International Journal of Engineering

Journal Homepage: www.ije.ir

High-Performance Robust Three-Axis Finite-Time Attitude Control Approach Incorporating Quaternion Based Estimation Scheme to Overactuated Spacecraft

A. H. Mazinan

Department of Control Engineering, Faculty of Electrical Engineering, South Tehran Branch, Islamic Azad University (IAU), No. 209, North Iranshahr St., P.O. Box 11365/4435, Tehran, Iran

PAPER INFO

Paper history:
Received 15 July 2015
Accepted in revised form 28 January 2016

Keywords:
Robust Finite-Time Attitude Control Approach
Overactuated Spacecraft
Quaternion Based Estimation Scheme
Measurement Noise

ABSTRACT

With a focus on investigations in the area of overactuated spacecraft, a new high-performance robust three-axis finite-time attitude control approach, which is organized in connection with the quaternion based estimation scheme is proposed in the present research with respect to state-of-the-art. The approach proposed here is realized based upon double closed loops to deal with the angular rates of the system, in the inner loop, and also the rotational angles of the system in line with the corresponding quaternion, in the outer loop, synchronously. With this goal, a combination of linear and its non-linear terms through the sliding mode control approach and also the proportional derivative based linear quadratic regulator control approach is organized. There is the white measurement noise to be realized the outcomes in such real situations, where it is coped with through the optimal estimation scheme to be designed, correspondingly. The results are organized with regard to the pulse modulation synthesis through the technique of the pulse width pulse frequency to manage a set of on-off reaction thrusters, as long as the control allocation is employed to handle the aforementioned overactuated system under control. The effectiveness of the approach investigated is finally considered in line with a series of the experiments to be tangibly verified.

***doi**: 10.5829/idosi.ije.2015.29.1a.08*

1. INTRODUCTION

A number of traditional attitude control approaches attempt to deal with the dynamics and its kinematics of the spacecraft. In making a novel effort in this area, the proposed approach is organized, in the double closed loops, for the purpose of handling the angular rates and the corresponding rotational angles, synchronously, through the inner and the outer closed loops of the system, respectively. Hereinafter, a combination of the linear and its non-linear terms by designing the sliding mode control approach and also the proportional derivative based linear quadratic regulator control approach is realized. In order to develop the investigated outcomes in such real situations, the white measurement noise is taken into real consideration. And the optimal estimation scheme is correspondingly designed to outperform the investigated outcomes, as well. There are the pulse modulation synthesis through the technique of the pulse width pulse frequency and also the control allocation to handle the present overactuated spacecraft through a set of on-off reaction thrusters. To consider state-of-the-art results in the proposed research, a number of potential methods in this field are considered in the proceeding sub-section.

1. 1. Related Works There are a number of methods and techniques in the area of spacecraft modeling and its control to be briefly considered. The work of Hu et al. is to realize robust attitude control under assigned velocities and constraints, while that of Cai et al. is to deal with the leader-following attitude control for a number of such systems [1, 2]. Hereinafter, the work of Kuo et al. is presented in the area of attitude dynamics and control via pseudo-wheels, once Zhang et al. research is given in attitude control with disturbance, generated by time varying exo-systems [3, 4]. Navabi et

*Corresponding Author's Email: *mazinan@azad.ac.ir* (A. H. Mazinan)

al. explore attitude control through earth's magnetic field, while Soleymani et al. deal with the relative motion through linearized time-varying perturbed terms [3-6]. Erdong et al. propose robust decentralized attitude coordination formation control, where the work of Bustan et al. is in robust fault-tolerant tracking control with input saturation [7, 8]. Lu et al. propose a design of control approach for attitude tracking with actuator saturation [9]. Soleymani et al. analyze the effect of the frozen conditions for relative motion dynamics [10]. Mazinan et al. explore full quaternion based finite-time cascade attitude control approach through pulse modulation synthesis and also the three-axis detumbling mode control approach [11, 12]. In making such efforts, Mazinan considers a large number of cases including a Lyapunov-based three-axis attitude intelligent control approach, maneuvers control based upon the propellant engine modes, high-precision full quaternion based finite-time cascade attitude control strategy, high-precision three-axis detumbling and pointing attitude control strategy and finally hybrid robust three-axis attitude control approach [13-17]. Pukdeboon et al. suggest an optimal sliding mode control for attitude tracking via Lyapunov function [18]. Yeh presents an approach to sliding-mode adaptive attitude control, while Yongqiang et al. suggest time-varying sliding mode attitude tracking control approach [19, 20]. A self-tuning proportional derivative integral control approach to three-axis stabilization with unknown parameters is suggested by Moradi [21]. Adaptive sliding mode control with its application to relative motion with constraints is given by Wu et al. And finally, the stability of the continuous-time Kalman filter is presented by Viegas et al. [22, 23].

The rest of the manuscript is organized as follows: The proposed control approach is first given in Section 2. The numerical simulations are then given in Section 3. Finally, the research concludes the investigated outcomes in Section 4.

