0 + S_0 (-q_2 sign(S_0) - k_2 S_0^2 - (84))$ $V_1(e_3, S_0) = -c_3 e_1^2 - e_2 S_0 - q_2 sign(S_0) S_0 - k_2 S_0^2 - (84)$ $V_1(e_3, S_0) = -c_3 e_1^2 - e_2 S_0 - q_2 sign(S_0) S_0 - k_2 S_0^2 - (86)$ $S_0 = -q_2 sign(S_0) - k_2 S_0 - 4x_3 - c_2 e_3 + a_4 x_2 x_5 + a_5 x_4^2 + a_6 \Omega x_2 + b_2 V_3$ (86) $S_0 = -q_3 sign(S_0) - k_2 S_0 - 4x_3 - c_2 e_3 + a_4 x_2 x_5 + a_5 x_4^2 + a_6 \Omega x_2 + b_2 V_3$ (87) $a_2 sign(S_0) - k_2 S_0 - 4x_3 - c_2 e_3 + a_3 + c_2 e_3 - a_4 x_2 x_5 - a_5 x_4^2 - a_6 \Omega x_2)$ (89) In this control input an adaptive control law which is proposed to compensate the external disturbances. $q_2 = k_{0acr} +  S_0 $ (90) where $k_{0acr} +  S_0 $ (91) Where $e_5 = x_{ad} - x_5$ (92) Substituting from equation no.28 (92) Substituting from equation no.28 (92) Substituting from equation no.28 (93) The sliding surface $S_{46} + v_5$ (94) $x_6 = S_{46} - x_5$ (95) $e_5 = x_{ad} - x_5$ (96) The Lyapmov candidate chosen for this is $V_5 = -\frac{1}{2} e_2^2$ (97) Derivative of $V_5$ is $V_5 = -\frac{1}{2} e_5^2$ (97) Dirivative of $V_5$ is $V_5 = -\frac{1}{2} e_5^2$ (97) Dirivative control $V_5$ is $V_5 = -\frac{1}{2} e_5^2$ (98) $V_5 = -e_5 (S_6 + V_5 - S_6)$ (100) $V_5 = -e_5 (S_6 + S_6)$ (101) $V_5 = -e_5 (S_6 + S_6)$ (102) $e_5 = k_5 (S_6 + V_5 - S_6)$ (103) Lyapunov candidate function chosen for this system is $V_6 (e_5, S_6) = -\frac{1}{2} (e_5^2 + S_5^2)$ (104) Three divitative of the Lyapunov function is $V_6 (e_5, S_6) = -\frac{1}{2} (e_5^2 + S_5^2)$ (104) Ther	$\dot{V}_4(e_3,S_\theta) = e_3\dot{e}_3 + S_\theta\dot{S}_\theta$	(81)
$\begin{aligned} s_{g} &= -q_{g}sign(S_{g}) - k_{g}S_{g} \\ k_{1}(s_{g},S_{g}) &= -c_{g}S_{g} - e_{g}S_{g} - q_{g}sign(S_{g})S_{g} - k_{g}S_{g}^{2} \\ (83) \\ V_{k}(s_{g},S_{g}) &= -c_{g}S_{g}^{2} - e_{g}S_{g} - q_{g}sign(S_{g})S_{g} - k_{g}S_{g}^{2} \\ (84) \\ V_{k}(s_{g},S_{g}) &= -c_{g}S_{g}^{2} - e_{g}S_{g} - q_{g}sign(S_{g})S_{g} - k_{g}S_{g}^{2} \\ (85) \\ System is asymptotically stable and control input can be obtained by \\ S_{g} &= -a_{g}sign(S_{g}) - k_{g}S_{g} \\ (86) \\ S_{g} &= -a_{a} - c_{g}S_{g} + x_{g} \\ (87) \\ - q_{g}Sign(S_{g}) - k_{g}S_{g} = -s_{g}S_{g} + x_{g}x_{g}S_{g} + x_{g}x_{g}^{2} + a_{g}X_{g}^{2} + b_{g}U_{g} \\ (87) \\ - q_{g}Sign(S_{g}) - k_{g}S_{g} = -s_{g}S_{g} + x_{g}x_{g} + a_{g}x_{g}^{2} + a_{g}X_{g}^{2} + b_{g}U_{g} \\ (88) \\ U_{3} &= \frac{1}{b_{g}}(-q_{g}Sign(S_{g}) - k_{g}S_{g} + x_{g}x_{g}^{2} + a_{g}x_{g}^{2} - a_{g}x_{g}^{2} - a_{g}X_{g}^{2} \\ (89) \\ In this control input an adaptive control law which is proposed to compensate the external disturbances. \\ q_{2} &= k_{garx} + 1S_{g} \\ where k_{horz} is a controller gain and q_{2} is a state variable whose value changes. \\ 3. Xaw Control: \\ Yaw error is defined as \\ e_{g} &= x_{g} - x_{g} \\ (91) \\ Where e_{g} &= k_{g} - x_{g} \\ (92) \\ Substituting from equation no. 28 \\ e_{g} &= x_{g} - x_{g} \\ (93) \\ The sliding surface S_{\psi} is defined and v_{5} is virtual control \\ e_{g} &= S_{g} - x_{g} - v_{5} \\ (94) \\ x_{g} &= S_{g} - v_{5} \\ (96) \\ The Lyapmov candidate chosen for this is \\ V_{5} &= \frac{1}{2}e_{5}^{2} \\ (97) \\ Derivative of V_{5} is \\ V_{5} &= e_{5}(x_{cd} + v_{5} - S_{g}) \\ (100) \\ V_{5} &= e_{5}c_{5}(x_{cd} + v_{5} - S_{g}) \\ (101) \\ V_{5} &= c_{5}c_{5} - c_{5}S_{g} < 0 \\ (102) \\ C_{5} is positive constant and the subsystem is asymptotically stable. \\ The sliding surface time derivative is \\ e_{e} - S_{g} &= + x_{e} \\ (103) \\ Lyapmov candidate function chosen for this system is \\ V_{6}(e_{5}, S_{g}) &= \frac{1}{2}(e_{5}^{2} + S_{0}^{2}) \\ (104) \\ Time derivative of the Lyapunov function is \\ V_{6}(e_{5}, S_{g}) &= e_{7}e_{5} + x_{6}S_{g} \\ (104) \\ $	Necessary sliding condition required to stabilize is	
$\begin{aligned} V_{q}(e_{3}, s_{0}) &= c_{3}e_{3}^{2} - e_{3}S_{g} + S_{g}(-q_{2}sign(S_{g}) \\ &= k_{2}S_{0}^{2} \end{aligned} \tag{83}$ $\begin{aligned} V_{q}(e_{3}, S_{3}) &= c_{1}e_{3}^{2} - e_{3}S_{g} - q_{2}sign(S_{g}) S_{g} - k_{2}S_{g}^{2} \\ &= (84) \\ V_{q}(e_{3}, S_{3}) &= c_{1}e_{3}^{2} - e_{3}S_{g} - q_{2}sign(S_{g}) S_{g} - k_{2}S_{g}^{2} \\ &= (84) \\ V_{q}(e_{5}, S_{g}) &= c_{1}e_{3}^{2} - e_{3}S_{g} - q_{2}sign(S_{g}) S_{g} - k_{2}S_{g}^{2} \\ &= (85) \\ System is asymptotical lystable and control input can be obtained by \\ S_{g} &= -q_{2}sign(S_{g}) - k_{2}S_{g} \\ &= (86) \\ U_{3} &= \frac{1}{h_{2}}(-q_{2}sign(S_{g})) - k_{2}S_{g} + x_{3,d} - c_{3}e_{3} + a_{4}x_{2}x_{6} + a_{5}x_{4}^{2} + a_{6}\Omega x_{2} + b_{2}U_{3} \\ &= (86) \\ U_{3} &= \frac{1}{h_{2}}(-q_{2}sign(S_{g})) - k_{2}S_{g} + x_{3,d} + c_{3}e_{3} - a_{4}x_{2}x_{6} - a_{5}x_{4}^{2} - a_{6}\Omega x_{2}) \\ &= (86) \\ U_{3} &= \frac{1}{h_{2}}(-q_{2}sign(S_{g})) - k_{2}S_{g} + x_{3,d} + c_{3}e_{3} - a_{4}x_{2}x_{6} - a_{5}x_{4}^{2} - a_{6}\Omega x_{2}) \\ &= (80) \\ Where theorem is a the control input an adaptive control law which is proposed to compensate the external disturbances. \\ &= (8a) \\ Q_{2} &= k_{0}ar^{2} + 1S_{0} \\ Where e_{3} is a controller gain and q_{2} is a state variable whose value changes. \end{aligned}$	$\dot{S}_{\theta} = -q_2 sign(S_{\theta}) - k_2 S_{\theta}$	(82)
