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Adaptive Synergetic Controller for Stabilizing the Altitude and Angle of Mini Helicopter

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ABSTRACT

This research proposes ASC (Adaptive Synergetic Controller) for the nonlinear model of MH (Mini Helicopter) to stabilize the desired altitude and angle. The model of MH is highly nonlinear, under-actuated and multivariable in nature due to its dynamic uncertainties and restrictions of velocities during the flight. ASC can force the tracking errors of the system states converges to zero in a finite interval of time. The MH system requires smooth controller and fast precise transition response from initial state till the desired state, therefore the parametric calculations and simulations can be done by the proposed ASC algorithm. It is validated that the above simulated results of the proposed controller have a better convergence rate and smoother stability response in order to track the desired altitude and angle when compared with SMC (Sliding Mode Controller). Moreover, it does not need any linearization, transformation and variations in the system model.

Key Words: **Adaptive Control, Synergetic Controller, Sliding Mode Control, Mini Helicopter, Control Algorithm and Adaptive Synergetic Control.**

1. INTRODUCTION

This article presents the modelling, controlling and its simulation of X-Cell (50) Yamaha MH. It is established on the bases of differential and state space mathematical model [1-3]. Adaptive controller based synergetic control algorithm is designed for stabilizing the desired or referred altitude and angle of MH is designed. Moreover, the synergetic control scheme is capable to update the dynamic performance (heading angle and altitude) of the system and complete system gains are fine-tuned by adaptive controller. Despite the other rotor planes, MH has complex dynamics due to its under-actuated, non-holonomic behavior in nature [4]. Formerly, many researchers, scientists pay attention on the linearization and stabilization of MH, because of its nonlinear dynamics [5].

For proper controlling, stabilizing altitude and heading angle of helicopter initially we require the stability of its nonlinear dynamics at different points commonly called as trim point conditions in control engineering [6-8]. Secondly, it may concern the referred position, velocity constraints and desired orientation to track given path. The controller designing of MH is more complex than general aircraft in terms of coupling between the lateral

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channels and longitudinal parameters. Simultaneously the other constraints like hysteresis effect, unwanted disturbance and highly nonlinearity increase the complexity in the designing of controller [9-10].

Previously, different linear and nonlinear control approaches were designed to control the dynamics of MH [11]. However, the main disadvantages of the previous algorithms are the multiple constraints, inherent complexity of the system parameters and low performance. To manage the aforementioned drawbacks, this research focus on nonlinear MIMO (Multiple Input Multiple Output) system based on adaptive control via synergetic controller. It is very difficult to achieve the equilibrium state in the presence of steady state errors and dynamic coupling technique [12-15]. The traditional method for equilibrium to overcome the disturbance is not enough, therefore a strong synergistic control method must be designed to control the MIMO based system. In [16-19], the same model of MH X-Cell 50 was used to ensure the steady hovering or stability of the proposed nonlinear autopilot controller, such that the nonlinear system stability was done by the Lyapunov direct method. The Lyapunov direct method does not require linearization of system states transformation.

The designed scheme also guarantees the better stability over other conventional methods and provides faster system response for equilibrium even in the presence of nonlinear uncertainties. Recently the advancement in the control theory, algorithm for the controlling of nonlinear system has been remarkable and the complexities of the helicopter are handled more mannerly such as dynamic inversion method, synergetic control method, etc. [20-24]. The results and simulations of the proposed scheme validate the better stability response when compared with SMC.

In this research, the performance of our proposed ASC is compared with conventional SMC. The major contributions of this research are: (1) a new ASC is designed which is able to handle the uncertainty and auto tuning of control parameters; (2) the proposed controller uses two control input commands as macro variables for controlling and stabilizing the altitude and heading angle of helicopter; (3) the 5th degree (higher degree) nonlinear equation of helicopter is become controllable by applying the Chow's theory; (4) the convergence rate of the synergetic controller provides the helicopter model to the desired altitude at short interval of time.

