International Journal of Non-Linear Mechanics 49 (2013) 50–56

Contents lists available at SciVerse ScienceDirect

International Journal of Non-Linear Mechanics

journal homepage: www.elsevier.com/locate/nlm

# Self-tuning PID controller to three-axis stabilization of a satellite with unknown parameters

Morteza Moradi *

Department of Engineering, Chalos Branch, Islamic Azad University, Chalos, Iran

ARTICLE INFO

*Article history:*
Received 2 October 2011
Received in revised form
30 August 2012
Accepted 1 September 2012
Available online 10 September 2012

*Keywords:*
Unknown parameters based satellite control
Self-tuning PID controller
Satellite attitude control

ABSTRACT

This paper addresses the three-axis stabilization of a satellite system in the presence of the gravity gradient and orbital eccentricity. Multivariable non-linear dynamics of the satellite system are converted into three well-known non-linear canonical independent models with unknown parameters. The new model is efficient and practical for designers to implement and analyze different control methodologies on satellite systems. A self-tuning PID controller is designed on the basis of the new proposed model to produce control signals for three reaction wheels in three axes. An adaptive algorithm is applied to tune and update gains of the PID controller and stability of the closed-loop system is guaranteed by using Lyapunov approach. Numerical simulations are performed to demonstrate feasibility and effectiveness of the self-tuning PID controller and a comparison with a fixed gain PD controller and a variable-structure controller is made.

© 2012 Elsevier Ltd. All rights reserved.

## 1. Introduction

The attitude control of a satellite is an important part of most missions in the space. Not only a suitable control methodology, but also appropriate actuators should be applied in order to help to achieve the goal of the mission and satisfy the constraints, e.g. solar radiation [1,2], reaction wheels [3–6], magnetic torque rod [7–9], thrusters [10], control moment gyro [11], etc. To stabilize the system with uncertainties, different methods have been proposed over the years. For instance, the adaptive method [12,13], $H^{\infty}$ control theory [14,15], fuzzy control [16,17], optimal control [18], and feedback linearization [19], etc.

It is a well-known fact that PID controllers have dominated industrial control applications even in aerospace engineering [1], although there has been considerable interest to research about the implementation of advanced controllers. They are straightforward to use, as almost everyone with some basic knowledge in control engineering may be able to employ it satisfactorily.

The fixed gain PID controller cannot perfectly stabilize non-linear systems with uncertainties in terms of the model and parameters. To enhance the performance of the PID controller, different algorithms were proposed. As explained in Ref. [20] Newton–Raphson method was employed to adjust the gains of PID. A fuzzy-based self-tuning method was proposed in [21]. Additionally, some tuning algorithms based on the adaptive and robust methods were proposed in [22–26].

This paper presents the adaptive-based PID controller and develops it for the satellite system. First, some manipulations are applied in order that the system equations are in a form suitable for the design and analysis of the controller. These manipulations allow engineers to design a controller without having much information about parameters of the system. In order to fulfill this purpose, the multivariable non-linear dynamic of the satellite was converted into three prevalent non-linear canonical systems. One more advantage can be counted for the new model. In fact, this model can be considered as three independent systems where a different control system is applied in each axis.

Therefore, a non-linear PID based controller is designed for a satellite system. The controller has been designed for a satellite system as PIDs are being extensively used in many industries. In the literature, added to the self-tuning PID controller, there have been various controllers [27,28] designed for non-linear canonical systems those with unknown parameters. Among them, few have been employed and analyzed for satellite systems. The adaptive PID controller is stable against the parameter variations while a fixed-gain PID controller, designed according to the linear dynamic of the system, is vulnerable in the disturbances and uncertainties [10]. Furthermore, a non-linear controller, the one proposed for three reaction wheels based on a variable-structure controller, produces chattering effects [6].