$\begin{aligned} -k_2 S_0 \\ \psi_4(e_2, S_0) &= -e_2 e_2^2 - e_2 S_0 - q_2 sign(S_0) S_0 - k_2 S_0^2 \\ (83) \\ \psi_4(e_2, S_0) &= -e_2 e_2^2 - e_2 S_0 - q_2 sign(S_0) S_0 - k_2 S_0^2 \\ (84) \\ \psi_4(e_2, S_0) &= -e_2 e_2^2 - e_2 S_0 - q_2 sign(S_0) S_0 - k_2 S_0^2 \\ (85) \\ System is asymptotically stable and control input can be obtained by \\ S_0 &= -x_{3d} - c_3 e_3 + x_4 \\ (87) \\ -q_2 sign(S_0) - k_2 S_0 \\ = -k_{3d} - c_3 e_3 + x_4 \\ (87) \\ -q_2 sign(S_0) - k_2 S_0 + x_{3d} + c_4 e_3 + a_4 x_2 x_6 + a_5 x_4^2 - a_6 \Omega x_2 \\ (88) \\ U_3 &= \frac{1}{b_2} (-q_2 sign(S_0) - k_2 S_0 + x_{3d} + c_4 e_3 - a_4 x_2 x_6 - a_5 x_4^2 - a_6 \Omega x_2 \\ (89) \\ In this control input an adoptive control law which is proposed to compensate the external disturbances. \\ q_2 &= k_{Darr} * 1 S_0 \\ (90) \\ where k_{Darr} s is a controller gain and q_2 is a state variable whose value changes. \\ 3. Yaw Control: \\ Yaw error is defined as \\ e_5 &= x_{3d} - x_5 \\ (91) \\ Where e_5 : is destred yaw and x_5 is actual yaw \\ Differentiating the yaw error \\ e_5 &= x_{3d} - x_5 \\ (92) \\ Substituting from equation no.28 \\ e_5 &= x_{3d} - x_5 \\ (93) \\ The sliding surface S_{\psi}$ is defined and $v_5$ is virtual control $e_5 = x_{3d} - x_5 \\ (94) \\ x_6 &= S_{\psi} = x_6 - v_5 \\ (95) \\ The Lyapunov candidate chosen for this is \\ V_5 &= e_5 e_5 \\ (96) \\ The Lyapunov candidate chosen for this is \\ V_5 &= e_5 e_5 \\ (96) \\ The Lyapunov candidate to stabilize Lyapunov function as \\ v_6 &= -S_{\psi} - S_{\psi} - S_{\psi} \\ (100) \\ V_5 &= e_5 (-e_5 e_5 - S_{\psi}) \\ (101) \\ V_5 &= e_5 (-e_5 e_5 - S_{\psi}) \\ (102) \\ e_6 &= S_0 - v_5 \\ (e_6 - S_0 - v_5 - (e_5 e_5 - S_{\psi}) \\ (103) \\ Lyapunov candidate function chosen for this system is \\ v_6 &= -S_{\psi} - S_{\psi} - S_{\psi} \\ (104) \\ Three dividue or this drug enrice to a subsystem is asymptotically stable. \\ The skiding surface time derivative is \\ e_6 &= S_0 - v_5 + x_6 \\ (103) \\ Lyapunov candidate function chosen for this system is \\ V_6 (e_5, S_0) &= \frac{1}{2} \left( (e_5^2 + S_0^2 \right) \\ (104) \\ Three derivative or this praymov function is \\ V_6 (e_5, S_0) &= \frac{1}{2}$	$\dot{V}_4(e_3, S_\theta) = -c_3 e_3^2 - e_3 S_\theta + S_\theta(-q_2 sign(S_\theta))$	
	$(-k_2S_{\theta})$	(83)
$\begin{aligned} & V_{q}(q_{0}, q_{0}) = -c_{q} \frac{2}{2} - e_{s} S_{0} - q_{s} z_{g}^{2} q_{1}(S_{0}) S_{0} - k_{s} S_{0}^{2} = < 0 \\ & (85) \end{aligned}$ $\begin{aligned} & System is asymptotically stable and control input can be obtained by \\ & S_{0} = -q_{2} z_{1} g_{1}(S_{0}) - k_{s} S_{0} \\ & (86) \\ & S_{0} = -x_{3d} - c_{3} e_{3} + x_{4} \\ & (87) \\ -q_{2} z_{1}^{2} g_{1}(S_{0}) - k_{s} S_{0} = -x_{3d} - c_{1} e_{3} + a_{4} x_{2} x_{6} + a_{4} x_{4}^{2} x_{4} + a_{6} \Omega x_{2} + b_{5} U_{3} \\ & (88) \\ & U_{3} = \frac{1}{b_{c}} (-q_{2} z_{1}^{2} g_{1}(S_{0}) - k_{2} S_{0} + \tilde{x}_{3d} + c_{3} e_{3} - a_{4} x_{2} x_{6} - a_{5} x_{4}^{2} - a_{0} \Omega x_{2}) \\ & (89) \end{aligned}$ In this control input an adaptive control law which is proposed to compensate the external disturbances. $\begin{aligned} & q_{2} = k_{barc2} *  S_{0}  \\ & \text{where } k_{arc2} \text{ is a controller gain and } q_{2} \text{ is a state variable whose value changes.} \end{aligned}$ $\begin{aligned} & 3.7aw \ Control: \\ & Yaw \ error is \ defined as \\ & e_{5} = x_{5d} - x_{5} \\ & (91) \end{aligned}$ Where $e_{6} : \text{ is cror, } x_{5d} \text{ is desired yaw and } x_{5} \text{ is actual yaw} \end{aligned}$ $\begin{aligned} & \text{Differentiating the yaw \ error} \\ & e_{6} = s_{b_{6}} - x_{5} \\ & (92) \\ & \text{Substituting from equation no.28} \\ & e_{5} = x_{5d} - x_{6} \\ & (93) \\ & \text{The skling surface } S_{9} \text{ is defined and } v_{5} \text{ is virtual control} \\ & e_{6} = s_{b_{6}} - s_{b_{7}} - s_{5} \\ & (95) \\ & e_{5} = s_{5d} - S_{b} + v_{5} \\ & (96) \\ & \text{The Lyapunov candidate chosen for this is \\ & V_{5} = \frac{1}{2} e_{5}^{2} \\ & (97) \\ & \text{Derivative of } V_{5} \text{ is} \\ & V_{5} = e_{5} (s_{5d} + v_{5} - S_{0}) \\ & (101) \\ & V_{5} = -e_{5d} - e_{5} e_{5} \\ & (102) \\ & V_{5} = e_{5} (-c_{5} e_{5} - S_{0}) \\ & (101) \\ & V_{5} = e_{5} (-c_{5} e_{5} - S_{0}) \\ & (102) \\ & V_{5} = e_{5} (-c_{5} e_{5} - S_{0}) \\ & (103) \\ & Lyapunov candidate function chose for this system is asymptotically stable. \\ & \text{The skling surface time derivative is \\ & e_{6} = S_{9} = v_{5} + x_{6} \\ & (103) \\ & Lyapunov candidate function chose for this system is \\ & V_{6} (e_{5} S_{0}) = e_{5} (e_{5} + S_{0} S_{0} \\ \\ & ($	$\dot{V}_4(e_3, S_\theta) = -c_3 e_3^2 - e_3 S_\theta - q_2 sign(S_\theta) S_\theta - k_2 S_\theta^2$	(84)
System is asymptotically stable and control input can be obtained by $\hat{s}_0 = -q_2 sign(S_0) - k_2 S_0$ (86) $\hat{s}_0 = -k_3 c - c_5 \hat{e}_3 + k_4$ (87) $-q_2 sign(S_0) - k_2 S_0 = -\tilde{x}_{3d} - c_5 \hat{e}_3 + a_4 x_2 x_6 + a_5 x_4^2 + a_6 \Omega x_2 + b_2 U_3$ (88) $U_3 = \frac{1}{b_2} (-q_2 sign(S_0) - k_2 S_0 + \tilde{x}_{3d} + c_3 \hat{e}_3 - a_4 x_2 x_6 - a_5 x_4^2 - a_6 \Omega x_2)$ (89) In this control input an adaptive control law which is proposed to compensate the external disturbances. $q_2 = k_{barr2} *  S_0 $ (90) where $k_{parr}$ is a controller gain and $q_2$ is a state variable whose value changes. 