The breakup of this manuscript is structured as shown. Section 2 defines the structure of MH. It is followed by the designing of the proposed controller in section 3. Section 4 discusses the convergence rate of the desired performance. The simulation result defines in section 5, which shows the robustness and desired performance of the system. Finally, section 6 outlines the conclusions.

2. SYSTEM MODEL

The basic helicopter model consists of four inputs called as lateral, longitudinal, pedal and collective. Two velocity components are angular, linear denoted as (p,q,r), (u,v,w), Euler angles (φ,ϑ,ψ) and its movements are (x,y,z) axis respectively, such that 'z' axis shows its altitude [25]. In this article we only consider two inputs of the MIMO model of MH and check their responses by tuning the system dynamics as per our desired altitude and collective pitch angle.

The following system model shown in Fig. 1 is taken from [18], Equations (1-2) show the differential equations model in which vertical altitude and rotational speed of rotors are written as,

$$z = K_1 C_1 \delta^2 - g - K_2 z - K_3 \dot{z}^2 - K_4 \tag{1}$$

$$\begin{cases} C_t = \left[K_{C1} + \left(K_{C1}^2 + K_{C2} \vartheta \right)^{\frac{1}{2}} \right]^2 \\ \dot{\delta} = -K_5 \delta - K_6 \delta^2 - K_1 \delta^2 * \sin \vartheta + K_8 \mu_1 + K_9 \\ \ddot{\vartheta}_c = K_{10} \left(-3.174 * 10^{-4} * \mu_2 + 0.5436 - \vartheta \right) - K_{11} \dot{\vartheta} - K_{12} \delta^2 \sin \vartheta \end{cases} \tag{2}$$

Where altitude or height of helicopter is denoted by ‘z’ in meters that is above the ground level, the rotational

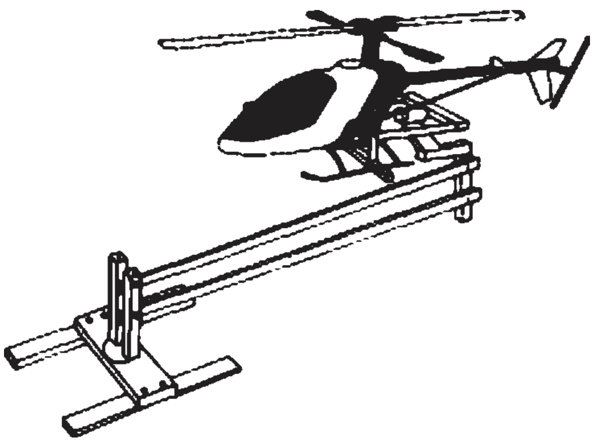

FIG. 1. MODEL OF YAMAHA X-CELL 50 MH

speed of rotors is defined by ‘δ’ (rad/s), gravitational force is ‘g’ (m/s^2), ‘v_c’ is the collective angle of pitch and ‘C_t’ is the coefficient of thrust. Where μ_1, μ_2 are the throttle and collective inputs which is utilized to control the altitude and angle of MH. The marginal values of the system constraints are taken from [17-19] are described in Table 1.

Fig. 2 represents the heading angle, angular rotation and the desired height of MH. The differential Equations (1-2) are now converted into state space matrix which is defined in Equations (3-6), where the altitude of MH varies with angle and at times the gravitational effects in the system in neglected [18].

$$\begin{cases} \dot{x} = \xi(x) + \zeta_1(x)\mu_1 + \zeta_2(x)\mu_2 \\ y = \left[y_1 y_2 \right]^T = \left[x_1 x_2 \right]^T \end{cases} \tag{3}$$

Where the input control variables and the system states are defined by:

