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Satellite Attitude Control by using Back Steeping and Feedback Linearization Methods

Saeed Rafi*[1] , Mahdi Siahi[2], Ruhollah Barzamini[3]

[1,3]Department of Electrical Engineering, Central Tehran Branch, Islamic Azad University, Tehran, Iran, saeid_rafee@yahoo.com
[2]Faculty of Mechanical, Electrical and Computer, Islamic Azad University, Science and Research branch, Tehran, Iran

Abstract

In this paper, a combination of step-back theories and linear feedback is used to control the status of a satellite. Dynamic equations govern the status of nonlinear and multi-input-multi-output satellites. The angles of rotation, the direction and top of the outputs of this system and the torques around the three axes of the satellite are its inputs. In the proposed algorithm, which uses the step-back theory, in the first step, the linear input-output feedback method is used for multi-inputmulti-output systems, and the desired angular velocities around the three axes of the satellite are determined. Using this method, in the second step, we will face three single-input-single-output subsystems. Then, in the second step, in order for the angular velocities to reach the desired values, the linear feedback theory is once again used to generate torques around three axes. Finally, computer simulation is performed to evaluate the efficiency of the proposed method.

Keywords: Satellite status control, step-back theory, linear feedback
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1. Introduction

With the rapid development of modern technology, the engineering and technical personnel have put forward higher requirements for the performance and reliability of equipment. Due to the complexity of equipment and harsh work environment, in order to avoid serious losses, adopting fault diagnosis technology for real-time monitoring of equipment's status is necessary. In the past few decades, there has been a rapid development in fault diagnosis technology.

Generally, the fault diagnosis methods can be divided into model-based approaches [1–3], knowledge-based approaches [4–6], and the methods based on signal processing [7– 9]. Among these troubleshooting approaches, knowledge based fault diagnosis methods are strongly dependent on the diagnostic systems themselves, and the diagnostic efficiency is subjective to the integrity of the information about the diagnostic systems. The fault diagnosis algorithms based on signal processing, especially filtering theory, are easy to implement in practical applications, but the first-order linear truncation in extended Kalman filters (EKF) can lead to low precision and filters' divergence. The model-based fault diagnosis approaches can make full use of the system's information for fault location, determination of the failures' type, and fault estimation to obtain higher accuracy. Therefore, the model based fault diagnosis technology has been widely studied by scholars [10, 11]. The state observer technique is very important in model-based fault diagnosis, and it is able to give specific estimated values of both failures and state variables simultaneously, which is beneficial to the subsequent design of fault-tolerant control law. Consequently, fault diagnosis based on observer has been a research hotspot [12, 13]. The representative results are analysed as follows.

A robust fault detection observer was designed for a Takagi-Sugeno (T-S) fuzzy model with sensor faults [14]. The approach used the technique of descriptor systems by considering sensor fault as an auxiliary state variable. The design of robust fault detection observer was formulated as a H- /H-infinity problem. A solution of the pursued problem based on no quadratic Lyapunov functions was then given via a linear matrix inequality formulation. An example was presented to demonstrate the design conditions. The example showed that the proposed fault detection observer was effective.

The small-amplitude oscillatory failures in the electrical flight control system of an aircraft were specifically studied [15]. A nonlinear observer-based solution to detect oscillatory failures with small amplitude at a very early stage was presented. By narrowing the detection threshold, the proposed approach could detect a fault with small amplitude and achieve early fault warning but was not able to give a specific form of the failure.

The online fault estimation question was further pursued [16]. A nonlinear aircraft model with multiple control surfaces was considered and a fault detection and isolation (FDI) algorithm was proposed for the stuck fault detection. The estimation effect was perfect; however, the proposed algorithm was based on an ideal analytical model, without considering external disturbances and measurement noise. Robust and accurate detection of failures in the actuators of a civil aircraft is a crucial issue. Actuator failures, if not accurately detected in time, can often lead to improper maintenance and may potentially lead to structural damage or waste of money. Motivated by the actual demand, the combination of the observer approach and the adaptive control theory is applied to carry out fault diagnosis for actuators in a class of nonlinear systems. The adaptive method has been applied in the development of fault detection observer. Adaptive control is one of the effective theories of nonlinear systems' design. By selecting adaptable compensators, the adaptive controller can achieve stable control of a nonlinear system whose parameters are not accurately known or affected by disturbances [17, 18]. The adaptive parameters' adjusting law of the unknown fault vector has been set up, guaranteeing the asymptotic stability of the observer.

The main contributions of this paper lie in three aspects. Firstly, different from the existing papers, the fault diagnosis algorithm in this paper is not based on ideal analytical models; in other words, the random measurement noise and external disturbances are taken into account simultaneously during the whole development process [19]. The designed fault diagnosis algorithm can successfully separate the measurement noise generated by the sensors, the unknown external disturbances, and the failures when they exist at the same time. Secondly, the fault diagnosis algorithm is able to give specific estimated values of both failures and state variables rather than just giving the estimated values of the state variables or a fault warning. This is very beneficial for indepth fault analysis and taking appropriate troubleshooting actions. Thirdly, the proposed algorithm is very simple and concise, which can overcome the problem of "explosion of complexity" and is easy to be applied to practical engineering. All the above three aspects of research work are not perfect in the existing literatures.

