Tracking Control for an Autonomous Airship based on Neural Dynamics model with the Basktepping technique and a Robust Sliding mode control.

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***Abstract*—** this paper presents a control approach hybrid for trajectory tracking of an autonomous airship. An integrated backstepping and sliding mode tracking control algorithm is developed for four dimensional tracking controls of an autonomous airship vehicles (AAV).

First, a kinematic controller based on Neural Dynamics model with the Basktepping technique is integrated together with the dynamic controller uses a sliding mode control.

In the traditional Backstepping method, speed jump occurs if the tracking error changes suddenly. The application of the biologically inspired model is designed to smooth the virtual velocity controller output, avoid speed jumps of autonomous airship vehicles in the large initial errors.

Computer simulation results illustrate the effectiveness and efficiency of the control strategy proposed controller.

***Keywords*—** Autonomous airship vehicle, Biological inspired neurodynamics, Backstepping control, External disturbance, Sliding mode control, Trajectory control.

I. INTRODUCTION

During the last years, the importance of autonomous lighter than air vehicles, also known as airships, has been increased due to the development of their applications such as telecommunication, broadcasting relays surveillance, advertising, monitoring, inspection, exploration, and so on.

With the rapid advance of airship technologies, the advanced flight control system plays a key role in the development of the airship. Non-linear dynamics, model uncertainties and external perturbations contribute to the difficulty of maneuvering an airship to follow a time-varying reference trajectory. Therefore, tracking of the trajectory remains a major technical challenge for the airship. [3].

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The vehicle dynamics of the autonomous airship is strongly coupled and highly nonlinear. In order to treat nonlinear uncertainties in the dynamics of the autonomous airship, many researchers have focused their interests on the applications of sliding control. The sliding mode method [3] is generally used for dynamic monitoring for the exceptional characteristic, including insensitivity to parameter variations and good rejection of disturbances.

So Sliding mode control is extraordinary suitable for robust tracking control of autonomous airship vehicle. However, one major drawback of the sliding-mode approach is the high frequency of control action (chattering). To eliminate/reduce chattering, various methods have been proposed to reach a continuous robust control. For example, S. Serdar proposed a chattering-free sliding-mode control method with an adaptive estimate term [3].

The backstepping methodology is a popular technique used to control lighter than air vehicles. Backstepping approach is a theoretically established and widely used in controlling nonlinear systems, and the backstepping control algorithm is the commonly used approach for tracking control.

However, the disavantage for backstepping method is quite obvious [4] .The velocity control law is directly related to the state errors, so large velocities will be generated in big initial error condition and sharp speed jump occurs while sudden tracking error happens.

It means that the required acceleration and forces/moments exceed their control constraint even infinite values at the velocity jump points, which is practically impossible.

Several control approaches have been proposed for the trajectory tracking of an airship in the literature. Moutinho and Azinheira designed the longitudinal and lateral control system of the AURORA airship using the dynamic inversion control method. This control system has limitations because it was developed based on the linear model, neglecting dynamic nonlinearity and coupling effects between longitudinal and lateral motions. Filoktimon and Evangelos (2008) proposed a backstepping control approach for trajectory tracking of a robotic airship. Lee and Rendon designed a backstepping design formulation for trajectory control of an unmanned airship [3].

The design of a backstepping control system should follow the exact model. However, the airship model always has

uncertainties, and the model parameters are difficult to estimate accurately in an operational situation.
Each method has it's advantage and disadvantage, it is difficult to use a single method to deal with all the problems. The backstepping control algorithms are the most commonly used approach for mobile robot tracking control and have been adopted in the autonomous airships control systems. The system control for backstepping is quite simple, and the system stability is strictly guaranteed by Lyapunov stability theory. The simulation studies have verified that the proposed control system is able to realize the real-time dynamic tracking of airship and has better performance than the traditional backstepping method.

The paper is structured as following parts. After a brief description of the dynamic control strategy and the existing problems in Section 1, the horizontal kinematic and dynamic models of autonomous airship are introduced in Section 2. In Section 3, the hybrid control strategy based on a biological inspired model and a backstepping method is presented. In Section 4, simulation and experimental comparison, including a circle and line followed by the autonomous airship. Section 5 contains the conclusion of the work.

II. Kinematic and Dynamic Models

A. Kinematic model

The motion of an autonomous Airship is generally represented by kinematic and dynamic equations which describe its evolution in a space of six degrees of freedom (6-DOF).

The two coordinate frame systems for the autonomous airship are illustrated in ***Fig. 1*** including the earth-fixed inertial frame $\{O_e - X_e Y_e Z_e\}$ (E frame), with the origin on the surface of the earth, the X-axis points north, the Y-axis points east, and the Z-axis points down, and the body-fixed frame system $\{o_b - x_b y_b z_b\}$ (B frame), with the origin on the center of volume CV, the x-axis points forward, the y-axis points right, and z-axis points downward. $r_G = \left[x_G \; y_G \; z_G\right]^T$ is the center of gravity position with respect to the volumetric center

The generalized coordinates of an airship are expressed by $\eta = [P, \Omega]^T$, where $P = [x, y, z]^T$ denotes the relative position with respect to the E frame, and $\Omega = [\theta, \psi, \varphi]^T$ defines the attitude angles, respectively, the pitch, yaw, and roll angles.
The center of volume (CV), is the center of gravity (CG), and it is chosen as the origin of the airship body-fixed frame. The generalized velocities of an airship are expressed by $q = [v, \omega]^T$, where $v = [u, v, w]^T$ defines the linear velocities in the B frame, namely, the forward, lateral and vertical velocities; and $\omega = [p, q, r]^T$ denotes the angular velocities about each axis of the B frame.