TABLE 1. YAMAHA X-CELL 50 MODEL CONSTANTS

Constants	Value	Unit	Constants	Value
g	9.8	m/s^2	K_{C2}	$6.1456*10^{-2}$
K_1	$25*10^{-2}$	M	a_1	$53.1*10^{-3}$
K_2	$10*10^{-2}$	1/s	a_2	$15.364*10^{-3}$
K_3	$10*10^{-2}$	1/m	a_3	$282*10^{-9}$
K_4	7.86	m/s^2	a_4	$163.2*10^{-6}$
K_5	$70*10^{-2}$	1/s	a_5	$-K_2$
K_6	$28*10^{-4}$	-	a_6	$-K_2$
K_7	$5*10^{-3}$	-	a_7	$-g*K_4$
K_8	$10.88*10^{-2}$	1/s^2	a_8	$-K_5$
K_9	-13.92	1/s^2	a_9	$-K_6$
K_{10}	800.0	1/s^2	$a_{10} = a_{14}$	$-K_6$
K_{11}	65.0	1/s	a_{11}	K_9
K_{12}	0.1	-	a_{12}	$0.5436*K_{10}$
KC_1	$32.59*10^{-3}$	-	a_3	$-K_{10}$

$$\xi(x)=\begin{cases}\mu=[\mu_1\mu_2]^T=[K_8*\mu_1-3.176*10^{-3}*\mu_2*K_{10}]\\ x=[x_1x_2x_3x_4x_5]^T=[z\dot{z}\delta\vartheta\dot{\vartheta}]\\ \xi(x)[\xi_1(x),\xi_2(x),\xi_3(x),\xi_4(x),\xi_5(x)]\\ \zeta_1(x)=\begin{bmatrix}0\\0\\1\\0\\0\end{bmatrix}\zeta_2(x)=\begin{bmatrix}0\\0\\0\\0\\1\end{bmatrix}\end{cases} \tag{4}$$

$$\xi(x)=\begin{cases}x_2\\ a_0+a_1x_2+a_2x_2^2+\left(a_3+a_4x_4-\sqrt{a_5+a_6x_4}\right)x_3^2\\ a_7+a_8x_3+\left(a_9\sin(x_4)+a_{10}\right)x_3^2\\ x_5\\ a_{11}+a_{12}x_4-a_{13}x_3^2\sin(x_4)+a_{14}x_5\end{cases} \tag{5}$$

$$\xi(x)=\begin{cases}\dot{x}_1=\xi_1x_2\\ \dot{x}_2=\xi_2=a_0+a_1x_2+a_2x_2^2+\left(a_3+a_4x_4-\sqrt{a_5+a_6x_4}\right)x_3^2\\ \dot{x}_3=\xi_3+\mu_1=a_7+a_8x_3+\left(a_9\sin(x_4)+a_{10}\right)x_3^2\\ \dot{x}_4=\xi_4=x_5\\ \dot{x}_5=\xi_5+\mu_2=a_{11}+a_{12}x_4+a_{13}x_3^2\sin(x_4)+a_{14}x_5\end{cases} \tag{6}$$

There are two couplings in the dynamics of system states and the second is the control input (operational coupling). In the following section, nonlinear model of the system is controlled by the ASC strategy to control the dynamics of the system and the results presented in this research. Lie bracket is represented by [$\xi(\mathbf{x})$, $\zeta(\mathbf{x})$] of functions $\xi(\mathbf{x})$ and $\zeta_1(\mathbf{x})$.

$$[\xi(x),\zeta_1(x)]=\frac{\partial\xi(x)}{\partial x}\xi_1(x)-\frac{\partial\xi_1(x)}{\partial x}\xi(x) \tag{7}$$

Similarly Lie Bracket of $\xi(\mathbf{x})$, $\zeta(\mathbf{x})$ and $\zeta_2(\mathbf{x})$ is given by:

$$[\xi(x),\zeta_1(x)]=\begin{bmatrix}0\\ 2x_3\left(a_3+a_4x_4-\sqrt{a_5+a_6x_4}\right)\\ 2x_3\left(a_9\sin(x_4)+a_{10}\right)\\ 0\\ 2a_{13}x_3\sin(x_4)\end{bmatrix} \tag{8}$$

$$[\xi(x),\zeta_2(x)]=\frac{\partial\xi(x)}{\partial x}\zeta_2(x)-\frac{\partial\zeta_2(x)}{\partial x}\xi(x)=\begin{bmatrix}0\\0\\0\\1\\a_{14}\end{bmatrix} \quad 990$$

Now, according to the Chow's theory, if the non-linear system is in the form of $\dot{x}=\dot{\xi}(x)+\zeta_1\mu_1+\zeta_2\mu_u+...+\zeta_m\mu_m$; having 5th order system matrix. It must be controllable using involute closure of set {ξ, $\zeta_{1,}$ …, ζ_2} [26]. However, if $\mathbf{x}_2$, $\mathbf{x}_3$ are non-zero then the above matrix is off 5th order because of the rotational speed and height convergence to zero.

3. SYNERGETIC CONTROLLER

Nonlinear systems are complex in nature, they can be controlled by adaptive, robust and synergetic control theory based on an analytical approach of aggregation [27]. The designing process of the controller begins by identifying the micro variable. In this research, an algorithm is proposed that follows an adaptive synergetic controlled which is the main contribution of this research [28]. In order to enhance the robust control design, including a continuous control law and finite time convergence of the errors in a fully non-linear system simulation [29]. The system dynamics of synergetic control along with attractors $\psi_i = 0$ are shown by:

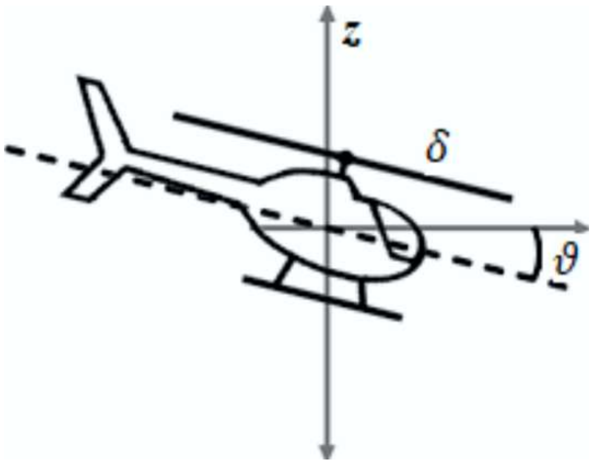

FIG. 2. THE MODEL OF MH

$$\mathrm{T}\dot{\rho} + \beta(\rho) = 0 \tag{10}$$

Where the convergence rate represented by T, ψ is the time derivative of macro variable and reaching effect function β(.) which is also equal to β(ρ) = ρ Therefore the Equation (10) can be written as:

$$\mathrm{T}\dot{\rho} + \rho = 0 \tag{11}$$

The above differential equation is evaluated by:

$$\rho(t) = \rho_0 e^{-\frac{t}{T}} \tag{12}$$

Where '*t*' is the time and '*T'* is the convergence rate as shown above. Transient speed of the controller can be enhanced by varying '*T*' inversely [30]. In the coming section, the algorithm can be made using the core parameters of synergetic controller for obtaining the roots of the expressions. The nonlinear equation of the system is already defined in Equation (3).

4. CONVERGENCE RATE

In accordance with dynamic Equation (10) $\mathrm{T}\dot{\rho} + \rho = 0$, ρ represented by ρ_0 at time t_0 and the simplification of the above expression is given by:

$$\rho_i(t) = \rho_i(t_0) e^{-\left(\frac{t_0}{Ti}\right)} \tag{13}$$

Here ρ_t is inversely proportional to the time *t* i.e. as the time approaches to infinity it becomes zero, therefore the movement of the system state from the initial state to final state is possible. Furthermore, the T_i in the above equation represent the convergence rate of the state variable to the final stage. If somehow the system variable is stable and the T_i remains smaller, the convergence rate is faster to achieve its target. The desired output utilizes the shorter process and give better result. Where e_1, e_2 are the error of altitude, heading angle and c_{ii} are the constants of controller that has minor value less than (0.1).

$$\begin{cases} \rho_1 = c_{11}e_1 + c_{12}e_1 + e_1 \\ \rho_2 = c_{21}e_2 + e_2 \end{cases} \tag{14}$$

Where $e_1 = i_1 - x_1$ and $e_2 = i_2 - x_3$.