1. 2. The Proposed Control Approach

The schematic diagram of the proposed control approach is illustrated in Figure 1. The outcomes are organized based upon two closed control loops including the inner and the outer loops. The responsibility of the inner loop is to deal with the angular rates of the system, i.e. $\omega(t)$ to be zero in the steady state, while the responsibility of the outer closed loop is to deal with the quaternion of the system, i.e. $q_s(t)$ to be desirable in the steady state based upon the referenced commands. There is the measurement noise, i.e. $n(t)$, as long as the optimal estimator scheme is designed to provide the estimated $\hat{q}_s(t)$ form the noisy $\tilde{q}_s(t) = q_s(t) + n(t)$. It is to note that the rotational angles are directly addressed through $\hat{q}_s(t)$, as well. A combination of the linear and its nonlinear approaches is provided through the proportional derivative based linear quadratic regulator (PDLQR) in connection with the sliding mode finite-time control (SMC), respectively, to provide the appropriate control torques, i.e. $\tau(t)$. The information on designing the proposed control approach is given in the proceeding sections.

1. 3. The Spacecraft Model

1. 3. 1. The Attitude Dynamics and Kinematics

The attitude dynamic equation is organized based on the following torque formula:

$$\vec{\tau}(t) = \frac{d\vec{H}(t)}{dt} + \vec{\omega}(t) \times \vec{H}(t) \tag{1}$$

where $\vec{H}$ denotes the angular momentum vector in the body coordinate and $\vec{\omega}$ denotes the angular rates vector in the three axes. Also, $\vec{\tau}$ is taken as the control torques and can be derived, in the three axes, by the following:

$$\begin{cases} \tau_x(t) = \dot{H}_x(t) + \omega_y(t)H_z(t) - \omega_z(t)H_y(t) \\ \tau_y(t) = \dot{H}_y(t) + \omega_z(t)H_x(t) - \omega_x(t)H_z(t) \\ \tau_z(t) = \dot{H}_z(t) + \omega_x(t)H_y(t) - \omega_y(t)H_x(t) \end{cases} \tag{2}$$

The angular rates, in the three axes, are resulted in Eq. (3), where I_x, I_y and I_z denote the moments of the inertial in the same three axes.

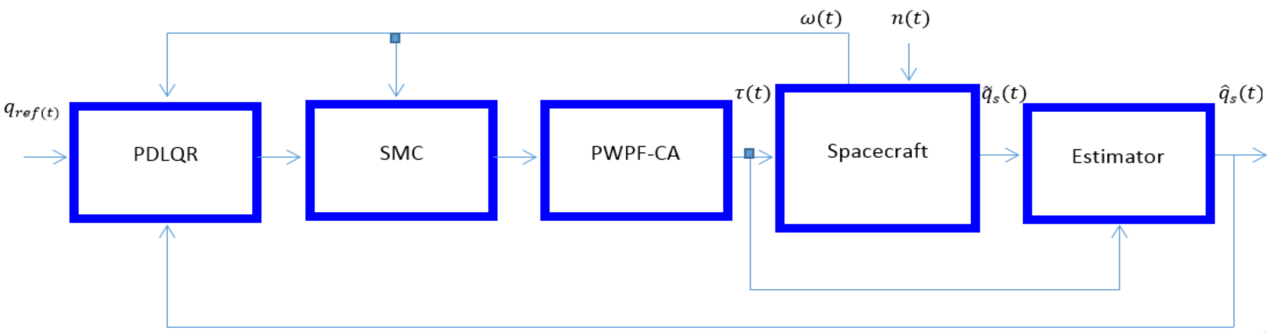

Figure 1. The schematic diagram of the proposed control approach

$$\begin{cases} \dot{\omega_x}(t) = \frac{\tau_x(t)}{I_x} - \frac{(I_z - I_y)}{I_x}\omega_y(t)\omega_z(t) \\ \dot{\omega_y}(t) = \frac{\tau_y(t)}{I_y} - \frac{(I_x - I_z)}{I_y}\omega_x(t)\omega_z(t) \\ \dot{\omega_z}(t) = \frac{\tau_z(t)}{I_z} - \frac{(I_y - I_x)}{I_z}\omega_x(t)\omega_y(t) \end{cases} \quad (3)$$

