Free Chattering Sliding Mode Control with Adaptive Algorithm for Ground Moving Target Tracking

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Abstract—In this paper a free chattering sliding mode is proposed to generate the guidance law, in order to achieve the tracking of the ground moving target while an adaptive method is improved to deal with uncertainty. Sliding mode control is low sensitivity to planet parameter variations and uncertainties which eliminates the necessity of exact modeling. One of the major advantages of the proposed controller lies that its implementation only requires online estimation without the knowledge of bounds on system uncertainties. At first, the error dynamic of the tracking problem is described based on the range between unmanned aerial vehicle and ground moving target. Then, the nonlinear guidance law is proposed based on adaptive second order sliding mode control to achieve robustness, invariance and finite time tracking, and the chattering effect has been eliminated. Adaptive estimation is used to improve the command state generation and deal with the uncertainty of the target estimation. Closed loop stability is proved via Lyapunov analysis. Moreover, the accurate tracking of the target state has been achieved in the presence of the uncertainty which has been demonstrated in the simulation section.

Keywords—ground moving target; unmanned aerial vehicle; sliding mode control; Adaptive algorithm

I. INTRODUCTION

The two past decades have witnessed a remarkable increase in the utilization of unmanned aerial vehicles (UAVs), both in military and civilian applications. In the applications of aerial surveillance, border patrol and convoy protection. One of the tasks for UAVs which have different applications is to track ground moving target (GMT) autonomously. There are different approaches for accurate path tracking in several recent research works. But, there is still a need to investigate more efficient methods. The issue about robust target tracking in the presence of the target or UAV uncertainty and disturbances is still open. It should be noted that most of the recent work investigate this problem in 2-D, assuming that the altitude is held constant and the speed is constant and bounded. But there are a lot of different tasks which lead to the altitude changes during the target tracking. Moreover, most of the recent works have used various filters to eliminate the noise, but uncertainty between two vehicles has not been considered yet.

Recently, various approaches have been considered and applied for the guidance law. One of the applications of Lyapunov vector field is for standoff coordination of UAVs. The Lyapunov guidance vector field approach has been proposed to generate the tracking commands in [1-3]. These studies are consisted of several assumptions such, as constant velocity of the target or its straight line moving. Another disadvantage of these works is that there should be a full knowledge about the target. In [4], optimal estimate of the target position is proposed which can be calculated from the measurements in the presence of estimation error. In this study, measurement errors have been considered as random variable and error terms should be small for accurate estimation. The ground target tracking control systems for fixed wing UAVs have been improved in [5]. In this study, in order to follow the reference path in the presence of unknown wind, the control surface deflection and thrust have been set appropriately. However, position and velocity of the target on the ground are assumed to be known. The tangent vector field is another approach to generate a desired heading angle and to achieve the standoff orbit between the UAV and target position. In [6], a sliding mode control concept for circular formation and orbit radius change without velocity control has been proposed. This approach has not considered uncertainty in the estimation or UAV states and it is not appropriate for target tracking in the presence of uncertainty and disturbance. Lyapunov stability based approaches in [7] have been used to construct vector field such as circular loiter attractors that are designed to be global attractors. Another vector field based method [8] has been proposed for nonlinear tracking for the UAV while there are constraints of the heading rate and velocity inputs. The reference trajectory is generated dynamically and the UAV tracks it instead of following predefined straight line or circular paths. In [9], reference trajectories are generated and the guidance laws are implemented for UAV to track these trajectories. An integrated tracking algorithm with a Lyapunov vector field-based guidance law has been presented in [10] to track the trajectory of a circular orbit loitering around the target of arbitrary motion. In this study, the Extended Kalman Filter (EKF) approach is used for position estimation of the target from measured values. However, uncertainties in estimate value or UAV states have not been considered in most of these studies [7-10]. A decentralized vector field guidance algorithm for coordinated standoff tracking of a ground moving target by multiple UAVs has been presented in [11]. In this study the tangent vector field guidance strategy using sliding mode concept is presented for target tracking in 2-D. Adaptive terms in an existing sliding mode control concept are used to reduce
the effect of unmodelled dynamics and disturbances in the heading angle. A guidance law has been used to aerial target tracking in [12]. Nonlinear adaptive observer has been used to estimate the states and unknown parameters related to the size of target while the range between UAV and target position is assumed to be unknown.