Considering i_1 is desired altitude, i_2 is desired angle, μ_1 and μ_2 are macro variable control signals of dynamical Equation (15).

$$T_1 r_1 + r_1 = 0 \tag{15}$$

Where $\rho_1 = c_{11}e_1 + c_{12}e_1 + e_1$, $e_1 = - x_1 = - x_2$, $e_1 = x_2 = - \xi_2$ and $e_1 = - \xi_2$.

The combined equation is given by:

$$T_1\, c_{11}e_1 + T_1 c_{12}\, e_1 + T_1\, e_1 + c_{11}e_1 + c_{12}\, e_1 + e_1 = 0 \tag{16}$$

Where,

$$e_1 = \xi_2 = -\left[a_1\xi_2 + 2a_2\xi_2 x_2 + \left(a_4x_5 - \frac{1}{2}a_6x_5\frac{1}{\sqrt{a_5 + a_6x_4}}\right)x_3^2 + 2x_3(\xi_3 - \mu_1)\left(a_3 + a_4x_4 - \sqrt{a_5 + a_6x_4}\right)\right] \tag{17}$$

By considering,

$$\begin{cases} A = \left[a_1\xi_2 + 2a_2\xi_2 x_2 + \left(a_4x_5 - \frac{1}{2}a_6x_5\frac{1}{\sqrt{a_5 + a_6x_4}}\right)x_3^2 + 2x_3(\xi_3)\left(a_3 + a_4x_4 - \sqrt{a_5 \_ a_6x_4}\right)\right] \\ B = T_1 2x_3\left(a_3 + a_4x_4 - \sqrt{a_5 + a_6x_4}\right) \end{cases} \tag{18}$$

And the μ_1 is obtained by:

$$\mu_1 = \frac{T_1c_{11}e_1 + T_1c_{11}e_1 + T_1A + c_{11}e_1 + c_{12}e_1 + e_1}{B} \tag{19}$$

Similarly, for μ_2

$$r_2 = c_{21}e_2 + e_2 \tag{20}$$

Where,

$$\begin{cases} e_2 = -x_4 = -x_5 \\ e_1 = -x_5 = -\xi_5 - \mu_5 \\ T_2\left(-c_{21}x_5 - \xi_5 - \mu_2\right) + c_{21}e_2 = 0 \end{cases} \tag{21}$$

Finally, the control signal μ_2 is given by:

$$\mu_2 = \frac{\left(-T_2c_{21}x_5 + T_2\xi_5\right) + c_{21}e_2 + e_2}{T_2} \tag{22}$$

5. SIMULATION RESULTS

In this section, the simulations of the proposed ASC is performed and the comparative analysis of ASC and SMC performance is shown by taking altitude=4m and angle=0.4rad as a reference signal.

In Fig. 3 the control inputs of the system are taken as μ_1 and μ_2. Initially μ_1 starts from zero and converges to 200 after the delay of 1 second while μ_1 starts from 410 and converges to -100.

In Fig. 4, the reference altitude is set as 3m from the ground, proposed controller follows by ASC and SMC control techniques and it is found that ASC it achieves stability just after 0.6 seconds whereas SMC almost takes 1.5 seconds for the same task.

Finally, Fig. 5, the rotational angle of the Mini Helicopter is also compared between ASC and SMC. The simulation result shows the approximate equal response for both controllers. This comparative analysis has easily acknowledged the importance of the proposed controller over SMC and other existing techniques.