2. System Statement

In this paper, satellite status control is considered as Figure 1:

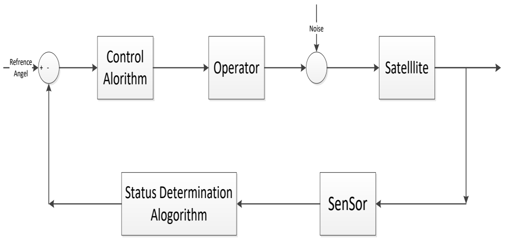

Fig. 1. Guide ring diagram block.

Consider a fault-free nonlinear system:

$$\begin{aligned} \dot{x}(t) &= g(x, t) + Bu(t) + Md(t) \\ y(t) &= Cx(t) + Nn(t) \end{aligned} \qquad (1)$$

where $x(t) \in \mathrm{R}n$ denotes the state vector and it can be measured directly; $y(t) \in \mathrm{R}m$ and $u(t) \in \mathrm{R}r$ denote an output vector and a control input vector, respectively; $d(t) \in \mathrm{R}n$ denotes an external disturbance vector that is applied to the system's actuator; $n(t) \in \mathrm{R}n$ denotes a random measurement noise (band-limited white noise) vector that is generated by the system's sensors; B and C are appropriately dimensional constant matrices; M and N are full rank const. matrices; $g(x, t)$ is a nonlinear function of the state variables $x(t)$. Remark 1. Nonlinear control system (1) describes the influence of disturbances on the state variables and the effect of measurement noise on the output, respectively. When there are actuators' failures, the fault system can be expressed as:

$$\begin{aligned} \dot{x}(t) &= g(x, t) + B[u(t) + f(t)] + Md(t) \\ y(t) &= Cx(t) + Nn(t) \end{aligned} \qquad (2)$$

where $f(t) \in \mathrm{R}r$ denotes an unknown time-varying fault vector.

3. Design of a combination of step-back controller and linear feedback maker to control the situation

In this part of the step-back method, we design a combination with linear feedback to estimate satellite angles. For this purpose, first the equations governing the satellite are rewritten in a desirable form:

$$\begin{aligned}
\dot{\omega}_x &= \frac{(I_y - I_z)\omega_y\omega_z}{I_x} - \frac{\omega_y h_z}{I_x} + \frac{\omega_z h_y}{I_x} + \frac{T_{dx}}{I_x} + \frac{T_{cx}}{I_x} \\
\dot{\omega}_y &= \frac{(I_z - I_x)\omega_x\omega_z}{I_y} - \frac{\omega_z h_x}{I_y} + \frac{\omega_x h_z}{I_y} + \frac{T_{dy}}{I_y} + \frac{T_{cy}}{I_y} \qquad (3) \\
\dot{\omega}_z &= \frac{(I_x - I_y)\omega_x\omega_y}{I_z} - \frac{\omega_x h_y}{I_z} + \frac{\omega_y h_x}{I_z} + \frac{T_{dz}}{I_z} + \frac{T_{cz}}{I_z}
\end{aligned}$$

Now, assuming that the angular velocities are constant and in the absence of perturbations, we first use the step-back controller:

$$\begin{aligned}
\dot{z}_x &= F_x + g_x T_{cx} + w_x - \dot{\omega}_{xd} \\
\dot{z}_y &= F_y + g_y T_{cy} + w_y - \dot{\omega}_{yd} \qquad (4) \\
\dot{z}_z &= F_z + g_z T_{cz} + w_z - \dot{\omega}_{zd}
\end{aligned}$$

Here g is defined as follows:

$$g = \begin{bmatrix} \frac{1}{I_x} & 0 & 0 \\ 0 & \frac{1}{I_y} & 0 \\ 0 & 0 & \frac{1}{I_z} \end{bmatrix} \qquad (5)$$

We design the controller linear feeder feedback as follows:

$$\begin{aligned}
T_{cx} &= \frac{1}{g_x}\left[-F_x + \dot{\omega}_{xd} - k_1 z_x\right] \\
T_{cy} &= \frac{1}{g_y}\left[-F_y + \dot{\omega}_{yd} - k_2 z_y\right] \qquad (6) \\
T_{cz} &= \frac{1}{g_z}\left[-F_z + \dot{\omega}_{zd} - k_3 z_z\right]
\end{aligned}$$

4. Simulation

In this section, we want to see the results of the controller simulation designed to control the status of the satellite. In all simulations, the initial conditions and physical parameters with time step 10 are as follows. The physical parameters are as follows:

$$\begin{aligned}
I_x &= 12(kgm^2) \\
I_y &= 9.5(kgm^2) \qquad (7) \\
I_z &= 6(kgm^2)
\end{aligned}$$

$$\begin{aligned}
h_x &= 5.4768(N\,m\,s) \\
h_y &= 1.1789(N\,m\,s) \qquad (8) \\
h_z &= -13.4327(N\,m\,s)
\end{aligned}$$