SMC is a nonlinear control approach that drives the state of the system onto a specified sliding surface and maintains the trajectory on this surface for the subsequent time. This control scheme is robust against uncertainties and external disturbances. However, in conventional SMC design, the knowledge of the bounds on system uncertainties has to be acquired which may induce poor tracking performance and undesirable oscillations in the control signal. To overcome this drawback, adaptive sliding mode control is used [13]. High order sliding mode control is a recent strategy that decreases that chattering effect and is also remains robust. In [14] a chattering free adaptive sliding mode controller has been proposed for stabilizing a class of multi-input multi-output (MIMO) systems affected by both matched and mismatched uncertainty. In [15], an adaptive second order terminal sliding mode controller has been proposed for controlling robot manipulators.

In this paper an adaptive free chattering sliding mode controller is proposed for GMT tracking via a UAV in the local ground frame while the possible sensors measure and estimate the position of target with uncertainty. Adaptive algorithm is used to estimate the unknown bounds of the target position errors. Since the tracking problem of GMT can be applied in specific altitude or specific time varying path, the proposed controller is designed for 3-D tracking of the GMT with constant or time-varying bias. Simulations depict the effectiveness of the proposed method which can compensate the uncertainty. Moreover, the chattering phenomenon is removed in the proposed method.

II. PROBLEM DESCRIPTION AND NECESSARY ASSUMPTIONS

A. Assumptions

**Assumption1.** The error obtained from vision-based estimator based on velocity and ground angle are bounded as follows

\[ |\delta_{p}\| < \rho_{p} \]

\[ |\delta_{\phi}\| < \rho_{\phi} \]  \hspace{1cm} (1)

where \( \rho_{p} \) and \( \rho_{\phi} \) are positive constants.

**Assumption2.** The uncertainty of the target position is bounded and is a unknown and bounded function based on estimate value as following

\[ x^{T} = \hat{x}^{T} + \delta_{x} \]

\[ y^{T} = \hat{y}^{T} + \delta_{y} \]  \hspace{1cm} (2)

**Assumption3.** For the uncertainty of the system based on target position, following inequalities are satisfied

\[ |\delta_{f_{1}}| < k_{1} + \Gamma_{1}|\hat{x}^{T}| + \alpha_{1}|\hat{x}^{T}| + v_{1}|\hat{y}^{T}| \]

\[ |\delta_{f_{2}}| < k_{2} + \Gamma_{2}|\hat{y}^{T}| + \alpha_{2}|\hat{y}^{T}| + v_{2}|\hat{y}^{T}| \]

\[ |\delta_{f_{3}}| < k_{3} \]  \hspace{1cm} (3)

where \( k_{i}, \Gamma_{i}, \alpha_{i} \) and \( v_{i} \) are positive unknown parameters.

**Assumption4.** In this paper, it is assumed that the estimate of GMT is obtained from vision based estimator and a pair of continuous data for the target position and velocity has been used.

B. Problem Formulation

The equations of motion governing the dynamics of the actual unmanned aerial vehicle (UAV) are given by [6]

\[ \dot{x} = v \cos(y) \cos(\chi) \]

\[ \dot{y} = v \cos(y) \sin(\chi) \]

\[ \dot{z} = v \sin(y) \]

\[ \dot{\psi} = c_{1}(v_{cmd} - v) \]

\[ \dot{\gamma} = c_{2}(y_{cmd} - y) \]

\[ \dot{\chi} = c_{3}(x_{cmd} - x) \]  \hspace{1cm} (4)

where \( x, y, z \), \( \psi, \gamma \) and \( \chi \) denote the vehicle position, velocity, elevation angle (flight path angle) and course (ground track or heading angle) angle, respectively. \( v_{cmd}, y_{cmd} \) and \( x_{cmd} \) are command sets. The ground speed can be expressed as \( v = \sqrt{(x^{2} + y^{2} + z^{2})} \). \( c_{1}, c_{2} \) and \( c_{3} \) are positive constants which are related to inner control loop stability.