The quaternion of the system can now be presented as:

$$q_s(t) = \begin{bmatrix} q_{0s}(t) \\ q_{1s}(t) \\ q_{2s}(t) \\ q_{3s}(t) \end{bmatrix} = \begin{bmatrix} cos\left(\frac{\varepsilon_r(t)}{2}\right) \\ sin\left(\frac{\varepsilon_r(t)}{2}\right).m_1 \\ sin\left(\frac{\varepsilon_r(t)}{2}\right).m_2 \\ sin\left(\frac{\varepsilon_r(t)}{2}\right).m_3 \end{bmatrix}; m = \begin{bmatrix} m_1 \\ m_2 \\ m_3 \end{bmatrix} \quad (4)$$

where $m_{i;} i = 1, 2, 3$ and $\varepsilon_r(t)$ denotes i^{th} eigenvector of rotations and the angle of rotations, respectively. Now, the relations between $\omega_x(t), \omega_y(t), \omega_z(t)$ and $q_{is}(t)$ can be presented by

$$\begin{bmatrix} \dot{q}_{0s}(t) \\ \dot{q}_{1s}(t) \\ \dot{q}_{2s}(t) \\ \dot{q}_{3s}(t) \end{bmatrix} = \frac{1}{2} \begin{bmatrix} 0 & -\omega_x(t) & -\omega_y(t) & -\omega_z(t) \\ \omega_x(t) & 0 & \omega_z(t) & -\omega_y(t) \\ \omega_y(t) & -\omega_z(t) & 0 & \omega_x(t) \\ \omega_z(t) & \omega_y(t) & -\omega_x(t) & 0 \end{bmatrix} \begin{bmatrix} q_{0s}(t) \\ q_{1s}(t) \\ q_{2s}(t) \\ q_{3s}(t) \end{bmatrix} \quad (5)$$

And the relation of the angular relations, i.e. ϕ, θ, ψ and q_{is} can be given through Eqs. (6)-(7)

$$\begin{cases} q_{0s}(t) = \cos\left(\frac{\psi(t)}{2}\right)\cos\left(\frac{\theta(t)}{2}\right)\cos\left(\frac{\phi(t)}{2}\right) \\ \qquad + \sin\left(\frac{\psi(t)}{2}\right)\sin\left(\frac{\theta(t)}{2}\right)\sin\left(\frac{\phi(t)}{2}\right) \\ q_{1s}(t) = \cos\left(\frac{\psi(t)}{2}\right)\cos\left(\frac{\theta(t)}{2}\right)\sin\left(\frac{\phi(t)}{2}\right) \\ \qquad - \sin\left(\frac{\psi(t)}{2}\right)\sin\left(\frac{\theta(t)}{2}\right)\cos\left(\frac{\phi(t)}{2}\right) \\ q_{2s}(t) = \cos\left(\frac{\psi(t)}{2}\right)\sin\left(\frac{\theta(t)}{2}\right)\cos\left(\frac{\phi(t)}{2}\right) \\ \qquad + \sin\left(\frac{\psi(t)}{2}\right)\cos\left(\frac{\theta(t)}{2}\right)\sin\left(\frac{\phi(t)}{2}\right) \\ q_{3s}(t) = \sin\left(\frac{\psi(t)}{2}\right)\cos\left(\frac{\theta(t)}{2}\right)\cos\left(\frac{\phi(t)}{2}\right) \\ \qquad - \cos\left(\frac{\psi(t)}{2}\right)\sin\left(\frac{\theta(t)}{2}\right)\sin\left(\frac{\phi(t)}{2}\right) \end{cases} \quad (6)$$

$$\begin{cases} \psi(t) = tan^{-1}\left(\frac{2(q_{1s}(t)q_{2s}(t) + q_{0s}(t)q_{3s}(t))}{q_{0s}^2(t) + q_{1s}^2(t) - q_{2s}^2(t) - q_{3s}^2(t)}\right) \\ \theta(t) = -sin^{-1}(2(q_{1s}(t)q_{3s}(t) - q_{0s}(t)q_{2s}(t))) \\ \phi(t) = tan^{-1}\left(\frac{2(q_{2s}(t)q_{3s}(t) + q_{0s}(t)q_{1s}(t))}{q_{0s}^2(t) - q_{1s}^2(t) - q_{2s}^2(t) + q_{3s}^2(t)}\right) \end{cases} \quad (7)$$

1. 3. 2. The Pulse with Pulse Frequency-Control Allocation Realizations The pulse width pulse frequency (PWPF) under the known parameters of $K_{pw,} T_{pw}, U_{on}$ and U_{off} are designed to deal with the on-off reaction thrusters. And the control allocation (CA) is also designed to deal with the overactuated system under control. Now, the three-axis control torques in line with a set of thrusters to be eight could clearly result in:

$$\begin{cases} \tau_x(t) = -M(T_5 + T_6 - T_7 - T_8) \\ \tau_y(t) = M(T_3 - T_1) + L(T_6 - T_8) \\ \tau_z(t) = M(T_2 - T_4) + L(T_5 - T_7) \end{cases} \quad (8)$$

where $T_i; i = 1,2, \dots, n$ denotes the i^{th} thruster's level. Also, M and L are taken as the physical parameters of the thruster's positions. Due to the fact that $T_i; i = 1, 2, \dots, n$, presented in Eq. (8), they are in need of binary information, a relay, i.e. $f_{on/off}$ has to be realized to cope with τ_x, τ_y and τ_z in the form of its effective ones, i.e. τ_{x_e}, τ_{y_e} and τ_{z_e} by the following:

$$\begin{bmatrix} \tau_{x_e}(t) \\ \tau_{y_e}(t) \\ \tau_{z_e}(t) \end{bmatrix} = E\, f_{on/off}\left(E^+ \begin{bmatrix} \tau_x(t) \\ \tau_y(t) \\ \tau_z(t) \end{bmatrix}\right) \quad (9)$$

It should be noted that the hysteresis of the $f_{on/off}$ may appropriately be chosen to present the efficient results.