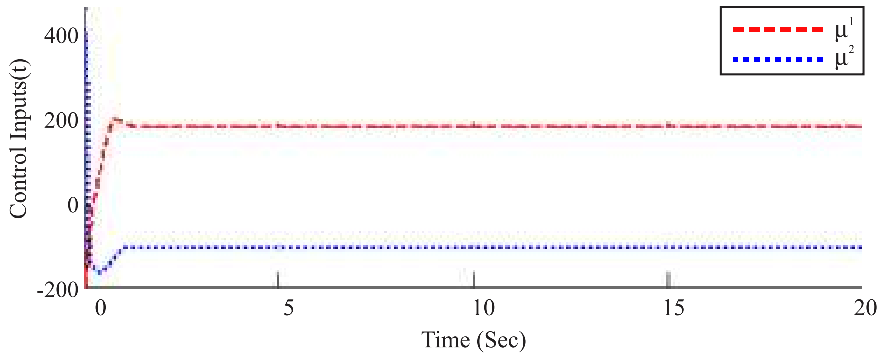

FIG. 3. CONTROL INPUTS OF THE SYSTEM

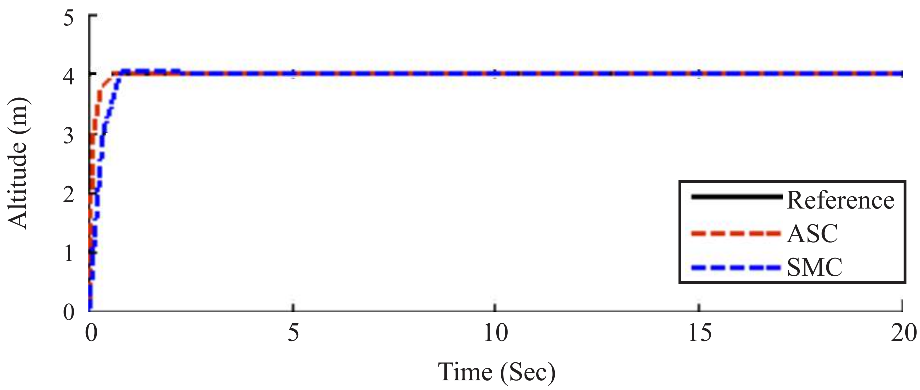

FIG. 4. COMPARISON OF ALTITUDES BETWEEN SMC AND ASC

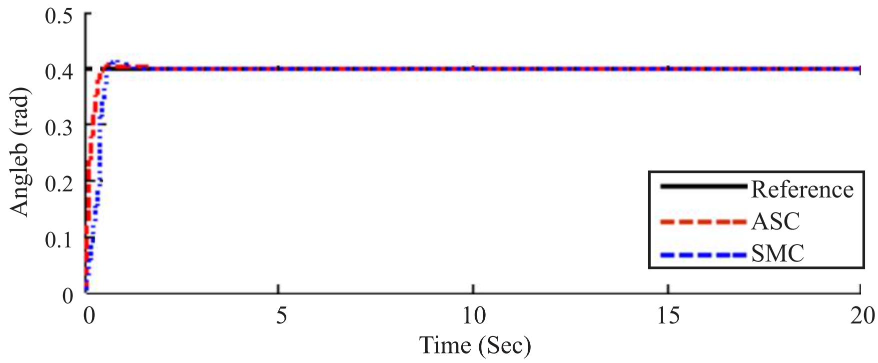

FIG. 5. COMPARISON OF ANGLES BETWEEN SMC AND ASC

6. CONCLUSION

In this research, a new ASC strategy is suggested for the stabilization of altitude and angle of nonlinear model of MIMO MH. ASC is used to estimate the uncertainties of the above system model and a novel ASC is designed via synergetic control theory. Moreover, the convergence rate of the above proposed approach is also investigated. Stability of the above system is proven, in sense of closed-loop bounded signals, and its tracking errors converges to zero. Simulated results validated the proposed control approach and achieved the tracking performance.

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