The target tracking can be accomplished if the states of the UAV converge to the reference states of the UAV. First, let consider ground moving target (GMT) equations of motion as the following model [11].

\[ \dot{x} = v_{T} \cos(\psi_{T}) \]

\[ \dot{y} = v_{T} \sin(\psi_{T}) \]

\[ \dot{z} = 0 \]

\[ x = 0 \]  \hspace{1cm} (5)

where \( x^{T}, y^{T} \) denotes the two-dimensional coordinate of the GMT in the vehicle frame. The initial height of the target is considered zero with zero speed in the z-axes. \( v_{T} \) is the ground speed of GMT which is equal to \( v_{T} = \sqrt{(x^{T})^{2} + (y^{T})^{2}} \). \( \psi_{T} \) is the ground angle of GMT and is obtained as \( \psi_{T} = \tan^{-1} \left( \frac{y^{T}}{x^{T}} \right) \).

**Remark1.** It is assumed that error dynamic of the UAV is obtained from the local reference of the reference states [2].

A low pass filter is used in order to deal with measurement errors and unreliability of the sensors in the estimation of GMT position which is estimated in real time with vision base estimators. The low pass filter decreases the possible noise on the target estimation and also avoids the singularity produced by data from the target estimation while the target is not in the board of vision sensors. It can disturb the performance of the guidance law.

The reference position and velocity of the UAV have been defined. The reference path is a GMT position with considering constant or Time-varying bias (\( \Delta \)). These biases have been considered to modify the relative range between UAV and GMT when it is necessary. Now, considering the GMT’s position which is obtained by vision-based estimator, the error between real and estimated position can be determined as \( \delta_{x} \) and \( \delta_{y} \) which are uncertain terms. Reference positions for UAV to follow them is as following

\[ x_{ref} = \hat{x}^{T} + \delta_{x} + \Delta_{x} \]

\[ y_{ref} = \hat{y}^{T} + \delta_{y} + \Delta_{y} \]

\[ z_{ref} = \Delta_{z} \]  \hspace{1cm} (6)
where \( \delta_x \) and \( \delta_y \) are the variables show the uncertainty in the UAV’s position based on assumptions (2) and (3). 
\( (\hat{x}^T, \hat{y}^T) \) are the estimated position of the target and a set of data estimation is obtained by vision based estimator and pass throughput least past filter for possible noises. Now, the reference velocity for UAV is determined by the derivative of Equation (6)
\[
\dot{x}_{ref} = \hat{x}^T + \Delta x
\]
\[
\dot{y}_{ref} = \hat{y}^T + \Delta y
\]
where \( \hat{x}^T = \theta^T \cos(\hat{\psi}^T), \hat{y}^T = \theta^T \sin(\hat{\psi}^T) \) and \( \Delta = 0 \) from mentioned assumption.

It is considered that
\[
\psi_T = \hat{\psi}_T \pm \delta \phi
\]
\( \psi_T \) is the real ground angle of target, \( \hat{\psi} \) is the estimation value which is obtained by \( \hat{\psi}_T = tan^{-1}(\frac{\hat{y}^T}{\hat{x}^T}) \). \( \delta \phi \) is bounded error value which is obtained from the ground angle of the error estimation.