1. 3. 3. The Control Approaches Realizations the PDLQR Approach The PDLQR approach is designed via the linear quadratic regulator (LQR) to optimize its performance index. Now, the gain of the LQR, i.e. $K_{lqr} = {R_J}^{-1} B^T P$ is given in Eq. (10) for the state space model of the system with the known parameters of A, B under the performance index with known parameters of Q_J, R_J

$$K_{lqr} = c^2[0 \quad 1] \begin{bmatrix} \sqrt{1 + \frac{2}{c}} & \frac{1}{c} \\ \frac{1}{c} & \frac{1}{c}\sqrt{1 + \frac{2}{c}} \end{bmatrix} = [c \quad \sqrt{c^2 + 2c}] \quad (10)$$

where c is taken as the constant value and P can be derived from the Riccati equation. And subsequently, the whole of the coefficients regarding the PDLQR approach are investigated through ($\mu = x, y, z$)

$$k_{p_\mu} = c\frac{I_\mu}{\tau_\mu} > 0 \ , k_{d_\mu} = \sqrt{c^2 + 2c}\frac{I_\mu}{\tau_\mu} > 0 \quad (11)$$

Finally, the control efforts of the PDLQR approach are realized based upon the quaternion errors, i.e. $q_{ie}; i = 1, 2, 3, 4$ in association with the angular rates in the three axes by the following

$$\begin{pmatrix} \tau_x(t) \\ \tau_y(t) \\ \tau_z(t) \end{pmatrix} = \begin{pmatrix} -T(k_{px}\, q_{1e}(t) + k_{dx}\, \omega_x(t)) \\ -T(k_{py}\, q_{2e}(t) + k_{dy}\, \omega_y(t)) \\ -T(k_{pz}\, q_{3e}(t) + k_{dz}\, \omega_z(t)) \end{pmatrix} \quad (12)$$

Here, by using $\vec{q}_e = \vec{q}_{ref}\vec{q}_s$, its expanded form can be written in Eq. (13), where $\vec{q}_{ref}$ indicates the referenced quaternion. In one such case, the $T = T_i; i = 1,2, \dots, n$ are the same for all the thrusters and also the conditions $\|\vec{q}_{ref}\| = 1$ should be satisfied.

$$\begin{bmatrix} q_{1e}(t) \\ q_{2e}(t) \\ q_{3e}(t) \\ q_{4e}(t) \end{bmatrix} = \begin{bmatrix} q_{4ref}(t) & q_{3ref}(t) & -q_{2ref}(t) & -q_{1ref}(t) \\ -q_{3ref}(t) & q_{4ref}(t) & q_{1ref}(t) & -q_{2ref}(t) \\ q_{2ref}(t) & -q_{1ref}(t) & q_{4ref}(t) & -q_{3ref}(t) \\ q_{1ref}(t) & q_{2ref}(t) & q_{3ref}(t) & q_{4ref}(t) \end{bmatrix} \begin{bmatrix} q_{1s}(t) \\ q_{2s}(t) \\ q_{3s}(t) \\ q_{4s}(t) \end{bmatrix} \quad (13)$$

1. 4. The SMFC Approach The SMFC approach is designed in connection with the nonlinear multi-input multi-output system of the following form:

$$\dot{x}(t) = f(x) + B(x)u(t) \tag{14}$$

where f and B are taken as the nonlinear terms. And $x(t) \triangleq [x_1(t) \quad x_2(t) \quad \cdots \quad x_n(t)]^T$ as well as $u(t) \triangleq [u_1(t) \quad u_2(t) \quad \dots \quad u_m(t)]^T$ are taken as the states of the system and the control efforts, respectively. Moreover, the condition $|f - \hat{f}| \leq \text{F}$ has to be satisfied, where F, f and $\hat{f}$ are taken as the known function, the bounded function regarding F and the estimated nonlinear or the time-varying function, respectively. The uncertainties on B can now be written in the multiplicative form, i.e. $B = (I + \Delta)\hat{B}$. Let us consider errors between the states and its desirable ones, i.e. $e(t) = x(t) - x_d(t)$, the sliding surface at i^{th} instant of time, i.e. $s_i(t) = e_i(t) + \lambda_i \int_0^t e_i(t)dr$ and finally the stability condition, i.e. $\dot{s}_i(t)s_i(t) \leq -\eta_i|s_i(t)|$, for each state, to realize the control approach. It can be translated to find a control law for the vector $u(t)$ that verifies the aforementioned stability condition. Accordingly, it is easily possible to realize the control efforts in the form of :

$$u(t) = \hat{u}(t) - \hat{B}^{-1}K\, sgn(s(t)) \tag{15}$$

where $\hat{u}(t) = \hat{B}^{-1} \underbrace{\left[-\hat{f}(x,t) + \dot{x}_d(t) - \lambda e(t)\right]}_{u'(t)}$ and $K \geq \hat{B}B^{-1}(F + \eta) + (\hat{B}B^{-1} - I)|u'(t)|$ are investigated. Now, the parametric uncertainties of spacecraft's moments of inertia can be presented as:

$$\begin{cases} I_x = \hat{I}_x + d_x \\ I_y = \hat{I}_y + d_y \\ I_z = \hat{I}_z + d_z \end{cases} \tag{16}$$