To develop an adaptive self-tuning PID controller, the new canonical model is considered as the basic model. Then, the controller is designed and the stability of the closed-loop system

* Tel.: +98 911 194 4027.
*E-mail address:* mortezamoradi64@gmail.com

0020-7462/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ijnonlinmec.2012.09.002

**Table 1**
Nomenclature.

| | | | |
|---|---|---|---|
| $S_s$ | Mass center of satellite | H | Momentum wheel vector |
| $X_bY_bZ_b$ | Body coordinate system | $\Omega$ | Mean angular velocity $(\mu/R^3)^{1/2}$ |
| $X_0Y_0Z_0$ | Orbital reference frame | $\mu$ | $G_0 \times M_E$, universal gravitational constant, Earth mass, respectively |
| $I_s$ | Inertia matrix | | |
| $\omega_s$ | Angular velocity vector | $h_i$ | momentum wheel in $i$-axis, $i$=$X$, $Y$, $Z$ |
| $\omega_i$ | Angular velocity in $i$-axis, $i = X,Y,Z$ | $T_g$ | Gravity gradient torque |
| $\varphi,\alpha,\psi$ | Euler's angles in axes, $X$, $Y$, $Z$, respectively | $T_d$ | Disturbance torque |
| $\Phi$ | Euler's angles vector | $\theta_0$ | True anomaly (eccentric orbit), angle (circular orbit) |
| $c$ ( ), $s$ ( ) | cos ( ), sin ( ), respectively | | |
| $x$ | State variable | $\theta$ | Adaptive parameters vector |
| $\dot{h}_i$ | Adjustable produced torque by reaction wheel in $i$-axis, $i = X, Y, Z$ | $\dot{h}$ | Adjustable produced torque vector by reaction wheel |
| $y_r$ | Desired trajectory | $F_{3\times 1}$, $G_{3\times 3}$ | Unknown parameters of the proposed model |
| $u_{PID}$ | Produced control signal by self-tuning PID controller | $K_p$, $k_i$, $k_d$ | Proportional, integral and derivative gains of PID controller |
| $\theta^*$ | Ideal adaptive parameters vector | | |
| $u^*$ | Ideal control signal | $S$ | Sliding surface |
| $R$ | Orbital radius (circular orbit), semi-major axis (eccentric orbit) | $\rho$ | Sliding mode design parameter |
| | | $\xi$ | Errors vector |
| | | $\gamma$ | Design parameter of adaptive algorithm |

is confirmed. In addition, some simulations are carried out. The results show that the new proposed method can stabilize the original non-linear system of the satellite in the presence of uncertainties and disturbances. The rest of the paper is organized as follows. In Section 2 the satellite system is attended and the new model is derived. In Section 3, the control system is designed, and thereafter, the results of the simulations are demonstrated in Section 4. Finally, the paper is concluded in Section 5.

## 2. Satellite model

The notations applied throughout the paper are listed in Table 1. Moreover, the satellite system is shown in Fig. 1. $X_0Y_0Z_0$ is the orbital reference frame, $Z_0$ axis points toward the mass center of the Earth, $X_0$ is in the direction of the satellite velocity, and $Y_0$ represents the third axis of this right-handed taken frame. $(\psi,\alpha,\varphi)$ are Euler's angles made via rotating about $Z_0Y_0X_0$, respectively. Euler's equation of motion can be written as

$$\dot{H}+\omega_s^{\times}H = T_g + T_d \tag{1}$$

$$H = I_s\omega_s + h, h = [h_X,h_Y,h_Z]^T$$

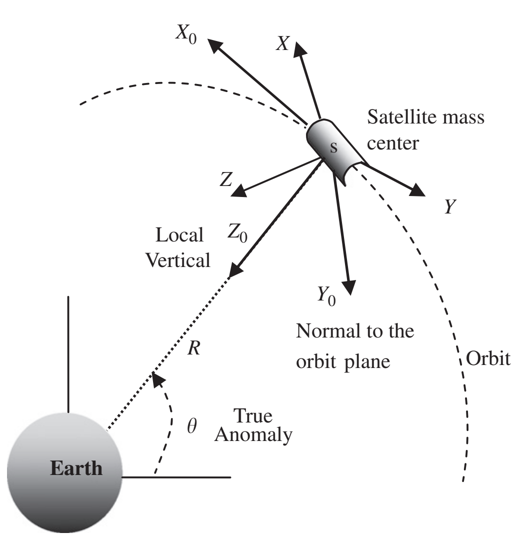


**Fig. 1.** System model, orbital and body reference frames.

$$I_s = \begin{bmatrix} I_{11} & -I_{12} & -I_{13} \\ -I_{21} & I_{22} & -I_{23} \\ -I_{31} & -I_{32} & I_{33} \end{bmatrix} \quad \omega_s^{\times} = \begin{bmatrix} 0 & -\omega_z & \omega_y \\ \omega_z & 0 & -\omega_x \\ -\omega_y & \omega_x & 0 \end{bmatrix}$$

The three independent canonical models are derived as follows. Let define the new vectors $\Phi=[\varphi,\alpha,\psi]^T$ and $\omega_s=[\omega_x,\omega_y,\omega_z]^T$.