Considering these motion variables, the 6-DOF kinematics equations of an autonomous airship can be written as: [1] [12]

$$\dot{\eta} = J(\eta) q \tag{1}$$

Where

$$J(\eta) = \begin{bmatrix} J_1 & 0_{3x3} \\ 0_{3x3} & J_2 \end{bmatrix} \tag{2}$$

with J_1 and J_2 respectively being the rotation matrix from the B frame to the E frame and the transform matrix from angular velocities to attitude angle rates.
The corresponding expressions of the two matrices can be expressed as follows:

$$J_1 = \begin{bmatrix} \cos\psi\cos\theta & \cos\psi\sin\theta\sin\phi & \cos\psi\sin\theta\cos\phi + \sin\psi\sin\phi \\ \sin\psi\cos\theta & \sin\psi\sin\theta\sin\phi + \cos\psi\cos\phi & \sin\psi\sin\theta\cos\phi - \cos\psi\sin\phi \\ -\sin\theta & \cos\theta\sin\phi & \cos\theta\cos\phi \end{bmatrix}$$

$$J_2 = \begin{bmatrix} 0 & \cos\phi & -\sin\phi \\ 0 & \sec\theta\sin\phi & \sec\theta\cos\phi \\ 1 & \tan\theta\sin\phi & \tan\theta\cos\phi \end{bmatrix}.$$

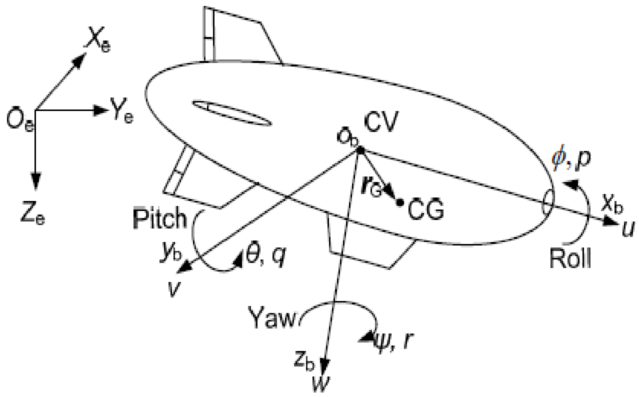

Fig. 1 Position of frames.

B. Dynamic model

The dynamic model of an autonomous airship can be expressed as a compact equation: [7]

$$M\dot{q} = \left[C(q) + D(q)\right]q + g(\eta) + \tau \tag{3}$$

Where $M \in R^{6\times6}$ is the matrix of inertia due to both the mass of the airship and the added mass of air at point O_e expressed in E; $\dot{q}$ is the acceleration screw, $C(q) \in R^{6\times6}$ is the Coriolis matrix and centripetal terms (including added mass terms). $D(q) \in R^{6\times6}$ is hydrodynamic *damping*; $g(\eta) \in R^6$ is restoring forces vector (from gravity and buoyancy) expressed in *E*; $\tau \in R^6$ is the actuation forces and torques.
The trajectory tracking problem for an airship is the design of a control law that asymptotically stabilizes both the position and the orientation. Therefore, we can

restrict the six-dimensional dynamics to the horizontal plane by making the following assumptions:

Assumption 1:

The dynamics associated with the pitch and roll motions are negligible [3] [12]. When the airship is cruising at a constant altitude, as shown in Fig. 3, pitch and roll variables are very small, and therefore, their effect on the motion in the horizontal plane can be neglected.

Assumption 2 :

We consider an airship with neutral buoyancy; that is, the gravitation is equal to buoyancy. Therefore, the resultant forces of gravitation and buoyancy have no effect on the dynamics in the horizontal motion of an airship [3] [12].

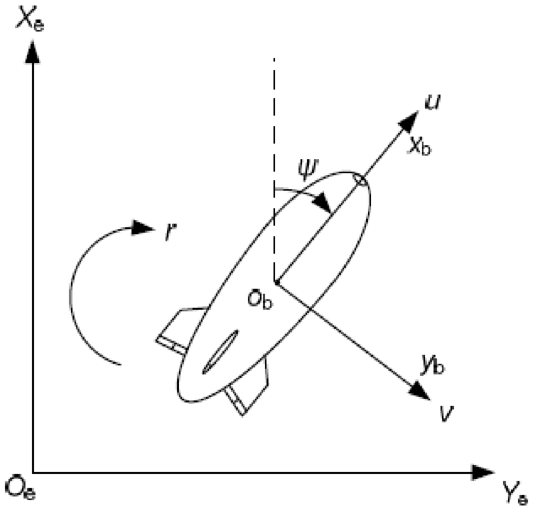

Fig. 2 Airship motion in the horizontal plane.