3.Yaw Control: Yaw error is defined as $e_5 = x_{5d} - x_5$ (91) Where $e_5$ is error, $x_{5d}$ is desired yaw and $x_5$ is actual yaw Differentiating the yaw error $\hat{e}_5 = x_{5d} - x_5$ (92) Substituting from equation no.28 (92) Substituting from equation no.28 (93) The sliding surface $S_0$ is defined and $v_5$ is virtual control $e_6 = S_0 + x_6 - v_5$ (94) $x_6 = S_0 + v_5$ (95) $\hat{e}_5 = x_{5d} - S_6$ (97) Derivative of $V_5$ is $V_5 = -\delta_2 \hat{e}_5$ (97) Derivative of $V_5$ is $V_5 = e_5 \hat{e}_5$ (97) Derivative of $V_5$ is $V_5 = e_5 \hat{e}_5$ (98) $V_5 = e_5 \hat{e}_5 - \hat{e}_5 \hat{e}_5 = 0$ (100) $\hat{V}_5 = c_6 \hat{e}_5 - e_5 \hat{e}_5 = 0$ (100) $\hat{V}_5 = c_6 \hat{e}_5 - e_5 \hat{e}_5 = 0$ (100) $\hat{V}_5 = c_6 \hat{e}_5 - e_5 \hat{e}_6 < 0$ (101) $\hat{V}_5 = c_6 \hat{e}_5 - e_5 \hat{e}_6 < 0$ (102) $\hat{e}_5 = \hat{s}_{4d} - \hat{c}_5 \hat{e}_5 = 0$ (103) Lyapunov candidate function chosen for this system is $\hat{e}_6 = \hat{S}_0 = \hat{v}_5 + \hat{x}_6$ (103) Lyapunov candidate function chosen for this system is $\hat{e}_6 = \hat{S}_0 = \hat{v}_5 + \hat{x}_6 + \hat{S}_0$ (104) Time derivative of the Lyapunov function is $\hat{V}_6(e_5, S_0) = = \hat{e}_5 + \hat{S}_5 + \hat{S}_6$ (105) Nearcover derivative is $\hat{e}_6 = \hat{S}_0 = \hat{v}_5 + \hat{x}_6$ (103) Lyapunov candidate function chosen for this system is $\hat{V}_6(e_5, S_0) = \hat{e}_5 + \hat{S}_5 + \hat{S}_6$ (104) Time derivative of the Lyapunov function is $\hat{V}_6(e_5, S_0) = \hat{e}_5 + \hat{S}_5 + \hat{S}_6$ (105)	$\dot{V}_4(e_3, S_{\theta}) = -c_3 e_3^2 - e_3 S_{\theta} - q_2 sign(S_{\theta}) S_{\theta} - k_2 S_{\theta}^2 < 0$	(85)
$\begin{aligned} & \sum_{p} = -q_2 \sin(x_0) - k_2 \sum_{q} & (86) \\ & \sum_{p} = -x_{3d} - c_3 e_3 + x_4 & (87) \\ & (87) - q_2 \sin(x_0) - k_2 \sum_{q} = -x_{3d} - c_3 e_3 + a_4 x_2 x_6 + a_5 x_4^2 + a_6 \Omega x_2 + b_2 U_3 & (88) \\ & U_3 = \frac{1}{b_2} (-q_2 \sin(x_0) - k_2 \sum_{q} + x_{3d} + c_3 e_3 - a_4 x_2 x_6 - a_5 x_4^2 - a_6 \Omega x_2) & (89) \\ & \text{In this control input an adaptive control law which is proposed to compensate the external disturbances.} & (90) \\ & where k_{bar2} is a controller gain and q_2 is a state variable whose value changes. & (90) \\ & where k_{bar2} is a controller gain and q_2 is a state variable whose value changes. & (91) \\ & Where e_5 = x_{5d} - x_5 & (92) \\ & Where e_6 = x_{5d} - x_5 & (92) \\ & Substituting from equation no.28 & (e_5 - x_5 - x_5) & (92) \\ & e_5 = x_5 - x_5 & (92) \\ & E_5 = x_5 - x_5 & (93) \\ & F_5 = x_5 - y_5 & (95) \\ & e_5 = x_5 - y_5 & (95) \\ & e_5 = x_5 - y_5 & (95) \\ & e_5 = x_5 - y_5 & (95) \\ & e_5 = x_5 - y_5 & (95) \\ & e_5 = x_5 - y_5 & (95) \\ & e_5 = x_5 - y_5 & (96) \\ & The Lyapunov candidate chosen for this is \\ & V_5 = \frac{1}{2} e_5^2 & (97) \\ & Derivative of V_5 is & (96) \\ & V_5 = e_5 (x_{5d} + v_5 - x_6) & (100) \\ & V_5 = e_5 (x_{5d} + v_5 - x_6) & (100) \\ & V_5 = -e_5 (e_5 - e_5) & (100) \\ & V_5 $	System is asymptotically stable and control input can be obtained by	
$\begin{aligned} & \int_{S_{p}} = -\dot{x}_{3d} - c_{3}\dot{e}_{3} + \dot{x}_{4} & (87) \\ & -q_{2}s[gn(S_{p}) - k_{2}S_{p} = -\dot{x}_{3d} - c_{3}\dot{e}_{3} + a_{4}x_{2}x_{6} + a_{5}x_{4}^{2} + a_{6}\Omega x_{2} + b_{2}U_{3} & (88) \\ & U_{3} = \frac{1}{b_{2}}(-q_{2}sign(S_{p}) - k_{2}S_{p} + \dot{x}_{3d} + c_{3}\dot{e}_{3} - a_{4}x_{2}x_{6} - a_{5}x_{4}^{2} - a_{6}\Omega x_{2}) & (89) \\ & \text{In this control input an adaptive control law which is proposed to compensate the external disturbances.} \\ & q_{2} = k_{bor2}^{2} +  S_{p}  & (90) \\ & \text{where } k_{bar2} = is a \text{ controller gain and } q_{2} \text{ is a state variable whose value changes.} & (91) \\ & \text{Where } e_{5} \text{ is error, } x_{5d} \text{ is desired yaw and } x_{5} \text{ is actual yaw} & (91) \\ & \text{Differentiating from equation no.28} & (92) \\ & \text{Substituting from equation no.28} & (92) \\ & \text{Substituting from equation no.28} & (93) \\ & e_{5} = x_{5d} - x_{5} & (94) \\ & e_{6} = S_{\psi} = x_{6} - v_{5} & (95) \\ & e_{6} = S_{\psi} = x_{6} - v_{5} & (95) \\ & e_{6} = s_{5d} - s_{5} & (96) \\ & \text{The Lyapunov candidate chosen for this is} \\ & V_{5} = \frac{1}{2}e_{5}^{2} & (97) \\ & \text{Dirivative of } V_{5} \text{ is designed to stabilize Lyapunov function as} \\ & v_{5} = -x_{5d} - c_{5}e_{5} & (96) \\ & \text{Virtual control } v_{5} \text{ is designed to stabilize Lyapunov function as} \\ & v_{5} = -x_{5d}^{2} - c_{5}e_{5} - S_{\phi} & (01) \\ & V_{5} = -c_{5}e_{5}^{2} - c_{5}e_{5} & (100) \\ & V_{5} = c_{5}e_{5}^{2} - e_{5}e_{5} & (100) \\ & V_{5} = c_{5}e_{5}^{2} - e_{5}e_{5} & (100) \\ & V_{5} = c_{5}e_{5}^{2} - e_{5}e_{5} & (100) \\ & V_{5} = c_{5}e_{5}^{2} - e_{5}e_{5} & (100) \\ & V_{5} = c_{5}e_{5}^{2} - e_{5}e_{5} & (100) \\ & V_{5} = c_{5}e_{5}^{2} - e_{5}e_{5} & (100) \\ & V_{5} = c_{5}e_{5}^{2} - e_{5}e_{5} & (100) \\ & V_{5} = c_{5}e_{5}^{2} - e_{5}e_{5} & (100) \\ & V_{5} = c_{5}e_{5}^{2} - e_{5}e_{5} & (100) \\ & V_{5} = c_{5}e_{5}^{2} - e_{5}e_{5} & (100) \\ & V_{5} = c_{5}e_{5}^{2} - e_{5}e_{5} & (100) \\ & V_{5} = c_{5}e_{5}^{2} - e_{5}e_{5} & (100) \\ & V_{5} = c_{5}e_{5}^{2} - e_{5}e_{5} & (100) \\ & V_{5} = c_{5}e_{5}^{2} - e_{5}e_{5} & $	$S_{\theta} = -q_2 sign(S_{\theta}) - k_2 S_{\theta}$	(86)
$-q_{2}sign(S_{0}) - k_{2}S_{0} = -x_{3d} - c_{2}\delta_{2} + a_{3}x_{2}x_{6} + a_{3}x_{4}^{2} + a_{6}\Omega_{2}x_{2} + b_{2}J_{3} $ (88) $U_{3} = \frac{1}{b_{2}}(-q_{2}sign(S_{0}) - k_{2}S_{0} + \dot{x}_{3d} + c_{3}\delta_{3} - a_{4}x_{2}x_{6} - a_{5}x_{4}^{2} - a_{6}\Omega_{2}x_{2})$ (89) In this control input an adaptive control law which is proposed to compensate the external disturbances. $q_{2} = k_{bar^{2}} +  S_{0} $ (90) where $k_{bar^{2}}$ is a controller gain and $q_{2}$ is a state variable whose value changes. 3. Yaw Control: Yaw error is defined as $e_{5} = x_{5a} - x_{5}$ (91) Where $e_{5}$ is zeror, $x_{5d}$ is desired yaw and $x_{5}$ is actual yaw Differentiating the yaw error $e_{6} = \dot{x}_{5d} - x_{5}$ (92) Substituting from equation no.28 $\dot{e}_{5} = \dot{x}_{5d} - x_{6}$ (93) The sliding surface $S_{\psi}$ is defined and $v_{5}$ is virtual control $e_{6} = S_{\psi} = x_{6} - v_{5}$ (94) $x_{6} = S_{\psi} - v_{5}$ (95) $e_{5} = \dot{x}_{5d} - \dot{x}_{6}$ (96) The Lyapunov candidate chosen for this is $V_{5} = e_{5}(\dot{x}_{5d} + v_{5} - S_{\psi})$ (97) Derivative of $V_{5}$ is $v_{5} = e_{5}(x_{5d} + v_{5} - S_{\psi})$ (100) $\dot{V}_{5} = e_{5}(x_{5d} + v_{5} - S_{\psi})$ (101) $V_{5} = e_{5}(-c_{5}e_{5} - S_{\psi})$ (102) $e_{5}$ is positive constant and the subsystem is asymptotically stable. The sliding surface three denotes in the subsystem is asymptotically stable. The sliding surface time derivative is $e_{6} = \dot{S}_{\psi} - \dot{v}_{5} + \dot{S}_{\phi}$ (103) Lyapunov candidate function chosen for this system is $V_{6}(e_{5}, S_{\psi}) = \frac{1}{4}(e_{5}^{2} + S_{\phi}^{2})$ (104) Time derivative of the Lyapunov function is $V_{6}(e_{5}, S_{\psi}) = \frac{1}{4}(e_{5}^{2} + S_{\phi}^{2})$ (105)	$S_{\theta} = -\ddot{x}_{3d} - c_3 \dot{e}_3 + \dot{x}_4$	(87)