The relation between the body angular velocities vector and the derivative of Euler's angles is written as addressed in [10]

$$\omega_s = C\dot{\Phi},\ C = \begin{bmatrix} 1 & 0 & -s\alpha \\ 0 & c\varphi & c\alpha\, s\varphi \\ 0 & -s\varphi & c\alpha\, c\varphi \end{bmatrix} \Rightarrow C^{-1} = \frac{1}{c\alpha}\begin{bmatrix} c\alpha & s\varphi s\alpha & c\varphi s\alpha \\ 0 & c\varphi c\alpha & -s\varphi c\alpha \\ 0 & s\varphi & c\varphi \end{bmatrix} \tag{2}$$

From Eq. (2)

$$\dot{\Phi} = D\omega_s \Rightarrow \ddot{\Phi} = \dot{D}\omega_s + D\dot{\omega}_s, \quad D = C^{-1}, \dot{D} = \frac{d}{dt}(C^{-1}) \tag{3}$$

Substituting Eqs. (1) and (2) in (3) results in following equation:

$$\ddot{\Phi} = \dot{D}\omega_s + DI_s^{-1}T_d + DI_s^{-1}T_g - DI_s^{-1}\dot{h} - DI_s^{-1}\omega_s^{\times}I_s\omega_s - DI_s^{-1}\omega_s^{\times}h \tag{4}$$

Then, Eq. (4) is rewritten as follows:

$$\begin{aligned} &\ddot{\Phi} = F - G\dot{h} \\ &F = \dot{D}\omega_s + DI_s^{-1}T_d + DI_s^{-1}T_g - DI_s^{-1}\omega_s^{\times}I_s\omega_s - DI_s^{-1}\omega_s^{\times}h \\ &G = DI_s^{-1} \end{aligned} \tag{5}$$

where $F$ and $G$ are $3\times 1$ and $3\times 3$ matrices, respectively. The matrices $D$ and $I_s^{-1}$ can be written in the form of the diagonal and non-diagonal matrices

$$I_s^{-1} = I_{sd}^{-1} + I_{snd}^{-1}\ D = \begin{bmatrix} 1 & s\varphi \tan\alpha & c\varphi \tan\alpha \\ 0 & c\varphi & -s\varphi \\ 0 & s\varphi/c\alpha & c\varphi/c\alpha \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & c\varphi & 0 \\ 0 & 0 & c\varphi/c\alpha \end{bmatrix} + \begin{bmatrix} 0 & s\varphi \tan\alpha & c\varphi \tan\alpha \\ 0 & 0 & -s\varphi \\ 0 & s\varphi/c\alpha & 0 \end{bmatrix} = D_1 + D_2 \tag{6}$$

where $D_1$ and $I_{sd}^{-1}$ are diagonal matrices and $D_2$ and $I_{snd}^{-1}$ are non-diagonal ones. From (6) we have

$$\begin{aligned} &G = DI_s^{-1} = (D_1+D_2)(I_{sd}^{-1}+I_{snd}^{-1}) = G_s + \overline{G}_s \\ &G_s = D_1 I_{sd}^{-1}, \qquad \overline{G}_s = D_1 I_{snd}^{-1} + D_2(I_{sd}^{-1}+I_{snd}^{-1}) \end{aligned} \tag{7}$$

where $\overline{G}_s$ is the interaction of axes. It causes the control action in an axis producing unwanted effect on the other axes. Forasmuch as the non-diagonal elements of the $I_s$ and $D$ are smaller than

دریافت فوری ← متن کامل مقاله

ISIArticles
مرجع مقالات تخصصی ایران

- ✓ امکان دانلود نسخه تمام متن مقالات انگلیسی
- ✓ امکان دانلود نسخه ترجمه شده مقالات
- ✓ پذیرش سفارش ترجمه تخصصی
- ✓ امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
- ✓ امکان دانلود رایگان ۲ صفحه اول هر مقاله
- ✓ امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
- ✓ دانلود فوری مقاله پس از پرداخت آنلاین
- ✓ پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات