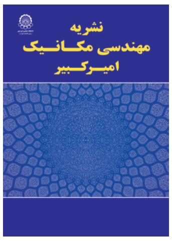

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Designing an Adaptive Control Algorithm for Amirkabir's Laboratory Attitude Simulator of a Spacecraft

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ABSTRACT: In this paper, after presenting a brief introduction about Amirkabir University of Technology's attitude simulator, governing equations are obtained. Viscous friction model is chosen to model the existing friction in the bearings of the attitude simulator. The main purpose of this paper is to design an adaptive attitude control algorithm for the attitude simulator in order to control it in the desired path and estimate the coefficients of friction due to simulator's bearings. In order to prevent singularity in simulations, Rodriguez parameters are used for kinematics representation. Firstly, the governing equations are transformed into a robotic form. The moments of inertia and coefficients of viscous friction model are assumed as uncertainties. Then, by introducing a Lyapunov function, the stability of the system is checked and the parameters are estimated. The adaptation law is obtained by the Lyapunov function and the stability of the system is then proved. In order to demonstrate the efficiency of this adaptive control algorithm, a nonlinear Lyapunov-based attitude control algorithm is designed and compared to the adaptive controller. The simulations are done in Matlab software package and the parameters of the moment of inertia matrix and coefficients of viscous friction model are estimated by the adaptation law of the controller. During the simulation, the rotational velocity of the reaction wheels are obtained and it is shown that this attitude control algorithm is implementable on the attitude simulator.

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1- Introduction

Attitude Determination and Control System (ADCS) is an important part of all modern satellites. Due to high cost and high risk of complex systems such as satellites, ground simulation and testing of spacecraft dynamics and functional tests of most subsystems are highly recommended prior to the launch. Conventional methods of ground simulation only allow a few seconds of testing and do not lend themselves to the measurement of pointing accuracy [1]. A solution is to mount the satellite on a spherical air bearing. This provides a frictionless pivot with three degrees of freedom. Many institutions have constructed physical simulators for the purpose of ground-based research in space dynamics, attitude control and for developing and testing formation flying algorithms using air-bearing [1]. The deficiency of air-bearing device is its high construction and maintenance cost [2]. Therefore, in order to overcome this imperfection, a semi-industrial attitude simulator is constructed at Amirkabir University of Technology (Fig. 1) [2-5]. This simulator is constructed in dumbbell form and a gimbal structure is used as a replacement of the air-bearing set. Hence, it possesses the benefits of the air-bearing Dumbbell structure whereas its construction cost is much lower.

In [2] the dynamics equation of the attitude simulator was obtained by applying some tests on the device. In [3] and [4] a PD control algorithm was designed and implemented on the simulator. In [5] a nonlinear Lyapunov based attitude control algorithm was designed and implemented on the device and great results were obtained. Finally, by evaluating these control algorithms, it was concluded that this attitude simulator is a very useful device for educational and semi-industrial purposes.

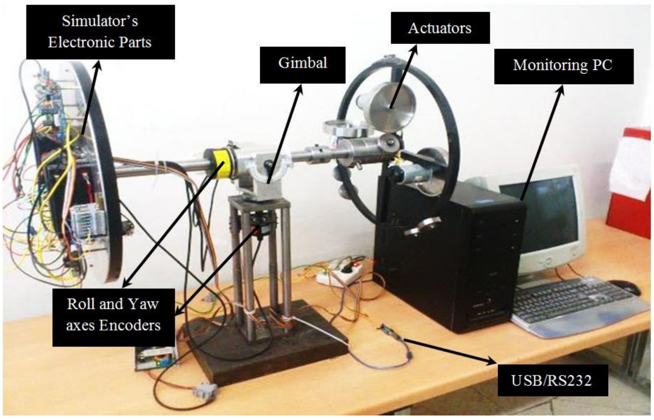

Figure 1. AUT simulator [5]

In this paper, an adaptive control algorithm is designed and simulated to control the simulator in the desired paths and approximate the coefficients of friction forces in the bearings of the device.

2- Dynamics Equation of the Simulator

In order to achieve controlling the simulator in the desired paths, an adaptive control is designed and simulated. This adaptive control algorithm predicts the moments of inertias of simulator's body and coefficients of viscous friction model of simulator's bearings.