$U_{3} = \frac{1}{b_{2}} (-q_{2}sign(S_{0}) - k_{2}S_{0} + \ddot{x}_{3d} + c_{3}\dot{e}_{3} - a_{4}x_{2}x_{6} - a_{5}x_{4}^{2} - a_{6}\Omega x_{2}) $ (89) In this control input an adaptive control law which is proposed to compensate the external disturbances. $q_{2} = k_{0}u_{2} *  S_{0} $ (90) where $k_{urr2}$ is a controller gain and $q_{2}$ is a state variable whose value changes. 3.Yaw Control: Yaw error is defined as $e_{5} = x_{5d} - x_{5}$ (91) Where $e_{i}$ is error, $x_{5d}$ is desired yaw and $x_{5}$ is actual yaw Differentiating the yaw error $e_{5} = x_{5d} - x_{5}$ (92) Substituting from equation no.28(93) The sliding surface $S_{\psi}$ is defined and $v_{5}$ is virtual control $e_{6} = S_{\psi} = x_{6} - v_{5}$ (94) $x_{6} = S_{\psi} = x_{6} - v_{5}$ (95) $e_{5} = \dot{x}_{5d} - \dot{x}_{5}$ (95) $f_{5} = \dot{x}_{5d} - \dot{x}_{5}$ (96) The Lyapunov candidate chosen for this is $V_{5} = \frac{1}{2}e_{5}^{2}$ (97) Derivative of $V_{5}$ is $V_{5} = e_{5}(\dot{x}_{3d} + v_{5} - S_{\psi})$ (98) $V_{5} = e_{5}(\dot{x}_{3d} + v_{5} - S_{\psi})$ (99) Virtual control $v_{v}$ is designed to stabilize Lyapunov function as $v_{5} = -x_{5d} - c_{5}e_{5} - S_{\psi})$ (101) $V_{5} = -c_{5}e_{5}^{2} - e_{5}S_{\psi} < 0$ (102) $c_{5}$ is positive constant and the subsystem is asymptotically stable. The sliding surface time derivative is $\dot{e}_{6} = \dot{S}_{\psi} = \dot{v}_{5} + \dot{x}_{6}$ (103) $Lyapunov candidate function chosen for this system is V_{6}(e_{5}, S_{\psi}) = e_{5}^{2}(e_{5}^{2} + S_{\psi}^{2})(104)Time derivative of the Lyapunov function isV_{6}(e_{5}, S_{\psi}) = e_{5}^{2}(e_{5}^{2} + S_{\psi}^{2})(104)Time derivative of the Lyapunov function isV_{6}(e_{5}, S_{\psi}) = e_{5}^{2}(e_{5} + S_{\psi}^{2})(104)The soluting vertifient condition reservited to extilitive isV_{6}(e_{5}, S_{\psi}) = e_{5}^{2}(e_{5} + S_{\psi}^{2})(104)$	$-q_2 sign(S_{\theta}) - k_2 S_{\theta} = -\ddot{x}_{3d} - c_3 \dot{e}_3 + a_4 x_2 x_6 + a_5 x_4^2 + a_6 \Omega x_2 + b_2 U_3$	(88)
In this control input an adaptive control law which is proposed to compensate the external disturbances. $q_2 = k_{barz^2} *  S_4 $ (90) where $k_{barz^2}$ is a controller gain and $q_2$ is a state variable whose value changes. 3.Yaw Control: Yaw error is defined as $e_5 = x_{5d} - x_5$ (91) Where $e_5$ is error, $x_{5d}$ is desired yaw and $x_5$ is actual yaw Differentiating the yaw error $\dot{e}_5 = \dot{x}_{5d} - \dot{x}_5$ (92) Substituting from equation no.28 (93) The sliding surface $S_{\psi}$ is defined and $v_5$ is virtual control $e_6 = \dot{s}_{5d} - x_6$ (93) The sliding surface $S_{\psi}$ is defined and $v_5$ is virtual control $e_6 = \dot{s}_{5d} - x_6$ (94) $x_6 = \dot{S}_{\psi} - v_5$ (94) $x_6 = \dot{S}_{\psi} - v_5$ (96) The Lyapunov candidate chosen for this is $V_5 = \frac{1}{2}e_5^2$ (97) Derivative of $V_5$ is $V_5 = e_5(\dot{s}_{5d} + v_5 - S_{\psi})$ (96) $V_5 = e_5(\dot{s}_{5d} + v_5 - S_{\psi})$ (100) $V_5 = e_5(-c_5e_5 - S_{\psi})$ (101) $V_5 = e_5(-c_5e_5 - S_{\psi}) = (100)$ $V_5 = e_5(-c_5e_5 - S_{\psi}) = (1$	$U_3 = \frac{1}{h_2} \left( -q_2 sign(S_\theta) - k_2 S_\theta + \ddot{x}_{3d} + c_3 \dot{e}_3 - a_4 x_2 x_6 - a_5 x_4^2 - a_6 \Omega x_2 \right)$	(89)
$q_{2} = k_{bar2} *  S_{\theta} $ (90) where $k_{bar2}$ is a controller gain and $q_{2}$ is a state variable whose value changes. 3. Yaw Control: Yaw error is defined as $e_{5} = x_{5d} - x_{5}$ (91) Where $e_{5}$ is error, $x_{5d}$ is desired yaw and $x_{5}$ is actual yaw Differentiating the yaw error $e_{5} = x_{5d} - x_{5}$ (92) Substituting from equation no.28 (93) $e_{6} = S_{4} = x_{6} - v_{5}$ (94) $x_{6} = S_{4} - v_{5}$ (95) $e_{6} = x_{5d} - v_{5}$ (94) $x_{6} = S_{4} - v_{5}$ (95) $e_{6} = x_{5d} - S_{4} + v_{5}$ (96) The Lyapunov candidate chosen for this is $V_{5} = e_{5}e_{5}$ (97) Derivative of $V_{5}$ is $V_{5} = e_{5}(x_{5} + v_{5} - S_{4})$ (100) $V_{5} = e_{5}e_{5}$ (100) $V_{5} = e_{5}(x_{5d} + v_{5} - S_{4d})$ (101) $V_{5} = -x_{5d}^{2} - e_{5}S_{4} < 0$ (102) $e_{5}$ is positive constant and the subsystem is asymptotically stable. The sliding surface time derivative is $e_{6} = S_{4} = v_{5} + x_{6}$ (103) Lyapunov candidate function chosen for this is $V_{6}(e_{5}, S_{4}) = \frac{1}{2}(e_{5}^{2} + S_{4}^{2})$ (104) Time derivative of the Lyapunov function is $V_{6}(e_{5}, S_{4}) = e_{5}(e_{5} + S_{4}S_{4})$ (105)	In this control input an adaptive control law which is proposed to compensate the external distur	bances.