It will be assumed that bias value for target tracking is considered in estimated value and we have
\[
\hat{x}^T_{new} = \hat{x}^T + \Delta x
\]
\[
\hat{y}^T_{new} = \hat{y}^T + \Delta y
\]
By considering the reference frame of target, the target tracking error can be determined as
\[
\begin{bmatrix}
\delta x
\delta y
\end{bmatrix} = \begin{bmatrix}
\cos(\hat{\psi}_T) & \sin(\hat{\psi}_T) & 0
\end{bmatrix} \begin{bmatrix}
\hat{x}_{ref} - x
\hat{y}_{ref} - y
\end{bmatrix} + \begin{bmatrix}
\delta x
\delta y
\end{bmatrix}
\]
(11)

Here, it is assumed that error terms are small against estimated parameters and following approximation is valid while the uncertainty will be appeared in the error dynamic later \( (\delta \phi \ll \hat{\psi}) \)

\[
\delta \phi \ll \hat{\psi}
\]
\[
\cos(\psi_T) = \cos(\hat{\psi}_T + \delta \phi) \equiv \cos(\hat{\psi}_T)
\]
\[
\sin(\psi_T) = \sin(\hat{\psi}_T + \delta \phi) \equiv \sin(\hat{\psi}_T)
\]
(13)
(14)

Error dynamic of systems is obtained as follows
\[
\begin{bmatrix}
e_1 \\
e_2 \\
e_3 \\
\end{bmatrix} =
\begin{bmatrix}
cos(\hat{\psi}_T) & sin(\hat{\psi}_T) & 0 \\
0 & 0 & 1 \\
0 & 0 & 0 \\
\end{bmatrix}
\begin{bmatrix}
\hat{x}_T - x \\
\hat{y}_T - y \\
\hat{z}_T - z \\
\end{bmatrix} +
\begin{bmatrix}
\delta x \\
\delta y \\
\delta z \\
\end{bmatrix}
\]
(15)

By differentiating Equation (15) and using defined dynamic for UAV and target Equation (4) and Equation (5), the following equation can be obtained
\[
\begin{bmatrix}
e_1' \\
e_2' \\
e_3' \\
\end{bmatrix} =
\begin{bmatrix}
0 & 0 & \hat{\psi}_T \\
0 & 0 & 0 \\
0 & 0 & 0 \\
\end{bmatrix}
\begin{bmatrix}
e_1 \\
e_2 \\
e_3 \\
\end{bmatrix} +
\begin{bmatrix}
0 & 0 & \hat{\psi}_T \\
0 & 0 & 0 \\
0 & 0 & 0 \\
\end{bmatrix}
\begin{bmatrix}
\delta x \\
\delta y \\
\delta z \\
\end{bmatrix} +
\begin{bmatrix}
-\nu \cos(y) \cos(\hat{\psi}_T - \chi) \\
-\nu \cos(y) \sin(\hat{\psi}_T - \chi) \\
-\nu \sin(y) \\
\end{bmatrix}
\]
(16)

where \( R =
\begin{bmatrix}
\cos(\hat{\psi}_T) & \sin(\hat{\psi}_T) & 0 \\
-\sin(\hat{\psi}_T) & \cos(\hat{\psi}_T) & 0 \\
0 & 0 & 1 \\
\end{bmatrix}
\)

III. GUIDANCE LAW FOR GMT TRACKING

A. Guidance Law Design

A guidance law is proposed to generate command states in this section. The purpose of the guidance law is to generate appropriate signals to guide a UAV to a reference position by command states. Adaptive second-order sliding mode is used to generate these signals in the presence of uncertain terms. Uncertain terms which will be described later, are bounded but have unknown values.