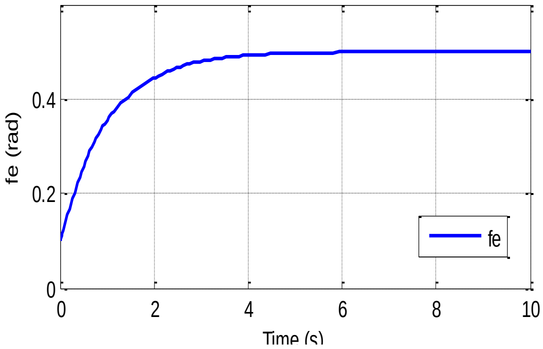

Fig. 2. Angle ϕ

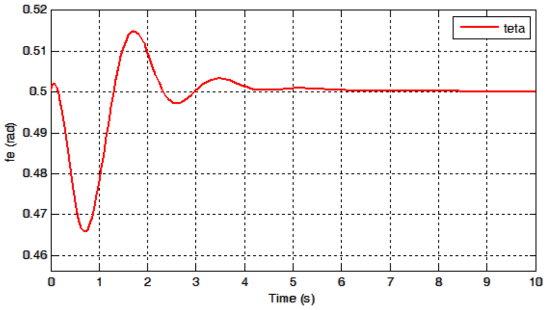

Fig. 3. Angle θ

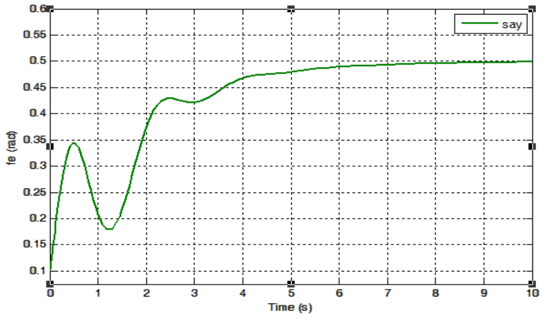

Fig. 4. Angle Ψ

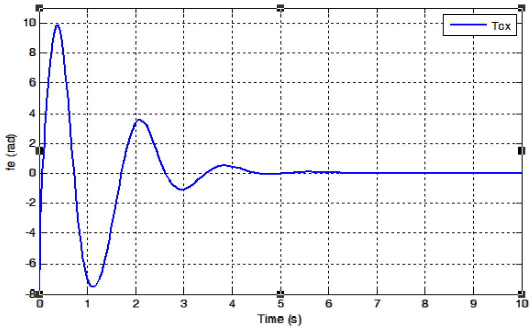

Fig. 5. Torque applied from the controller to the operator Tcx

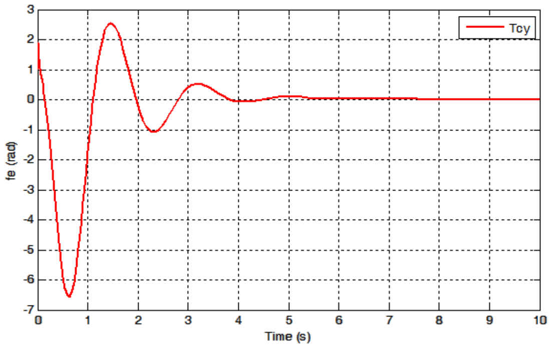

Fig. 6. Torque applied from the controller to the operator Tcy

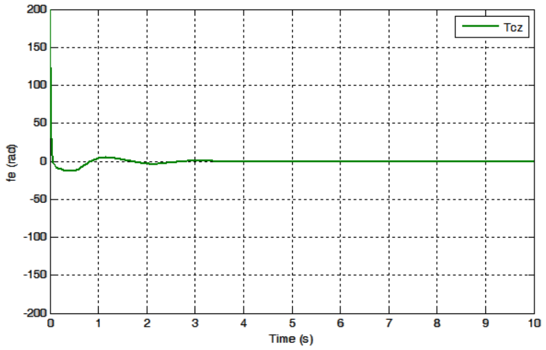

Fig. 7. Torque applied from the controller to the operator Tcz

5. Conclusion

In this paper, in order to control the position of the satellite and that the angles of the satellite are stable in three axes, a combination of step-back control rules and linear feedback have been used and its stability has been proved by MATLAB. Linear feedback was used to determine the situation due to the nonlinearity of the governing equations. This controller is able to issue control acceleration in a very short time and with great accuracy. First, in the first step, the input-output linear feedback method is used for multi-input-multi-output systems, and the desired angular velocities around the three axes of the satellite are determined. Then, using this method, in the second step, the following three We encountered the single-input-single-output system and went to the second step, where in order for the angular velocities to reach the desired values, the linear feedback theory was once again used to generate torques around three axes, and the simulation results show And with less energy consumed in a shorter time the satellite will reach the desired state and good stability.

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