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$v_{5} - v_{5}(x_{5d} + v_{5} - 5\psi)$ Virtual control $v_{5}$ is designed to stabilize Lyapunov function as $v_{5} = -\dot{x}_{5d} - c_{5}e_{5}$ (100) $\dot{v}_{5} = e_{5}(-c_{5}e_{5} - S_{\psi})$ (101) $\dot{v}_{5} = -c_{5}e_{5}^{2} - e_{5}S_{\psi} < 0$ (102) $c_{5}$ is positive constant and the subsystem is asymptotically stable. The sliding surface time derivative is $\dot{e}_{6} = \dot{S}_{\psi} = \dot{v}_{5} + \dot{x}_{6}$ (103) Lyapunov candidate function chosen for this system is $V_{6}(e_{5}, S_{\psi}) = \frac{1}{2}(e_{5}^{2} + S_{\psi}^{2})$ (104) Time derivative of the Lyapunov function is $\dot{V}_{6}(e_{5}, S_{\psi}) = e_{5}\dot{e}_{5} + S_{\psi}\dot{S}_{\psi}$ (105) Necessary sliding condition required to stabilize is	$\dot{V}_{5} = e_{5}(\dot{x}_{5,5} + n_{5} - S_{5})$	(99)
$v_{1} = -\dot{x}_{5d} - c_{5}e_{5}$ (100) $\dot{V}_{5} = e_{5}(-c_{5}e_{5} - S_{\psi})$ (101) $\dot{V}_{5} = -c_{5}e_{5}^{2} - e_{5}S_{\psi} < 0$ (102) $c_{5} \text{ is positive constant and the subsystem is asymptotically stable.}$ The sliding surface time derivative is $\dot{e}_{6} = \dot{S}_{\psi} = \dot{v}_{5} + \dot{x}_{6}$ (103) Lyapunov candidate function chosen for this system is $V_{6}(e_{5}, S_{\psi}) = \frac{1}{2}(e_{5}^{2} + S_{\psi}^{2})$ (104) Time derivative of the Lyapunov function is $\dot{V}_{6}(e_{5}, S_{\psi}) = e_{5}\dot{e}_{5} + S_{\psi}\dot{S}_{\psi}$ (105) Necessary sliding condition required to stabilize is	$V_5 = c_5 (x_{5a} + v_5 - S_{\psi})$ Virtual control $v_{-}$ is designed to stabilize I vanunov function as	(55)
$\dot{v}_{5} = x_{5a} - c_{5}c_{5}$ $\dot{v}_{5} = e_{5}(-c_{5}e_{5} - S_{\psi})$ (101) $\dot{v}_{5} = -c_{5}e_{5}^{2} - e_{5}S_{\psi} < 0$ (102) $c_{5} \text{ is positive constant and the subsystem is asymptotically stable.}$ The sliding surface time derivative is $\dot{e}_{6} = \dot{S}_{\psi} = \dot{v}_{5} + \dot{x}_{6}$ (103) Lyapunov candidate function chosen for this system is $V_{6}(e_{5}, S_{\psi}) = \frac{1}{2}(e_{5}^{2} + S_{\psi}^{2})$ (104) Time derivative of the Lyapunov function is $\dot{V}_{6}(e_{5}, S_{\psi}) = e_{5}\dot{e}_{5} + S_{\psi}\dot{S}_{\psi}$ (105) Necessary sliding condition required to stabilize is	$v_1$ reduction for $v_5$ is designed to stabilize Eyapanov function as $v_7 = -\dot{x}_{-3} - c_7 e_7$	(100)
$\dot{V}_{5} = c_{5}(-c_{5}c_{5}) - e_{5}N_{\psi} < 0$ (102) $c_{5} \text{ is positive constant and the subsystem is asymptotically stable.}$ The sliding surface time derivative is $\dot{e}_{6} = \dot{S}_{\psi} = \dot{v}_{5} + \dot{x}_{6}$ (103) Lyapunov candidate function chosen for this system is $V_{6}(e_{5}, S_{\psi}) = \frac{1}{2}(e_{5}^{2} + S_{\psi}^{2})$ (104) Time derivative of the Lyapunov function is $\dot{V}_{6}(e_{5}, S_{\psi}) = e_{5}\dot{e}_{5} + S_{\psi}\dot{S}_{\psi}$ (105) Necessary sliding condition required to stabilize is	$\dot{V}_5 = \kappa_{5a} - \epsilon_5 \epsilon_5$ $\dot{V}_7 = \epsilon_7 (-\epsilon_7 \epsilon_7 - S_7)$	(100)
$c_{5} = c_{5}c_{5} - c_{5}c_{\psi} < 0$ (102) $c_{5} \text{ is positive constant and the subsystem is asymptotically stable.}$ The sliding surface time derivative is $\dot{e}_{6} = \dot{S}_{\psi} = \dot{v}_{5} + \dot{x}_{6}$ (103) Lyapunov candidate function chosen for this system is $V_{6}(e_{5}, S_{\psi}) = \frac{1}{2}(e_{5}^{2} + S_{\psi}^{2})$ (104) Time derivative of the Lyapunov function is $\dot{V}_{6}(e_{5}, S_{\psi}) = e_{5}\dot{e}_{5} + S_{\psi}\dot{S}_{\psi}$ (105) Necessary sliding condition required to stabilize is	$\dot{V}_{r} = -c_{r}\rho_{r}^{2} - \rho_{r}S_{r} < 0$	(107)
The sliding surface time derivative is $\dot{e}_6 = \dot{S}_{\psi} = \dot{v}_5 + \dot{x}_6$ (103) Lyapunov candidate function chosen for this system is $V_6(e_5, S_{\psi}) = \frac{1}{2}(e_5^2 + S_{\psi}^2)$ (104) Time derivative of the Lyapunov function is $\dot{V}_6(e_5, S_{\psi}) = e_5 \dot{e}_5 + S_{\psi} \dot{S}_{\psi}$ (105) Necessary sliding condition required to stabilize is	$r_5 = c_{5}c_{5} = c_{5}c_{\psi} = 0$	(102)
$\dot{e}_{6} = \dot{S}_{\psi} = \dot{v}_{5} + \dot{x}_{6} $ (103) Lyapunov candidate function chosen for this system is $V_{6}(e_{5}, S_{\psi}) = \frac{1}{2}(e_{5}^{2} + S_{\psi}^{2}) $ (104) Time derivative of the Lyapunov function is $\dot{V}_{6}(e_{5}, S_{\psi}) = e_{5}\dot{e}_{5} + S_{\psi}\dot{S}_{\psi} $ (105) Necessary sliding condition required to stabilize is	The sliding surface time derivative is	
$V_{6}(e_{5}, S_{\psi}) = \frac{1}{2}(e_{5}^{2} + S_{\psi}^{2}) $ (104) Time derivative of the Lyapunov function is $\dot{V}_{6}(e_{5}, S_{\psi}) = e_{5}\dot{e}_{5} + S_{\psi}\dot{S}_{\psi} $ (105) Necessary sliding condition required to stabilize is	$\dot{\rho}_c = \dot{S}_{tc} = \dot{\nu}_r + \dot{x}_c$	(103)
$V_6(e_5, S_{\psi}) = \frac{1}{2} (e_5^2 + S_{\psi}^2) $ (104) Time derivative of the Lyapunov function is $\dot{V}_6(e_5, S_{\psi}) = e_5 \dot{e}_5 + S_{\psi} \dot{S}_{\psi}$ (105) Necessary sliding condition required to stabilize is	Lyapunov candidate function chosen for this system is	(103)
$\dot{v}_{6}(e_{5}, S_{\psi}) = e_{5}\dot{e}_{5} + S_{\psi}\dot{S}_{\psi} $ (104) Time derivative of the Lyapunov function is $\dot{V}_{6}(e_{5}, S_{\psi}) = e_{5}\dot{e}_{5} + S_{\psi}\dot{S}_{\psi} $ (105) Necessary sliding condition required to stabilize is	$V_{1}(\rho_{1}, S_{1}) = \frac{1}{2}(\rho^{2} + S^{2})$	(104)
Time derivative of the Lyapunov function is $\dot{V}_6(e_5, S_\psi) = e_5 \dot{e}_5 + S_\psi \dot{S}_\psi$ (105) Necessary sliding condition required to stabilize is	$v_{6}(v_{5}, \delta\psi) = \frac{1}{2}(v_{5} + \delta\psi)$ Time derivative of the Lypnum on function in	(104)
$v_6(e_5, s_{\psi}) - e_5e_5 + s_{\psi}s_{\psi} $ (105) Necessary sliding condition required to stabilize is	The derivative of the Lyapunov function is $\dot{V}(a, S) = a \dot{a} + S \dot{S}$	(105)
	$r_6(v_5, v_{\psi}) = v_5v_5 + v_{\psi}v_{\psi}$ Necessary sliding condition required to stabilize is	(105)

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$\dot{S}_{\psi} = -q_3 sign(S_{\psi}) - k_3 S_{\psi}$	(106)
$\dot{V}_6(e_5, S_{\psi}) = -c_5 e_5^2 - e_5 S_{\psi} + S_{\psi}(-q_3 sign(S_{\psi}) - k_3 S_{\psi})$	(107)
$\dot{V}_6(e_5, S_{\psi}) = -c_5 e_5^2 - e_5 S_{\psi} - q_3 sign(S_{\psi}) S_{\psi} - k_3 S_{\psi}^2$	(108)
$\dot{V}_{6}(e_{5},S_{\psi}) = -c_{5}e_{5}^{2} - e_{5}S_{\psi} - q_{3}sign(S_{\psi})S_{\psi} - k_{3}S_{\psi}^{2} < 0$	(109)
System is asymptotically stable and control input can be obtained by	
$\dot{S}_{\psi} = -q_3 sign(S_{\psi}) - k_3 S_{\psi}$	(110)
$\dot{S}_{\psi} = -\ddot{x}_{5d} - c_5 \dot{e}_5 + \dot{x}_6$	(111)
$-q_3 sign(S_{\psi}) - k_3 S_{\psi} = -\ddot{x}_{5d} - c_5 \dot{e}_5 + a_7 x_2 x_4 + a_8 x_6^2 + b_3 U_4$	(112)
$U_4 = \frac{1}{h_1} \left( -q_3 sign(S_{\psi}) - k_3 S_{\psi} + \ddot{x}_{5d} + c_5 \dot{e}_5 - a_7 x_2 x_4 - a_8 x_6^2 \right)$	(113)
In this control input an adaptive control law which is proposed to compensate the external disturb	bances.
$q_3 = k_{bar3} *  S_{\psi} $	(114)
where $k_{bar3}$ is a controller gain and $q_3$ is a state variable whose value changes.	
4. Horizontal X-Position Control:	
x-position error is defined as	
$e_7 = x_{7d} - x_7$	(115)
Where $e_7$ is error, $x_{7d}$ is desired x-axis position and $x_7$ is actual x-axis position	
Differentiating the x-axis position error is	(110)
$e_7 = x_{7d} - x_7$ Substituting from equation no 30	(116)
$\dot{\rho}_{r} = \dot{x}_{r,t} - x_{r}$	(117)
The sliding surface $S_r$ is defined and $v_7$ is virtual control	(117)
$e_8 = S_x = x_8 - v_7$	(118)
$x_8 = S_x - v_7$	(119)
$\dot{e}_7 = \dot{x}_{7d} - S_x + v_7$	(120)
The Lyapunov candidate chosen for this is	
$V_7 = \frac{1}{2}e_7^2$	(121)
Derivative of $V_7$ is	
$V_7 = e_7 \dot{e}_7$	(122)
$V_7 = e_7 \left( x_{7d} + v_7 - S_x \right)$	(123)
v intual control $v_7$ is designed to stabilize Lyapunov function as	(124)
$\dot{V}_7 = \kappa_{7d} c_{7c7}$ $\dot{V}_7 = \rho_7 (-c_7\rho_7 - S_1)$	(124)
$\dot{V}_7 = c_7 (c_7 c_7 - c_7 s_x)$ $\dot{V}_7 = -c_7 c_7^2 - c_7 s_x < 0$	(126)
$C_7$ is positive constant and the subsystem is asymptotically stable.	(120)
The sliding surface time derivative is	
$\dot{e}_8 = \dot{S}_x = \dot{v}_7 + \dot{x}_8$	(127)
Lyapunov candidate chosen for this system is	
$V_8(e_7, S_x) = \frac{1}{2}(e_7^2 + S_x^2)$	(128)
Time derivative of the Lyapunov function is	
$\dot{V}_8(e_7, S_x) = e_7 \dot{e}_7 + S_x \dot{S}_x$	(129)
Necessary sliding condition to be stabilize is	(120)
$S_x = -q_4 sign(S_x) - k_4 S_x$ $\dot{V}(a, S_x) = a_1 a_2^2 - a_2 S_x + S_x (a_1 a_2 a_2 a_3) + S_x$	(130)
$V_8(e_7, S_x) = -c_7 e_7 - e_7 S_x + S_x (-q_4 sign(S_x) - k_4 S_x)$ $V_8(e_7, S_x) = -c_7 e_7 - e_7 S_x + S_x (-q_4 sign(S_x) - k_4 S_x)$	(131)
$\dot{V}_8(e_7, S_x) = -c_7 e_7 - e_7 S_x - q_4 sign(S_x) S_x - k_4 S_x$ $\dot{V}_8(e_7, S_x) = -c_8 e_7^2 - e_7 S_x - q_4 sign(S_x) S_x - k_4 S_x$	(132)
$V_8(e_7, S_x) = c_7e_7 = e_7S_x = q_4sign(S_x)S_x = k_4S_x < 0$	(155)
System is asymptotically stable and control input can be obtained by	
$\dot{S}_x = -q_4 sign(S_x) - k_4 S_x$	(134)
$\dot{S}_x = -\ddot{x}_{7d} - c_7 \dot{e}_7 + \dot{x}_8$	(135)
$-q_4 sign(S_x) - k_4 S_x = -\ddot{x}_{7d} - c_7 \dot{e}_7 + a_9 x_8 + \left( U_x * \frac{U_1}{m} \right)$	(136)
$U_r = \frac{m}{m} (-q_4 sign(S_r) - k_4 S_r + \ddot{x}_{7d} + c_7 \dot{e}_7 - a_9 x_8)$	(137)
In this control input an adaptive control law which is proposed to compensate the external disturb	nances
$a_A = k_{harA} *  S_r $	(138)
where $k_{bar4}$ is a controller gain and $q_4$ is a state variable whose value changes.	()
· · ·	
5 Havisantal V Desition Control	
S. HORZONIAL 1-POSILION CONTROL: Y-position error is defined as	
Position error is defined us	
$e_9 = x_{9d} - x_9$	(139)
Where $e_9$ is error, $x_{9d}$ is desired y-axis position and $x_9$ is actual y-axis position	

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Differentiating the y-axis position error is	
$\dot{e}_9 = \dot{x}_{9d} - \dot{x}_9$	(140)
$\dot{e}_{\rm q} = \dot{x}_{\rm qd} - x_{\rm 10}$	(141)
The sliding surface $S_y$ is defined and $v_9$ is virtual control	
$e_{10} = S_y = x_{10} - v_9$	(142)
$x_{10} = S_y - v_9$	(143)
$\dot{e}_9 = \dot{x}_{9d} - S_y + v_9$ The Lemma and idea chosen for this is	(144)
The Lyapunov candidate chosen for this is $V = \frac{1}{2}c^2$	(145)
$V_9 - \frac{1}{2} e_9$ Derivative of <i>V</i> is	(145)
$\dot{V}_0 = e_0 \dot{e}_0$	(146)
$\dot{V}_{9} = e_{9} \left( \dot{x}_{9d} + v_{9} - S_{v} \right)$	(147)
Virtual control $v_9$ is designed to stabilize Lyapunov function	
$v_9 = -\dot{x}_{9d} - c_9 e_9$	(148)
$V_9 = e_9(-c_9e_9 - S_y)$	(149)
$V_9 = -c_9 e_9^2 - e_9 S_y < 0$	(150)
The sliding surface time derivative is	
$\dot{e}_{10} = \dot{S}_v = \dot{v}_9 + \dot{x}_{10}$	(151)
Lyapunov candidate chosen for this system is	
$V_{10}(e_9, S_y) = \frac{1}{2}(e_9^2 + S_y^2)$	(152)
Time derivative of the Lyapunov function is	
$\dot{V}_{10}(e_9, S_y) = e_9 \dot{e}_9 + S_y \dot{S}_y$	(153)
Necessary sliding condition required to stabilize is $\dot{c} = a \operatorname{sigm}(c) + b c$	(154)
$S_y = -q_5 Sign(S_y) - \kappa_5 S_y$ $\dot{V}_{(a, S_y)} = c_a^2 - c_s S_y + S_{(-a, sign(S_y))} - k_s S_y$	(155)
$\dot{V}_{10}(e_5, S_y) = -c_5e_5 - e_5S_y + S_y(-q_5Sign(S_y) - \kappa_5S_y)$ $\dot{V}_{10}(e_5, S_y) = -c_5e_5 - e_5S_y - e_5S_y + S_y(-q_5Sign(S_y) - \kappa_5S_y)$	(155)
$\dot{V}_{10}(e_0, S_y) = -c_0 e_0^2 - e_0 S_y - q_s sign(S_y) S_y - k_s S_y$ $\dot{V}_{10}(e_0, S_y) = -c_0 e_0^2 - e_0 S_y - q_s sign(S_y) S_y - k_s S_y^2 < 0$	(150)
	(101)
System is asymptotically stable and control input can be obtained by	
$S_{y} = -q_5 sign(S_y) - k_5 S_y$	(158)
$S_y = -\ddot{x}_{9d} - c_9 \dot{e}_9 + \dot{x}_{10} $	(159)
$-q_5 sign(S_y) - k_5 S_y = -\ddot{x}_{9d} - c_9 \dot{e}_9 + a_{10} x_{10} + \left( U_y * \frac{b_1}{m} \right)$	(160)
$U_{y} = \frac{m}{U_{1}} (-q_{5} sign(S_{y}) - k_{5}S_{y} + \ddot{x}_{9d} + c_{9}\dot{e}_{9} - a_{10}x_{10})$	(161)
In this control input an adaptive control law which is proposed to compensate the external disturb	bances.
$q_5 = k_{bar5} *  S_y $	(162)
where $k_{bar5}$ is a controller gain and $q_5$ is a state variable whose value changes	
6. Height Control:	
Z-position error is defined as	
$e_{11} = x_{11d} - x_{11}$	(163)
where $e_{11}$ is error, $x_{11d}$ is desired z-axis position and $x_{11}$ is actual z-axis position	
Differentiating the z-axis position error $\dot{a} = \dot{x}$	(164)
$e_{11} = x_{11d} - x_{11}$ Substituting from equation no.34	(104)
$\dot{e}_{11} = \dot{x}_{11d} - x_{12}$	(165)
The sliding surface $S_z$ is defined and $v_{11}$ is virtual control	
$e_{12} = S_z = x_{12} - v_{11}$	(166)
$\begin{aligned} x_{12} - S_z - v_{11} \\ \dot{e}_{11} = \dot{x}_{11d} - S_z + v_{11} \end{aligned}$	(167)
The Lyapunov candidate chosen for this is	(100)
$V_{11} = \frac{1}{2}e_{11}^2$	(169)
Derivative of $V_{11}$ is	
$\dot{V}_{11} = e_{11}\dot{e}_{11}$	(170)
$V_{11} = e_{11} (\dot{x}_{11d} + v_{11} - S_z)$ Virtual control <i>u</i> , is designed to stabilize Lypping function as	(171)
v intual control $v_{11}$ is designed to stabilize Lyapunov function as $v_{11} = -\dot{x}_{11d} - c_{11}e_{11}$	(172)
$\dot{V}_{11} = e_{11}(-c_{11}e_{11} - S_z)$	(173)
$\dot{V}_{11} = -c_{11}e_{11}^2 - e_{11}S_z < 0$	(174)
where $c_{11}$ is positive constant the subsystem is asymptotically stable.	