Afterwards, the Δ is acquired in the following form:

$$\Delta = \begin{bmatrix} \frac{-d_x}{\hat{I}_x + d_x} & 0 & 0 \\ 0 & \frac{-d_y}{\hat{I}_y + d_y} & 0 \\ 0 & 0 & \frac{-d_z}{\hat{I}_z + d_z} \end{bmatrix} \tag{17}$$

As is obvious, the upper bound of the f can be defined through F. Subsequently, by assuming Eq. (18), the results can be written, in its final form, by:

$$F = \begin{bmatrix} \max(\frac{\hat{I}_x(d_y - d_z) + (\hat{I}_z - \hat{I}_y)d_x}{\hat{I}_x(\hat{I}_x + \hat{d}_x)}) & 0 & 0 \\ 0 & \max(\frac{\hat{I}_y(d_z - d_x) + (\hat{I}_x - \hat{I}_z)d_y}{\hat{I}_y(\hat{I}_y + \hat{d}_y)}) & 0 \\ 0 & 0 & \max(\frac{\hat{I}_z(d_x - d_y) + (\hat{I}_y - \hat{I}_x)d_z}{\hat{I}_z(\hat{I}_z + \hat{d}_z)}) \end{bmatrix} \tag{18}$$

1. 4. 1. The Optimal Estimation Scheme The optimal estimation, designed in the approach investigated here, is based upon the well-known Kalman filter scheme. In brief, it can be considered by addressing the general known form of the continuous system including the state and its measurement equations as follows [23]:

$$\begin{cases} \dot{x}(t) = Ax(t) + Bu(t) + Gw(t) \\ y(t) = Cx(t) + Du(t) + Hw(t) + v(t) \end{cases} \tag{19}$$

where $x(t), u(t)$ and $y(t)$ are related to the state, the input and the output of the system, respectively. Here, A, B, C, D, G and H are related to the system parameters with noise, while $w(t)$ and $v(t)$ are related to the white process noise and the white measurement noise, respectively, satisfying Eq. (20)

$$\begin{cases} E(w(t)) = E(v(t)) = 0 \\ E(w(t)w^T(t)) = Q \\ E(v(t)v^T(t)) = R \\ E(w(t)v^T(t)) = N \end{cases} \tag{20}$$

where $E(.)$ denotes the expected value and there is

$$P = lim_{t\to\infty} E((x(t) - \hat{x}(t)(x(t) - \hat{x}(t)^T) \tag{21}$$

The estimated state, i.e. $\hat{x}(t)$ is taken to minimize the steady-state error covariance through:

$$\dot{\hat{x}}(t) = A\hat{x}(t) + Bu(t) + L(y(t) - C\hat{x}(t) - Du(t)) \tag{22}$$

The optimal solutions can be derived for the Kalman filter by using Eqs. (23)-(24):

$$\begin{bmatrix} \hat{y}(t) \\ \hat{x}(t) \end{bmatrix} = \begin{bmatrix} C \\ I \end{bmatrix} \hat{x}(t) + \begin{bmatrix} D \\ 0 \end{bmatrix} u(t) \tag{23}$$

The filter gain L is calculated by solving an algebraic Riccati equation to be of the following form:

$$L = (PC^T + \bar{N})\bar{R}^{-1} \tag{24}$$

where the following are taken and P solves the corresponding algebraic Riccati equation.

$$\begin{cases} \bar{R} = R + HN + N^T H^T + HQH^T \\ \bar{N} = G(QH^T + N) \end{cases} \tag{25}$$

2. THE NUMERICAL SIMULATIONS

Numerical simulations are conducted to verify the performance of the proposed control approach. At first, the nominal values of the spacecraft's moments of inertia and also the PWPF parameters during the mission are all tabulated in Table 1.

By choosing $c = 5.0$, $T_i = 30.0\, N$ $(i = 1, 2, \cdots, 8)$, $M = 0.65\, m$ and $L = 1\, m$, the coefficients of the

PDLQR approach are designed by Equation (11), as tabulated in Table 2, where the SMC approach is correspondingly realized.

In realizing the optimal estimation scheme, the initial condition for the estimated states are taken to be zero, while the initial condition for the estimated errors covariance and also the process noise variance are taken as the identity matrix.

Regarding the outer closed loop, at first, the initial values of the rotational angles of the system are taken as 20°, 30° and 60°, respectively. After that, Figures 2-4 illustrate the tracking of the three-axis rotational angles of the system, which are abruptly varied in the wide range of time variation. And the corresponding tracking errors of the rotational angles of the system are synchronously illustrated in Figure 4, as well. The noisy quaternion of the system in the same outer closed loop, which are provided in the presence of the Gaussian noise under the mean of zero and also the variance of 0.1, is illustrated in Figure 6. The tracking results of the estimated quaternion of the system with respect to the referenced quaternion is illustrated in Figure 7, as well. It is to note that the referenced quaternion is directly addressed through the corresponding referenced rotational angles.

Now, regarding the inner closed loop, the angular rates of the system are all illustrated in Figure 8. All in all, the results indicate that the proposed control approach is well behaved.

TABLE 1. The nominal spacecraft's moments of inertia and the PWPF parameters

	The moments of inertia	The PWPF parameters
1	$\hat{I}_x = 20$	$\begin{cases} K_{pw} = 3.00 \\ T_{pw} = 2.00 \end{cases}$
2	$\hat{I}_y = 80$	$U_{on} = 0.80$
3	$\hat{I}_z = 80$	$U_{off} = 0.10$

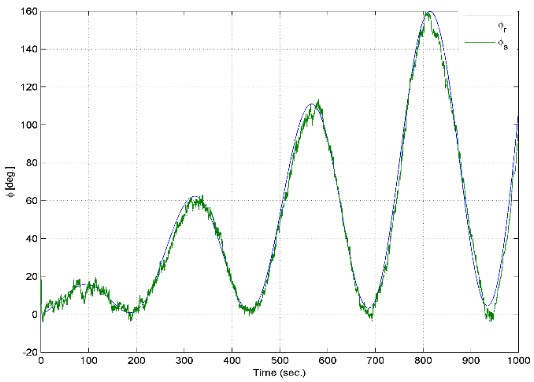

Figure 2. The tracking of the x-axis rotational angle

TABLE 2. The coefficients of the PDLQR approach, realized in the proposed approach

	The parameters	The values
1	$k_{px,y,z}$	2.560, 4.040, 4.040
2	$k_{dx,y,z}$	3.029,4.780, 4.780

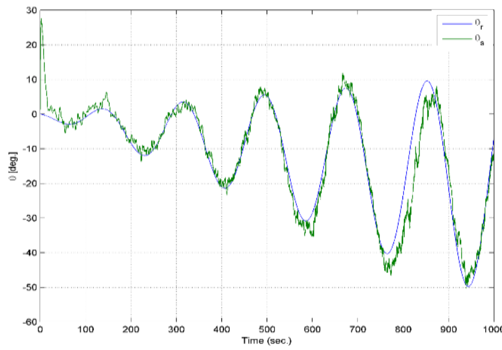

Figure 3. The tracking of the y-axis rotational angle

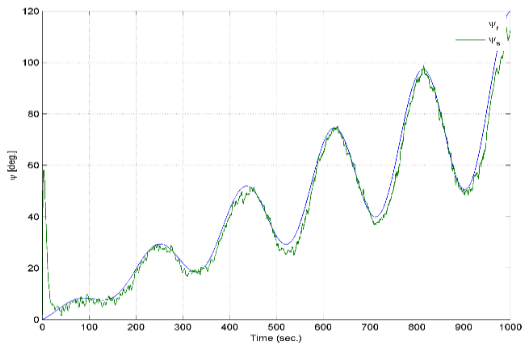

Figure 4. The tracking of the z-axis rotational angle

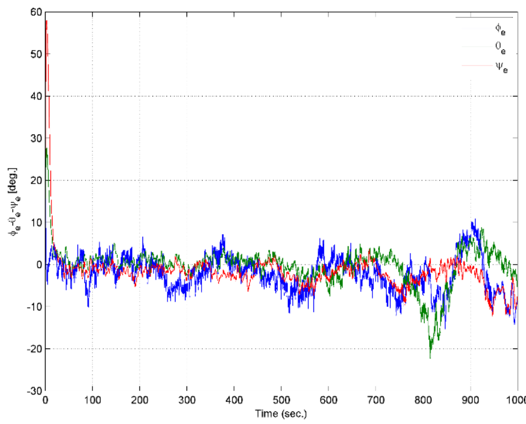

Figure 5. The tracking errors of the three-axis rotational angles

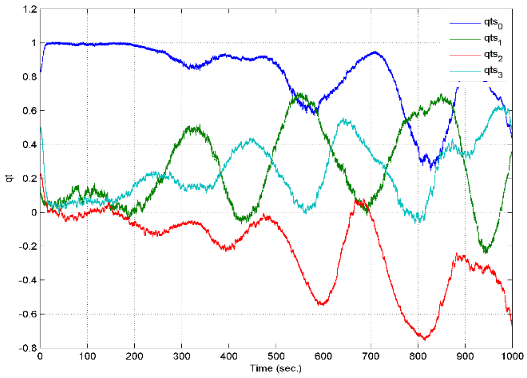

Figure 6. The noisy quaternion

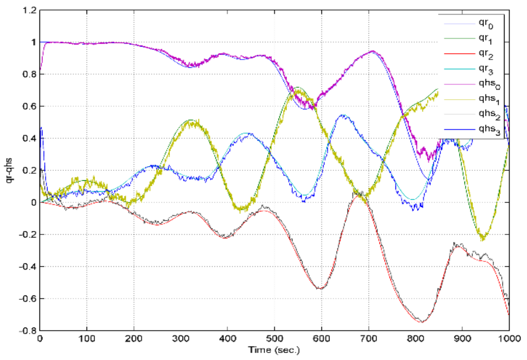

Figure 7. The tracking of the estimated quaternion

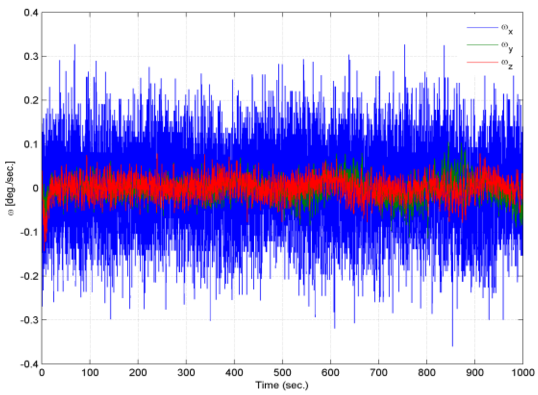

Figure 8. The three-axis angular rates

3. CONCLUSION

In making an effort in the area of the spacecraft modelling and its control, the novel approach is organized to deal with the angular rates and the corresponding rotational angles of the system, in its synchronous manner. There are both the inner and the outer closed loops to handle a combination of linear and its non-linear terms. It is shown that the sliding mode control approach in connection with the proportional derivative based linear quadratic regulator control approach are realized to develop the investigated outcomes in such real situations. It is carried out through the white measurement noise to be estimated by using the optimal estimation scheme to outperform the investigated tracking outcomes. The proposed approach is organized in line with the pulse modulation synthesis and the control allocation, as well.

4. ACKNOWLEDGMENTS

The corresponding author would like to express the best and the warmest regards to the respected Editors of “International Journal of Engineering (IJE)”. Moreover, Dr. Mazinan sincerely appreciates the Islamic Azad University (IAU), South Tehran Branch, Tehran, Iran, which plays a significant role in the process of paper investigation and organization along with a contract with the Research Department. Finally, the cooprations of Mrs. Maryam Aghaei Sarchali, Miss Mohadeseh Mazinan and also Mr. Mohammad Mazinan for their efficient supports in the same area are greatly appreciated.

5. REFERENCES

1. Hu, Q., Li, B. and Zhang, Y., "Robust attitude control design for spacecraft under assigned velocity and control constraints", ***ISA transactions***, Vol. 52, No. 4, (2013), 480-493.
2. Cai, H. and Huang, J., "The leader-following attitude control of multiple rigid spacecraft systems", ***Automatica***, Vol. 50, No. 4, (2014), 1109-1115.
3. Kuo, Y.-L. and Wu, T.-L., "Open-loop and closed-loop attitude dynamics and controls of miniature spacecraft using pseudowheels", ***Computers & Mathematics with Applications***, Vol. 64, No. 5, (2012), 1282-1290.
4. Zhang, X., Liu, X. and Zhu, Q., "Attitude control of rigid spacecraft with disturbance generated by time varying exosystems", ***Communications in Nonlinear Science and Numerical Simulation***, Vol. 19, No. 7, (2014), 2423-2434.
5. M. Navabi and N. N. Kamran, “Earth’s magnetic field for spacecraft attitude control application”, ***International Journal of Engineering- Transactions B***, Vol. 28, No. 5, (2015), 648-653.
6. Soleymani, A. and Toloei, A., "High accuracy relative motion of spacecraft using linearized time-varying j2-perturbed terms", ***International Journal of Engineering-Transactions A: Basics***, Vol. 26, No. 4, (2012), 323-332.
7. Erdong, J., Xiaolei, J. and Zhaowei, S., "Robust decentralized attitude coordination control of spacecraft formation", ***Systems & Control Letters***, Vol. 57, No. 7, (2008), 567-577.
8. Bustan, D., Pariz, N. and Sani, S.K.H., "Robust fault-tolerant tracking control design for spacecraft under control input

saturation", ***ISA transactions***, Vol. 53, No. 4, (2014), 1073-1080.