Under these assumptions, a simplified 4-DOF model of motion is obtained as follows:

$$M\,\dot{q} = \tau + \left[C\left(q\right) + D\left(q\right)\right]q \tag{4}$$

$$\dot{\eta} = J\left(\eta\right)q \tag{5}$$

Where

$$J\left(\Omega\right) = \begin{bmatrix} J_{11} & J_{12} & 0 & 0 \\ J_{21} & J_{22} & 0 & 0 \\ 0 & 0 & J_{33} & 0 \\ 0 & 0 & 0 & J_{44} \end{bmatrix},$$

$J_{11} = \cos\psi$, $J_{12} = -\sin\psi$, $J_{21} = \sin\psi$, $J_{22} = \cos\psi$,

$J_{33} = 1$, $J_{44} = 1$;

The airship described responds to the previous assumptions; the following 4-DOF model is constructed. [15]

$$M = \begin{bmatrix} m_x & 0 & 0 & 0 \\ 0 & m_y & 0 & 0 \\ 0 & 0 & m_z & 0 \\ 0 & 0 & 0 & I_z \end{bmatrix};\ D(q) = \begin{bmatrix} X_u & 0 & 0 & 0 \\ 0 & Y_v & 0 & 0 \\ 0 & 0 & Z_w & 0 \\ 0 & 0 & 0 & N_r \end{bmatrix}$$

$$C(q) = \begin{bmatrix} 0 & mr & 0 & -Y_{\dot{v}}v + mx_G r \\ -mr & 0 & 0 & X_{\dot{u}}u \\ 0 & 0 & 0 & 0 \\ Y_{\dot{v}}v - mx_G r & -X_{\dot{u}}u & 0 & N_r \end{bmatrix};$$

Where $m_x = m - X_{\dot{u}}$, $m_y = m - Y_{\dot{v}}$, $m_z = m - Z_{\dot{w}}$; $I_z = I_{zz} - N_{\dot{r}}$; m is the gross mass; I_{zz} denotes the moment of inertia with respect to z axis; $X_{\dot{u}}, Y_{\dot{v}}, Z_{\dot{w}}, N_{\dot{r}}$ and X_u, Y_v, Z_w, N_r are the added inertial parameters, $\eta = \left[x, y, z, \psi\right]^T$ denotes the position and orientation in the E frame; $q = \left[u, v, w, r\right]^T$ denotes the forward, lateral, heave and yaw angular velocities. $\tau = \left[\tau_X, 0, 0, \tau_N\right]^T$ denotes the forward force and yaw moment. [12]

C. Tracking control problem

The autonomous airship is usually required to move at a low forward speed and a low rotational speed when it executes investigation tasks. This needs a precious tracking control. The problem we consider here is the trajectory tracking problem. It means that we want to find a control law so that the autonomous airship vehicle can track the reference vehicle.

The control objective is to design a control law that causes the airship to track a desired trajectory asymptotically [3]. Consider that the autonomous airship major movement is in four degrees of freedom (DOF): surge, sway, heave, yaw, so in this paper, only the four DOF tracking control problem is represented. The controller design problem can be described as follows.

The desired state of the autonomous airship is defined as:

$$\eta_d = \begin{bmatrix} x_d & y_d & z_d & \psi_d \end{bmatrix}^T \tag{6}$$

Where $\eta_d = \begin{bmatrix} x_d & y_d & z_d & \psi_d \end{bmatrix}^T$ the desired state of autonomous airship in the inertial frame is, $\begin{pmatrix} x_d & y_d & z_d \end{pmatrix}$ is coordinate of desired path in the inertial frame, ψ_d is the counter-clockwise rotation angle of airship along the Z-axis.

The desired forward and angular velocities can be deduced By: [5] [6]

$$\begin{aligned} u_d &= \dot{x}_d \cos\psi_d + \dot{y}_d \sin\psi_d \\ v_d &= \dot{x}_d(-\sin\psi_d) + \dot{y}_d \cos\psi_d \\ w_d &= \dot{z}_d \\ r_d &= \dot{\psi}_d \end{aligned} \tag{7}$$

The actual state of airship is represented by:

$\eta = \begin{bmatrix} x & y & z & \psi \end{bmatrix}^T$, $q = \begin{bmatrix} u & v & w & r \end{bmatrix}^T$.

As the objective of the path tracking controllers is to make airship follow the known path by controlling the velocity and angular velocities, so the tracking error $e = \eta_d - \eta = \begin{bmatrix} e_x & e_y & e_z & e_\psi \end{bmatrix}^T$ converges to zero. $\lim_{t \to \infty} \left\| \eta_d - \eta \right\| = 0$.

Here ***e*** is the tracking error in the inertial frame.

A detailed model of tracking control problem is given in Fig. 3.

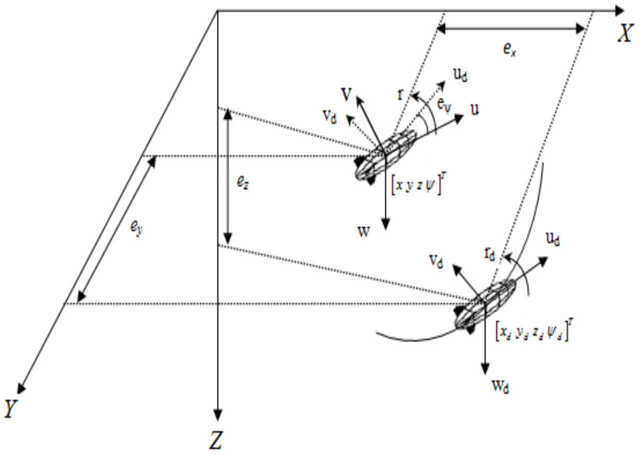

Fig. 3 Tracking control problem.

III. CONTROL ALGORITHMS

The basic control architecture of the system is illustrated in Figure 4. The design of the hybrid control strategy consists of two parts: (1). the external loop which represents a virtual speed controller using position and orientation state errors; (2). an internal loop representing a sliding mode controller using a velocity state vector. (See Figure 6)

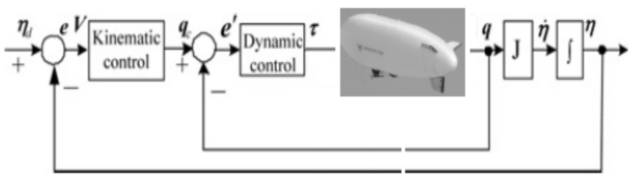

Fig.4 The cascaded controller of Airship.

A. Backstepping based trajectory tracking Controller

Backstepping method for nonholonomic mobile robot has been designed a lot for velocity tracking. But the autonomous airship in this study is a holonomic system, so the backstepping control law for the mobile robot is not fit for this control system. For this reason, a new backstepping control law is designed for UAV and makes it possible to follow a given reference posture with stability. [4] [7] [9]

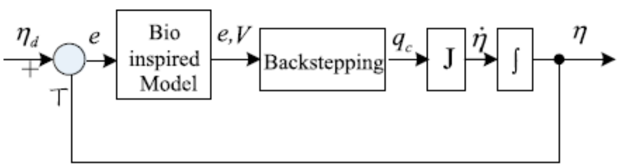

Fig.5 The external loop.

The tracking error in the body-fixed frame is

$$E = \begin{bmatrix} e_1 \; e_2 \; e_3 \; e_4 \end{bmatrix}^T = J^T e = J^T \begin{bmatrix} e_x \; e_y \; e_z \; e_\psi \end{bmatrix}^T$$

$$J = \begin{bmatrix} \cos\psi & -\sin\psi & 0 & 0 \\ \sin\psi & \cos\psi & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$E = \begin{bmatrix} e_1 \\ e_2 \\ e_3 \\ e_4 \end{bmatrix} = \begin{bmatrix} \cos\psi & \sin\psi & 0 & 0 \\ -\sin\psi & \cos\psi & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} e_x \\ e_y \\ e_z \\ e_\psi \end{bmatrix} \quad (8)$$

Introducing Eq. (8) into Eq. (7), we have the model of kinematical error: The position error dynamics can be obtained from the time derivative of (8) as:

$$\dot{E} = \begin{bmatrix} \dot{e}_1 \\ \dot{e}_2 \\ \dot{e}_3 \\ \dot{e}_4 \end{bmatrix} = \begin{bmatrix} -u + r e_2 + u_d \cos e_\psi - v_d \sin e_\psi \\ -v - r e_1 + u_d \sin e_\psi + v_d \cos e_\psi \\ w_d - w \\ r_d - r \end{bmatrix} \quad (9)$$

Taking now the following Lyapunov function candidate as $V_1 = \frac{1}{2}\left(e_1^2 + e_2^2 + e_3^2 + e_4^2\right)$, considering Eq. (9), the time derivative is given as:

$$\begin{aligned} \dot{V}_1 &= e_1 \dot{e}_1 + e_2 \dot{e}_2 + e_3 \dot{e}_3 + e_4 \dot{e}_4 \\ &= e_1\left(-u + r e_2 + u_d \cos e_\psi - v_d \sin e_\psi\right) \\ &\quad + e_2\left(-v - r e_1 + u_d \sin e_\psi + v_d \cos e_\psi\right) \\ &\quad + e_3\left(w_d - w\right) + e_4\left(r_d - r\right) \\ &= e_1\left(-u + u_d \cos e_\psi - v_d \sin e_\psi\right) \\ &\quad + e_2\left(-v + u_d \sin e_\psi + v_d \cos e_\psi\right) \\ &\quad + e_3\left(w_d - w\right) + e_4\left(r_d - r\right) \end{aligned} \quad (10)$$

According to the theory of Lyapunov stability, the virtual velocity controller $q_c = \begin{bmatrix} u_c \; v_c \; w_c \; r_c \end{bmatrix}^T$ based on the backstepping approach can be defined as: given by [14]

$$\begin{aligned} u_c &= k\left(e_x \cos\psi + e_y \sin\psi\right) + \left(u_d \cos e_\psi - v_d \sin e_\psi\right); \\ v_c &= k\left(-e_x \sin\psi + e_y \cos\psi\right) + \left(u_d \sin e_\psi + v_d \cos e_\psi\right); \\ w_c &= w_d + k_z e_z; \\ r_c &= r_d + k_\psi e_\psi \end{aligned} \quad (11)$$

where k, k_z, k_ψ are the positive constants.

B. Trajectory tracking controller based on Neural Dynamics model

Bio-inspired (Neurodynamics) model was first proposed by Grossberg from the current mechanism using circuit element to simulate the cell membranes throught up by Hodkin and Huxley. The dynamic characteristics of the membrane voltage on the film can be described by the following state equation [4] [7] [9]:

$$C_m \frac{dV_m}{dt} = -\left(E_p + V_m\right) g_p + \left(E_{Na} - V_m\right) g_{Na} - \left(E_k + V_m\right) g_k$$

Where C_m represents membrane capacitance, E_k, E_{Na} and E_p are Nernst potential, sodium ions, and passive ions of the membrane current, respectively; g_k, g_{Na} and g_p are conductance of neutral channel, sodium ion, and potassium ion, respectively. By setting

$x_i = E_p + V_m$, $A = g_p$, $B = E_{Na} + E_p$, $C_m = 1$,

$D = E_k - E_p$, $S_i^+(t) = g_{Na}$, $S_i^-(t) = g_k$,

The bio-inspired model can be simplified into :

$$\frac{dx_i}{dt} = -Ax_i + \left(B - x_i\right) S_i^+\left(t\right) - \left(D + x_i\right) S_i^-\left(t\right) \quad (12)$$

Note that x_i is the membrane potential of i^{th} number neurone. The parameters *A*, *B* and *D* are passive decay rate of the membrane potential, and upper and lower nerve excitation, respectively; the variables $S_i^+\left(t\right)$ and $S_i^-\left(t\right)$ represent the excitatory and inhibitory input of the i^{th} neuron, respectively.

The shunting dynamic of an individual neuron can be modeled by this equation. The state responses of the models are limited to the finite interval $\left[-D, B\right]$ because of the auto gain-regulation of the model. So we can infer the shunting equation to the following form:

$$\dot{x} = -Ax_i + \left(B - x_i\right) f\left(e_i\right) - \left(D + x_i\right) g\left(e_i\right)$$

Where ***i*** is the neuron index, $f\left(e_i\right) = \max\left(e_i, 0\right)$, $g\left(e_i\right) = \max\left(-e_i, 0\right)$. It is guaranteed that the neural activity will stay in this interval for any value of the excitatory and inhibitory inputs. It is continuous and smooth. We put biological neurons model to the traditional velocity controller, so the equation (12) can be written as:

$$\begin{aligned} u_c &= k\left(S_x \cos\psi + S_y \sin\psi\right) + \left(u_d \cos e_\psi - v_d \sin e_\psi\right); \\ v_c &= k\left(-S_x \sin\psi + S_y \cos\psi\right) + \left(u_d \sin e_\psi + v_d \cos e_\psi\right); \\ w_c &= w_d + k_z S_z; \\ r_c &= r_d + k_\psi S_\psi. \end{aligned} \quad (12)$$

Where $S_i\left(i = x, y, z, \psi\right)$ represent the outputs of the biological neurons model.

C. Sliding mode control

After the velocity controller generates the virtual velocity of the autonomous airship, a sliding-mode controller is used to generate the control forces and moments $\tau = \left[\tau_X \;\; 0 \;\; 0 \;\; \tau_N\right]^T$. Then the control inputs τ will be applied to the autonomous airship dynamic model to produce the actual velocity in surge, sway, heave and yaw $\left(q = \left[u \quad v \quad w \quad r\right]^T\right)$ in the body-fixed frame respectively. So it will be easy to get the actual airship vehicle's states $\left(\eta = \left[x \quad y \quad z \quad \psi\right]^T\right)$ in the inertial frame by $\dot{\eta} = J q$. As a rule, sliding-mode control can be divided into two parts.

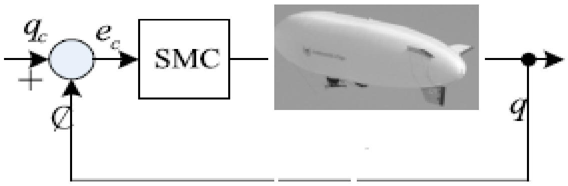

Fig. 6 internal loop.

First, define a sliding manifold ***s.*** Second, find a control law to move toward the sliding manifold. The sliding manifold is defined as [8] **:**

$$s = \dot{e}_c + 2\Lambda e_c + \Lambda^2 \int e_c \quad (13)$$

Where $e_c = q_c - q$ is the velocity error between the virtual velocity and the actual velocity, Λ represents a strictly positive constant, ***s*** is a 4x1 vector.

Derivation of (13), then

$$\dot{s} = \ddot{e}_c + 2\Lambda\dot{e}_c + \Lambda^2 e_c = \ddot{e}_c + 2\Lambda\left(\dot{q}_c - \dot{q}\right) + \Lambda^2 e_c \quad (14)$$

When the system is operating on the sliding surface, (14) equals zero, i.e.

$$\dot{s} = \ddot{e}_c + 2\Lambda\dot{e}_c + \Lambda^2 e_c = \ddot{e}_c + 2\Lambda\left(\dot{q}_c - \dot{q}\right) + \Lambda^2 e_c = 0 \quad (15)$$

We put equation (2) into equation (15), then

$$\ddot{e}_c + 2\Lambda\left(\dot{q}_c - M^{-1}\left(\tau - Cq - Dq - g\right)\right) + \Lambda^2 e = 0 \quad (16)$$

So the equivalent control law can be concluded as

$$\tau_{eq} = M\left(\dot{q}_c + \frac{\ddot{e}_c}{2\Lambda} + \frac{\Lambda}{2} e_c\right) + Cq + Dq + g \quad (17)$$

Considering the difficulty of computing $\ddot{e}_c$ in (17), a feedback control input of acceleration error is introduced

$$\ddot{e}_c = -k\dot{e}_c \quad (18)$$

Where ***k*** is a constant scalar representing the strictly positive constant that determines the rate of acceleration error. The conventional sliding-mode can be designed as

$$\tau = \tau_{eq} + k \,\mathrm{sgn}\left(s\right) \quad (19)$$

To eliminate chattering problem caused by the discontinuous term, an adaptive term [13] is added in the control law to replace the switching term in Equation (19).

$$\tau_{disc} = \tilde{\tau}_{est} + K s \quad (20)$$

Where $\tilde{\tau}_{est}$ is an adaptive term that estimates the unknown term $\tilde{\tau}$ and K is also a constant scalar, representing the strictly positive constant for the convergence rate of the controller.

The update rate of $\tilde{\tau}_{est}$ is as following : $\dot{\tilde{\tau}}_{est} = \Gamma s$ (21)

where Γ represent the strictly positive constant that determines the rate of adaption, then produce a new siding mode controller, called adaptive sliding mode controller. The total control law can be defined as :

$$\tau = \tau_{eq} + \tau_{disc} = \tau_{eq} + \tilde{\tau}_{est} + K\, s \qquad (22)$$

IV. Simulation and analysis

In this paper, two methods were simulated for trajectory tracking problem: the backstepping controller and the Bio-Inspired Neurodynamics controller. The backstepping method given in Eq. (11) was used as a case study to illustrate the performance of the proposed control strategies. The aim of the simulation is to illustrate the advantages of the proposed controller in driving an autonomous airship vehicle on to a desired trajectory.

The control system was simulated using the variable step Runge-Kutta integrator in MATLAB. The model parameters of the airship [8] are given in Table 1.

Table 1 Model parameters of the airship

Parameter	Value	Parameter	Value
m (kg)	9.07	$X_{\dot{u}}\,(kg)$	-1.13
$X_u\,(kg)$	10	$Y_{\dot{v}}\,(kg)$	-7.25
$Y_v\,(kg)$	10	$Z_{\dot{w}}\,(kg)$	-7.25
$Z_w\,(kg)$	10	$N_{\dot{r}}\,(kg)$	-8.87
$N_r\,(kg)$	10	$I_z\,(kg.m^2)$	18.76
x_G (m)	0.041		

A. Circular trajectory tracking

Considering that the turning circle maneuver is an important practical trajectory maneuver that the airship needs to perform frequently, we examine the control performance of circle trajectory tracking using the designed control scheme. The desired trajectory is generated using the following command generator:

$x_d = \sin(t)$ m ; $y_d = -\cos(t)$ m ; $z_d = t$ m ;

$\psi_d = t$.

The desired velocities were selected as:

$$v_d = \left[u_d\ v_d\ w_d\ r_d\right]^T = \left[0.5m/s, 0m/s, 0m/s, 0rad/s\right]^T$$

and the initial state of the airship was set to be:

$$\eta_0 = \left[x_0\ y_0\ z_0\ \psi_0\right]^T = \left[-0.5m, -1.5m, 0, -\pi\right]^T .$$

Sampling time is 0.01 s, parameters of backstepping controller are $k = 12; k_\psi = 1; k_z = 12$, and parameters of Neurodynamics controller are $A = -12, B = D = 10$.

Simulation results were obtained for two cases: (1) the model parameters are known and (2) there are parameter uncertainties and external disturbances.

Case 1: The following simulations concern the trajectory tracking control design based on the accurate model parameters.

The simulation results of trajectory tracking are shown in fig.7. Both simulation results show satisfactory behavior of the airship. It can be seen from Fig 7. The airship takes some time to reach and stay on the desired path for both track control procedures. However, the virtual velocity responses (linear and angular velocities in Fig.8) are different for the two different velocity controllers.

The virtual velocity based on the backstepping approach exhibits sharp speed jumps when the tracking errors change suddenly at the initial time; For example, the virtual sway speed (**vc**) of the backstepping method jumps to more than **05m/s**, whereas this value for the Neurodynamics method is about **-01 m/s** in Fig.7.

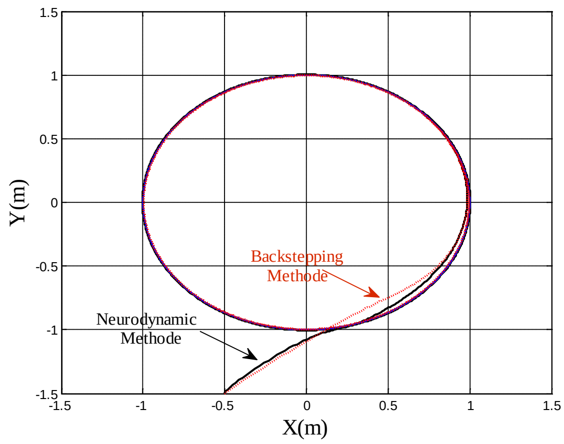

Fig.7.Systems trajectories using Bio-Inspired Neurodynamics model (black line) and the backstepping method (red dashed line).

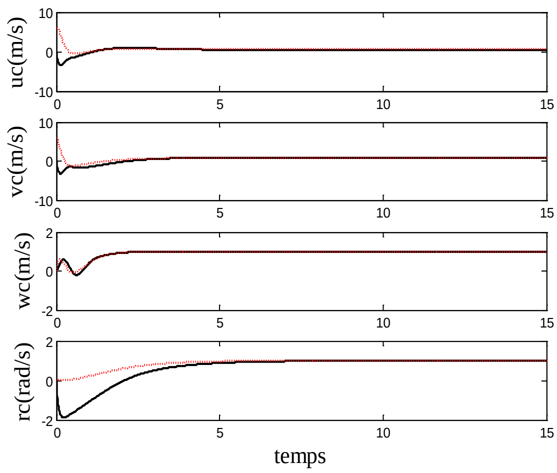

Fig.8. Virtual velocity using Bio-Inspired Neurodynamics model (black solid line) and the backstepping method (red dashed line).

While all the work in this paper is based on numerical simulation and analysis, our major contribution is the application of the Bio-Inspired Neurodynamics model. Our main idea is that the bio-inspired neurodynamics model can address the sharp speed jumps seen when using the backstep method, and that a smooth and physically realizable control signal is generated without any limitation, which cannot be achieved using the backstepping method.

Case 2: We concern the robustness properties of the designed control scheme to parameter uncertainties and external disturbances. We conducted simulations in which errors of the order of ***5%*** on all parameters in Table 2 were assumed [3]. In practice, the external disturbances mainly may be the wind disturbances.

We assume that the wind disturbances in the lateral direction are $dw = 10\cos(t)$ ***m/s***, where ***10 m/s*** is the wind velocity; that is, wind disturbances vary in form of a cosine function with a magnitude of ***10 m/s***.

Simulation results concerning the inaccurate model parameters and wind disturbance are shown in Figs.9 and 10.

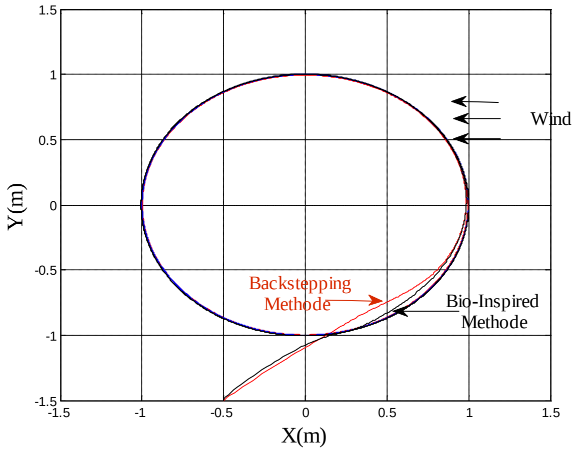

Fig.9. Systems trajectories using Bio-Inspired Neurodynamics model (black line) and the backstepping method (red dashed line) with inaccurate parameters and disturbances.

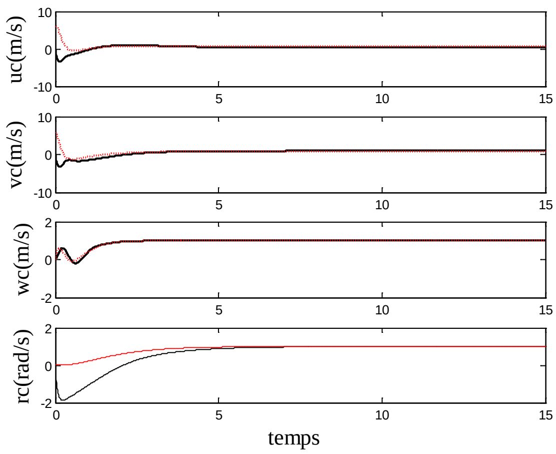

Fig. 10 Virtual velocity using Bio-Inspired Neurodynamics model (black solid line) and the backstepping method (red dashed line) with inaccurate parameters and disturbances.

Fig.9 end Fig.10 presents the simulation results of circle trajectory tracking and virtual velocity with inaccurate parameters and wind disturbances. The red dotted line represents the trajectory using Backstepping method, whereas the black solid line represents the trajectory using Bio-inspired Neurodynamics method. From Fig.11, we conclude that the proposed control scheme can track the desired trajectory accurately despite parameter uncertainties and external disturbances.

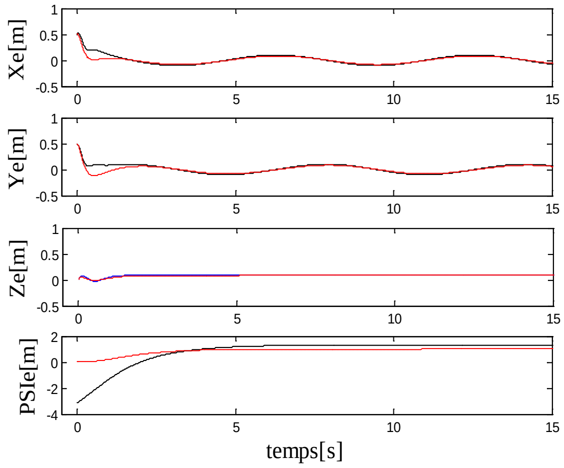

Fig. 11 Position and Euler angles tracking errors.

B. Square trajectory tracking

A typical square trajectory is studied second. Its equation is a piecewise function.

The three dimensional state vector of autonomous airship can be expressed as:

$$\eta(t) = [x(t) \quad y(t) \quad z(t) \quad \psi(t)]^T$$

Assume that the desired track state of the Airship is as following:

When $0 < t \le 100$:

$$x_d(t) = 10;\ y_d(t) = 20;\ z_d(t) = 0.2 * t;\ \psi_d(t) = 0,$$

When $100 < t \le 200$:

$$x_d(t) = 10 + 0.5*(t-100);\ y_d(t) = 20;\ z_d(t) = 20;$$

$$\psi_d(t) = 0.$$

When $200 < t \le 300$:

$$x_d(t) = 60;\ y_d(t) = 55 + 0.2*(t-200);\ z_d(t) = 20;$$

$$\psi_d(t) = 0.$$

When $300 < t \le 400$:

$$x_d(t) = 60 - 0.5*(t-300);\ y_d(t) = 75;\ z_d(t) = 20;$$

$$\psi_d(t) = 0.$$

When $t > 400$:

$$x_d(t) = 10;\ y_d(t) = 70 - 0.2*(t-400);\ z_d(t) = 20;$$

$$\psi_d(t) = 0.$$

The actual initial state

$$\eta(0) = [x(0) \quad y(0) \quad z(0) \quad \psi(0)]^T = [0 \quad 0 \quad 0 \quad 0]^T$$

The parameter setting of the cascaded controller is shown in Table 2.