The sliding surface time derivative is

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$\dot{e}_{12} = \dot{S}_z = \dot{v}_{11} + \dot{x}_{12}$	(175)
Lyapunov candidate chosen for this system is	
$V_{12}(e_{11},S_z) = \frac{1}{2}(e_{11}^2 + S_z^2)$	(176)
Time derivative of the Lyapunov function is	
$\dot{V}_{12}(e_{11},S_z) = e_{11}\dot{e}_{11} + S_z\dot{S}_z$	(177)
Necessary sliding condition to be stabilize is	
$\dot{S}_z = -q_6 sign(S_z) - k_6 S_z$	(178)
$\dot{V}_{12}(e_{11},S_z) = -c_{11}e_{11}^2 - e_{11}S_z + S_z(-q_6 sign(S_z) - k_6S_z)$	(179)
$\dot{V}_{12}(e_{11}, S_z) = -c_{11}e_{11}^2 - e_1S_z - q_6 sign(S_z) S_z - k_6S_z^2$	(180)
$\dot{V}_{12}(e_{11},S_z) = -c_{11}e_{11}^2 - e_{11}S_{11} - q_6 sign(S_z) S_z - k_6 S_z^2 < 0$	(181)
System is asymptotically stable and control input can be obtained by	
$\dot{S}_z = -q_6 sign(S_z) - k_6 S_z$	(182)
$\dot{S}_z = -\ddot{x}_{11d} - c_{11}\dot{e}_{11} + \dot{x}_{12}$	(183)
$-q_6 sign(S_z) - k_6 S_z = -\ddot{x}_{11d} - c_{11}\dot{e}_{11} + a_{11}x_{12} + \left(U_1 * \frac{(Cx_1 * Cx_3)}{m}\right) - g$	(184)
$U_1 = \frac{m}{(Cx_1 * Cx_3)} (-q_6 sign(S_z) - k_6 S_z + \ddot{x}_{11d} + c_{11} \dot{e}_{11} - a_{11} x_{12} + g)$	(185)
In this control input an adaptive control law which is proposed to compensate the external disturbat	nces.
$q_6 = k_{bar6} *  S_z $	(186)

where  $k_{bar6}$  is a controller gain and  $q_6$  is a state variable whose value changes.

#### **IV. SIMULATION RESULTS**

In this section, the performance of the proposed algorithm is compared with nominal SMC with backstepping controller in MATLAB simulation. The initial conditions  $\phi(t_0)$ ,  $\theta(t_0)$ ,  $\psi(t_0)$ ,  $x(t_0)$ ,  $y(t_0)$  and  $z(t_0)$  are set as (0, 0, 0, 0, 0, 0). The desired trajectory for the attitude and altitude  $(\phi_d, \theta_d, \psi_d, x_d, y_d = adz_d)$  of the quadrotor are chosen as (0, 0, 0, sin(t), cos(t) and 0.1 \* t). External disturbances  $d_{\emptyset} = 2 * sin(t)$ ,  $d_{\theta} = 2 * sin(t)$ ,  $d_{\psi} = 2 * sin(t)$ ,  $d_x = 2 * sin(t)$ ,  $d_y = 2 * sin(t)$  and  $d_z = 2 * sin(t)$  are added. The quadrotor physical parameters are given in [26] and control gain parameters are given in the table 4.1.

Table 4.1: Parameters of the controller



Fig.1 Adaptive  $q_1$  value

To show the effectiveness of proposed adaptive control algorithm for trajectory tracking problem of quadrotor, simulation is conducted with a helical reference trajectory with red color lines and Actual trajectory with blue lines as shown in Fig.2 and Fig.3. The Fig.1 shows that the value of adaptive reaching law gain  $q_1$  is not constant and it is varying as per the proposed adaptive law in order to adjust the control input so that they can compensate the external disturbances. The Fig.4 to Fig.5 shows the output along the X-axis with Sliding Mode Back-Stepping Controller without adaptive control law and with adaptive control law.

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Fig.6. Output of Y-axis without Adaptive Control Law

Fig.7. Output of Y-axis with Adaptive Control Law

The Fig.6 to Fig.7 shows the output along the Y-axis with Sliding Mode Back-Stepping Controller without adaptive control law and with adaptive control law.

From the results one conclude that the system behavior of the proposed controller is robust against external disturbances. Also results obtained from the experiments suggest that performance of the proposed controller is better than nominal SMC with backstepping controller.

#### V. CONCLUSIONS

This article investigates the trajectory tracking problem of the quadrotor UAV in the presence of external disturbances. First nominal SMC with backstepping controller with reaching law is designed in MALAB. However, the system is unable to deal with

external disturbances to deal with this problem, an adaptive reaching law is designed that successfully estimates the external disturbances and improves trajectory tracking performance.

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