Assume that the states of the UAV converge to their command value by autopilot in small enough time and we have
\[
\| v_{cmd} - v \| \rightarrow 0
\]
\[
\| \gamma_{cmd} - \gamma \| \rightarrow 0
\]
\[
\| \chi_{cmd} - \chi \| \rightarrow 0
\]

To use the error model, following equations are considered
\[
\begin{bmatrix}
e_1' \\
e_2' \\
e_3' \\
\end{bmatrix} =
\begin{bmatrix}
0 & \hat{\psi}_T & 0 \\
0 & 0 & 0 \\
0 & 0 & 0 \\
\end{bmatrix}
\begin{bmatrix}
e_1 \\
e_2 \\
e_3 \\
\end{bmatrix} +
\begin{bmatrix}
0 & \hat{\psi}_T & 0 \\
0 & 0 & 0 \\
0 & 0 & 0 \\
\end{bmatrix}
\begin{bmatrix}
\delta x \\
\delta y \\
\delta z \\
\end{bmatrix} +
\begin{bmatrix}
\delta x \\
\delta y \\
\delta z \\
\end{bmatrix}
\]
(17)

where \( \delta f = R \delta e \)
\( \delta e = [\delta f_1, \delta f_2, \delta f_3] \)
\( f(e) = [f_1, f_2, f_3] = [0, -\hat{\psi}_T, 0] \)
(18)

\[
\begin{bmatrix}
u_{cmd} \\
\gamma_{cmd} \\
\chi_{cmd} \\
\end{bmatrix} =
\begin{bmatrix}
\nu_{3} \\
\nu_{3} \\
\nu_{3} \\
\end{bmatrix}
\]
(19)

Robust control scheme based on adaptive sliding mode control will be proposed to deal with uncertain term which has been shown as \( \delta f \). A set of Integral sliding mode surfaces is defined in the error space passing through the origin to represent a sliding manifold as follows:
\[
s = [s_1, s_2, s_3]^T =
\begin{bmatrix}
e_1 + c_1 \int e_1 \\
e_2 + c_2 \int e_2 \\
e_3 + c_3 \int e_3 \\
\end{bmatrix}
\]
(20)

By differentiating the sliding surface, following equations are obtained as

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The main idea behind the second-order sliding mode is to act on the second-order derivative of the sliding variables rather than the first derivative in the conventional sliding mode. The second-order sliding mode is determined from the basic equality condition $\sigma = \ddot{\sigma} = 0$ that reaches in finite time.

The proposed controller is designed in the following two steps. At first, a linear Integral sliding surface is defined and then another sliding manifold is obtained using the previously defined sliding surface so that the derivative of the control input occurs in the first derivative of the sliding manifold. The actual control input is obtained by integrating the derivative of the control signal which contains the discontinuous function. Thus, the actual control signal becomes continuous and the chattering effects will be eliminated. The uncertain term of the system is compensated by using an adaptive tuning law.

The virtual control signals for the guidance law can be rewritten as below for $i = 1, 2, 3$,

$$u_i = -f_i - c_i e_i - \beta_i s_i - \int u_1^s$$

where $u_1^s = \frac{u_1^s}{u_1^s}$ is the switching control vector which drives the tracking errors to their equilibrium. Switching inputs are defined as following

$$\begin{align*}
\dot{u}_1^s &= \frac{\left(\dot{k}_1 + \dot{f}_1 \tau + \ddot{a}_1 \dot{\tau} + \dddot{a}_1 \right)}{2} + \frac{\dot{\tau}}{\tau} + \left(\dddot{a}_1 \right)sign(a_1) + \Omega_1 \\
\dot{u}_2^s &= \frac{\left(\dot{k}_2 + \dot{f}_2 \tau + \ddot{a}_2 \dot{\tau} + \dddot{a}_2 \right)}{2} + \frac{\dot{\tau}}{\tau} + \left(\dddot{a}_2 \right)sign(a_2) + \Omega_2 \\
\dot{u}_3^s &= \frac{\left(\dot{k}_3 + \dot{f}_3 \tau + \ddot{a}_3 \dot{\tau} + \dddot{a}_3 \right)}{2} + \frac{\dot{\tau}}{\tau} + \left(\dddot{a}_3 \right)sign(a_3) + \Omega_3
\end{align*}$$

where $\Omega_1 = \lambda_1 |a_1|^{p_1}sign(a_1)$, $\Omega_2 = \lambda_2 |a_2|^{p_2}sign(a_2)$ and $\Omega_3 = \lambda_3 |a_3|^{p_3}sign(a_3)$, $\lambda_i$ are positive constants and $\eta_i$ are constants between zero and one. Last terms of switching control are used to achieve faster convergence when uncertain terms are ignored or compensated.