9. Lu, K., Xia, Y. and Fu, M., "Controller design for rigid spacecraft attitude tracking with actuator saturation", ***Information Sciences***, Vol. 220, (2013), 343-366.
10. Soleymani, A. and Toloei, A., "Effects analysis of frozen conditions for spacecraft relative motion dynamics", ***International Journal of Engineering-Transactions A: Basics***, Vol. 25, No. 4, (2012), 301-308.
11. Mazinan, A. H., Pasand, M. and Soltani, B., "Full quaternion based finite-time cascade attitude control approach via pulse modulation synthesis for a spacecraft", ***ISA transactions***, Vol. 58, (2015), 567-585.
12. Mazinan, A. H. and Khalaji, A., "Tadc: A new three-axis detumbling mode control approach", ***International Journal of Dynamics and Control***, (2015), 1-10.
13. Mazinan, A. H., "A lyapunov-based three-axis attitude intelligent control approach for unmanned aerial vehicle", ***Journal of Central South University***, Vol. 22, No. 12, (2015), 4669-4678.
14. Mazinan, A. H., "On spacecraft maneuvers control subject to propellant engine modes", ***ISA transactions***, Vol. 58, No., (2015), 222-236.
15. Mazinan, A. H., "High-precision full quaternion based finite-time cascade attitude control strategy considering a class of overactuated space systems", ***Human-centric Computing and Information Sciences***, Vol. 5, No. 1, (2015), 1-14.
16. Mazinan, A. H., "High-precision three-axis detumbling and pointing attitude control strategy for a class of complicated space systems", ***International Journal of Dynamics and Control***, (2015), 1-22.
17. Mazinan, A. H., "On comprehensive cascade control strategy considering a class of overactuated autonomous non-rigid space systems with model uncertainties", ***Robotics and Autonomous Systems***, (2015) 45-56.
18. Pukdeboon, C. and Zinober, A., "Control lyapunov function optimal sliding mode controllers for attitude tracking of spacecraft", ***Journal of the Franklin Institute***, Vol. 349, No. 2, (2012), 456-475.
19. Yeh, F. K., "Sliding-mode adaptive attitude controller design for spacecrafts with thrusters", ***Control Theory & Applications, IET***, Vol. 4, No. 7, (2010), 1254-1264.
20. Yongqiang, J., Xiangdong, L., Wei, Q. and Chaozhen, H., "Time-varying sliding mode controls in rigid spacecraft attitude tracking", ***Chinese Journal of Aeronautics***, Vol. 21, No. 4, (2008), 352-360.
21. Moradi, M., "Self-tuning pid controller to three-axis stabilization of a satellite with unknown parameters", ***International Journal of Non-Linear Mechanics***, Vol. 49, No., (2013), 50-56.
22. Wu, J., Liu, K. and Han, D., "Adaptive sliding mode control for six-dof relative motion of spacecraft with input constraint", ***Acta Astronautica***, Vol. 87, No., (2013), 64-76.
23. Viegas, D., Batista, P., Oliveira, P. and Silvestre, C., "On the stability of the continuous-time kalman filter subject to exponentially decaying perturbations", ***Systems & Control Letters***, Vol. 89, (2016), 41-46.

High-Performance Robust Three-Axis Finite-Time Attitude Control Approach Incorporating Quaternion Based Estimation Scheme to Overactuated Spacecraft

A. H. Mazinan

Department of Control Engineering, Faculty of Electrical Engineering, South Tehran Branch, Islamic Azad University (IAU), No. 209, North Iranshahr St., P.O. Box 11365/4435, Tehran, Iran

PAPER INFO

Paper history:
Received 15 July 2015
Accepted in revised form 28 January 2016

Keywords:
Robust Finite-Time Attitude Control Approach
Overactuated Spacecraft
Quaternion Based Estimation Scheme
Measurement Noise

چکیده

با تمرکز بر پژوهش در حوزه فضاپیماهای فوق تحریک، یک روش کنترل وضعیت مقاوم سه محوره جدید با کارآیی بالا بر اساس تخمین مبتنی بر کواترنیون در این تحقیق پیشنهاد شده است. این روش کنترلی بر پایه طراحی دو حلقه برای کنترل هم‌زمان سرعت زاویه‌ای و چرخش زاویه‌ای در راستای کواترنیون صورت پذیرفته است. با این هدف، یک ترکیب خطی و غیرخطی با به کارگیری کنترل مد لغزشی، و همچنین کنترل تناسبی مشتقی مبتنی بر رگولاتور درجه دوم خطی طراحی شده است. در این پژوهش، نویز سفید اندازه‌گیری بررسی، و متناظراً از یک روش تخمین مبتنی بر کواترنیون استفاده شده است. نتایج حاصل بر پایه آنالیز مدلاسیون پالس از طریق تکنیک پهنای پالس و فرکانس پالس با هدف راه اندازی یک مجموعه رانشگرهای عکس العملی دو وضعیه بیان شده است، در شرایطی که ایده تخصیص کنترل جهت راه اندازی سامانه فوق تحریک مطرح شده است. برتری نتایج روش پیشنهادی در راستای یک مجموعه آزمایش‌ها ارزیابی و تایید شده است.

***doi**: 10.5829/idosi.ije.2015.29.1a.08*