Table 2. The controller parameters (Airship).

Λ	Γ	K	k	Kψ	Kz	A	B	D
3	1	30	3	3	3	14	9.5	9.5

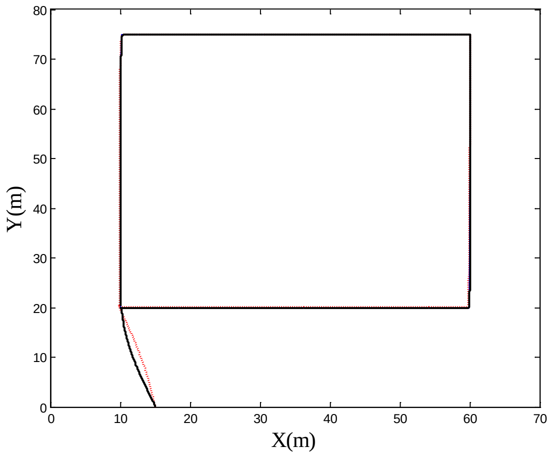

Fig.12 Systems trajectories using bio-inspired Neurodynamics model (black solid line) and the backstepping method (red dashed line).

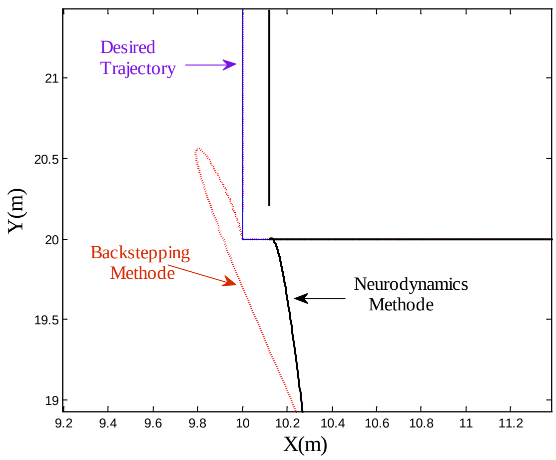

Fig.13 Zoom Fig.12

Figs. 12 and 14 show the tracking control results and velocity q_c of the backstepping method (red dotted lines) and the bio-inspired Neurodynamics method (black solid lines), respectively.
In Fig. 12, the two kinds of methods can all catch up and land on the desired path smoothly.

As can be seen in FIG.14, the auxiliary velocity terms (linear and angular velocities) with the bio-inspired Neurodynamics model are smoother than with the backstepping model and show a less sharp jumps. For example, the auxiliary surge speed uc of the backstepping method jumps to about -8 m/s in the initial point, but the bioinspired method is less than ***-1 m/s*** in Fig.14.

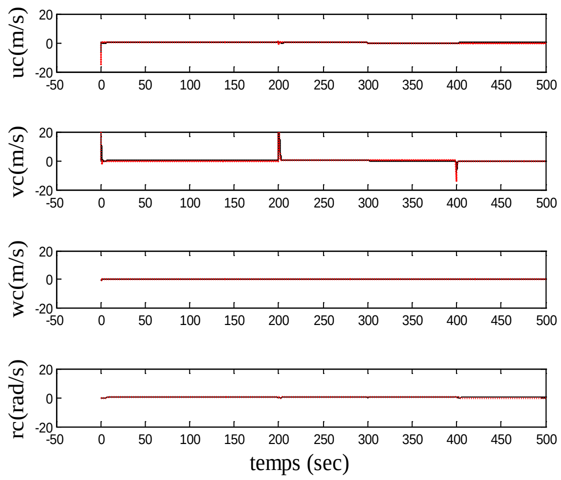

Fig.14 Virtual velocity using Bio-inspired Neurodynamics model (black solid line) and the backstepping method (red dashed line).

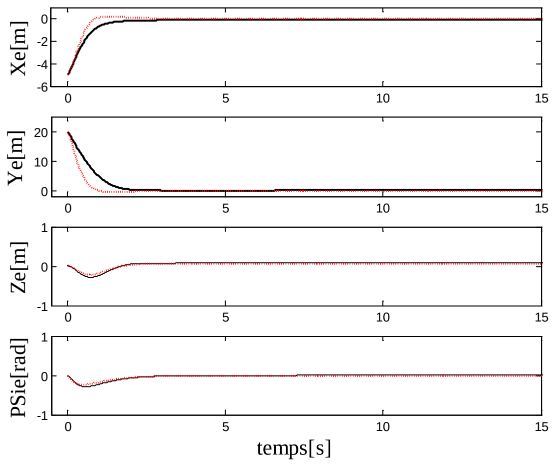

Fig.15 Position and Euler angles tracking errors.

V. CONCLUSION

In this article, general information is first introduced on the problem of trajectory follow-up of autonomous airships. Then a backstepping and sliding mode tracking control algorithm is proposed for three-dimensional tracking control problem. In the control system, there exist two closed loop systems: inner loop ensures the velocity tracking and the outer loop ensures the position and orientation tracking. In the traditional backstepping method, it always suffers from the sharp speed jump problem. Because of the smooth and bounded response properties, the proposed velocity controller uses the bio inspired model to eliminate or inhibit the sharp speed jumps. From the simulation results, it is clearly to see bio-inspired method reduces the sharp speed jumps without significant performance loss while the conventional backstepping method may cause sharp speed jump problem.

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