Adaptive gains in Eq. (27) estimate the bound of uncertainty such that assumption (3) is satisfied. The adaptive gains are estimated by using following adaptation laws for $i = 1, 2, 3$,

$$\dot{\xi}_i = \tau_i |a_i|$$

where $X_1 = x, X_2 = y$ and $X_3 = 0$. $\omega_i, \xi_i, \tau_i$ and $\eta_i$ are positive tuning parameters.

**B. Stability Analysis**

Theorem I. Given the error dynamic of GMT tracking from Eq. (16), the proposed guidance law ensures that tracking errors converge to their equilibrium, while all other signals are bounded.

Proof. Let choose a positive function as

$$V(t) = \frac{1}{2} \sigma^T(t) \sigma(t) + \frac{1}{2} \sum_{i=1}^{3} \left(\dot{k}_i \right)^2 + \left(\dot{\tau}_i \right)^2 + \left(\ddot{a}_i \right)^2 + \left(\dddot{a}_i \right)^2$$

Taking the time derivative of the Lyapunov function, gives us

$$\dot{V}(t) = \sigma^T \dot{\sigma} + \sum_{i=1}^{3} \left[\dot{\kappa}_i \dot{k}_i + \dot{\tau}_i \dot{\tau}_i + \ddot{a}_i \dot{\tau}_i + \dddot{a}_i \dot{\tau}_i + \dddot{a}_i \dot{\tau}_i \right]$$

Therefore, to guarantee the existence of the sliding motion ($\sigma^T \dot{\sigma} \leq 0, i = 1, 2, 3$) in the presence of unknown terms and to eliminate the chattering effect caused by the discontinuous $sign$ function (high frequency vibration), an adaptive continuous control law is proposed as

$$\begin{align*}
\dot{u}_1 &= -\frac{d}{dt}f(e) - c_1 e_1 - \beta_1 s_1 - u_1^s \\
\dot{u}_2 &= -\frac{d}{dt}f(e) - c_2 e_2 - \beta_2 s_2 - u_2^s \\
\dot{u}_3 &= -\frac{d}{dt}f(e) - c_3 e_3 - \beta_3 s_3 - u_3^s
\end{align*}$$
Replacing $\bar{z}_i$ from Eq. (24) into the above equation, results in

$$\dot{V}(t) = \sum_{i=1}^{3} \left[ \sigma_i(f_i + u_i + \delta f_i + c_i e_i + \beta_i \bar{z}_i) + \hat{k}_i \dot{\hat{k}}_i + \hat{T}_i \dot{\hat{T}}_i 
+ \hat{a}_i \dot{\hat{a}}_i + \hat{u}_i \dot{\hat{u}}_i \right]$$

By introducing the control law Eq. (26), the following equation is obtained

$$\dot{V}(t) = \sum_{i=1}^{3} \left[ \sigma_i(\delta f_i - u_i) + \hat{k}_i \dot{\hat{k}}_i + \hat{T}_i \dot{\hat{T}}_i + \hat{a}_i \dot{\hat{a}}_i + \hat{u}_i \dot{\hat{u}}_i \right]$$

Using adaptation laws Eq. (28), we have

$$\dot{V}(t) \leq \sum_{i=1}^{3} \left[ |\sigma_i(\delta f_i - u_i)| + |\hat{k}_i| |\dot{\hat{k}}_i| + |\hat{T}_i| |\dot{\hat{T}}_i| + |\hat{a}_i| |\dot{\hat{a}}_i| + |\hat{u}_i| |\dot{\hat{u}}_i| \right]$$

According to the switching control with Eq. (27) and assumption (3)

$$\dot{V}(t) \leq \sum_{i=1}^{3} \left[ -\lambda_i |\sigma_i| + \hat{k}_i |\dot{\hat{k}}_i| + |\hat{T}_i| |\dot{\hat{T}}_i| + |\hat{a}_i| |\dot{\hat{a}}_i| + |\hat{u}_i| |\dot{\hat{u}}_i| \right]$$

$$\dot{V}(t) \leq \sum_{i=1}^{3} \left[ -\lambda_i \sqrt{2} |\sigma_i| + |\hat{k}_i| |\dot{\hat{k}}_i| + |\hat{T}_i| |\dot{\hat{T}}_i| + |\hat{a}_i| |\dot{\hat{a}}_i| + |\hat{u}_i| |\dot{\hat{u}}_i| \right]$$

where $\sigma = \min\{\lambda \sqrt{2}, \omega \sqrt{2}, \xi \sqrt{2}, \omega \sqrt{2}, \xi \sqrt{2}, \omega \sqrt{2}\}$ is a vector with positive values. The above inequality holds if the tuning parameters satisfy following inequalities

$$\omega_i, \xi_i, \tau_i, \eta_i < 1 \text{ and } \lambda_i > 0$$

Therefore, according to the Lyapunov stability criterion, the grinding surface in Eq. (23) converge to zero in finite time [16-17] and error variables converge to their equilibrium in the presence of defined unknown terms. Reaching time value for sliding manifolds and estimated parameters satisfy the following inequality

$$t_{\text{reach}} \leq \frac{2V_0(t_0)}{\sigma}$$

In this section, the guidance law for GMT tracking is generated in the presence of the uncertainty which is consisted of the unknown parameters in estimates value. The command generation has been adopted online to reach the robust performance against defined uncertainty. Integral action in the guidance leads us to produce continuous command states to track ground moving target.

IV. SIMULATION

Numerical simulations are presented to validate the robustness and effectiveness of the proposed control scheme. Simulations are conducted using ODE45 solver of the Matlab software for solving differential equations. A curved path in x-y plane is designed as the target motion where $x(t) = 2m$, $y(t) = 2m$ and $z(t) = 0$. The actual value of ground speed is equal to 2 m/s and the ground angle is defined as $\psi_g = \sin(0.1t)$. The reference value for the UAV altitude is defined as $\Delta_z = 100$ (m). The initial position of the UAV is $(0,0,0)$ T. Error parameters of estimated value are also defined as follows:

$$\delta_x = 0.1 \dot{x}^T, \delta_y = 0.1 \dot{y}^T$$

The constant gains in the proposed control have been selected as follows

$$\beta_1 = 2, \beta_2 = 2, \beta_3 = 2, \alpha_1 = 20, \alpha_2 = 3/5, \xi_1 = 3/5, \tau_1 = 20, \eta_1 = 2.$$

Fig. 1. GMT tracking response in x-y plane and 3D.
control for Fig. (2) demonstrates the comparison work between the actual value, which is defined by time varying target position. is appropriate and the UAV position have converged to the errors dynamic converge to zero while transient time response of order adaptive sliding mode control. Fig. 3 shows the convergence of adaptive gains to their values. As it seems obvious, adaptive gains are smooth and feasible in front of the proposed algorithm. Uncertainty terms can be compensated via proposed method and all tracking errors converge to zero in a small finite time. Simulation results show that uncertainty has been compensated via proposed method and all tracking errors converge to zero in a small finite time.

V. CONCLUSION

This paper investigates the second order sliding mode control scheme with novel adaptive gains to deal with uncertainty on the estimated value. This control approach produces continuous control signal which is suitable to generate an appropriate guidance law. Uncertainty terms can cause instability in the system but, these terms are compensated via the proposed controller. The control strategy is also robust against other similar bounded uncertainties, disturbances and noises. The sliding surfaces which consist of the errors and their derivatives converge to their equilibrium in finite time. Simulation results show that uncertainty has been compensated via proposed method and all tracking errors converge to zero in a small finite time.

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