At the first step of designing this control algorithm, the dynamic equation of attitude simulator should be written in robotic form as follows:

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$$M(q)\ddot{q}+V(q,\dot{q})\dot{q}+G(q)+F(\dot{q})=\tau \tag{1}$$

This equation is manipulator's dynamics equation in the presence of friction. In this equation, $M(q)$ represents an $n\times n$ mass matrix, $V(q,\dot{q})$ is the Coriolis/centripetal vector, and $G(q)$ is the gravity vector.

Dynamics equation of the attitude simulator in the presence of friction in its bearings is defined by:

$$J\dot{\omega}+\left[\omega^{\times}\right](h_1+h_2)+I_w\dot{\Omega}+C\omega=0 \tag{2}$$

In this equation, J and I_w represent simulator and reaction wheel's moments of inertias; ω represents simulator's angular velocity and C is 3×3 diagonal matrix of coefficients of viscous friction and h_1 and h_2 are angular momentums of body and reaction wheels, respectively. To obtain robotic form of simulator's dynamics, Rodriguez parameters were used as simulator's kinematics equation.

$$\omega=G^{-1}(\sigma)\dot{\sigma} \tag{3}$$

Where

$$G(\sigma)=\frac{1}{2}\left(I_{3\times3}+\left[\sigma^{\times}\right]+\sigma\sigma^{T}-\left[\frac{1}{2}\left(1+\sigma^{T}\sigma\right)\right]I_{3\times3}\right) \tag{4}$$

and σ represents Rodriguez parameters. By inserting ω from Eq. (3) in Eq. (2) and doing some mathematical operations; the dynamics of simulators in the presence of friction (viscous friction model) in bearings is obtained in robotic form.

$$\begin{aligned}
&M(q)\ddot{q}+V(q,\dot{q})\dot{q}+G(q)+F(\dot{q})=\tau\\
&M(q)=G^{-T}JG^{-1}\\
&V(q,\dot{q})=-G^{-T}JG^{-1}\dot{G}G^{-1}-G^{-T}\left[h_1^{\times}\right]G^{-1}\\
&F(\dot{q})=G^{-T}CG^{-1}\dot{\sigma}\\
&\tau=G^{-T}\left[h_2^{\times}\right]\omega-G^{-T}I_w\dot{\Omega}
\end{aligned} \tag{5}$$

3- Designing Adaptive Attitude Control Algorithm

The dynamics equation is rewritten as follows:

$$M(q)\ddot{q}+V(q,\dot{q})\dot{q}+G(q)+F(\dot{q})=W\left(q,\dot{q},\ddot{q}\right)\phi \tag{6}$$

where W is an $n\times r$ regression matrix and Φ represents $r\times1$ vector of parameters. By assuming the moments of inertias of the attitude simulator and coefficients of viscous friction as unknown parameters, the adaptive control algorithm is obtained by the following equation.

$$\begin{aligned}
&\tau=\hat{M}(q)\left(\ddot{q}_d+K_V\dot{e}+K_Pe\right)+\hat{V}(q,\dot{q})\dot{q}+\hat{G}(q)\\
&+\hat{F}(\dot{q})
\end{aligned} \tag{7}$$

By performing some math operations error dynamics equation is obtained by:

$$\ddot{q}_d+K_V\dot{e}+K_Pe=\hat{M}^{-1}(q)W\left(q,\dot{q},\ddot{q}\right)\tilde{\phi} \tag{8}$$

In this equation $\tilde{\phi}=\phi-\hat{\phi}$ and the following expression is obtained for the adaptation law:

$$\dot{\hat{\phi}}=\Gamma W^{T}\hat{M}^{-1}(q)B^{T}PE \tag{9}$$

To simulate this control algorithm, the following values were chosen for parameters of attitude simulator.

Table 1. Exact and initial values of simulator's parameters

Parameters	Exact Value	Initial value
I_{11}	0.43	0.1
I_{12}	-0.0016	0
I_{13}	0.017	0
I_{22}	3.3	3
I_{23}	0.009	0
I_{33}	3.37	3
C_1	0.1	0
C_2	0.2	0
C_3	0.3	0

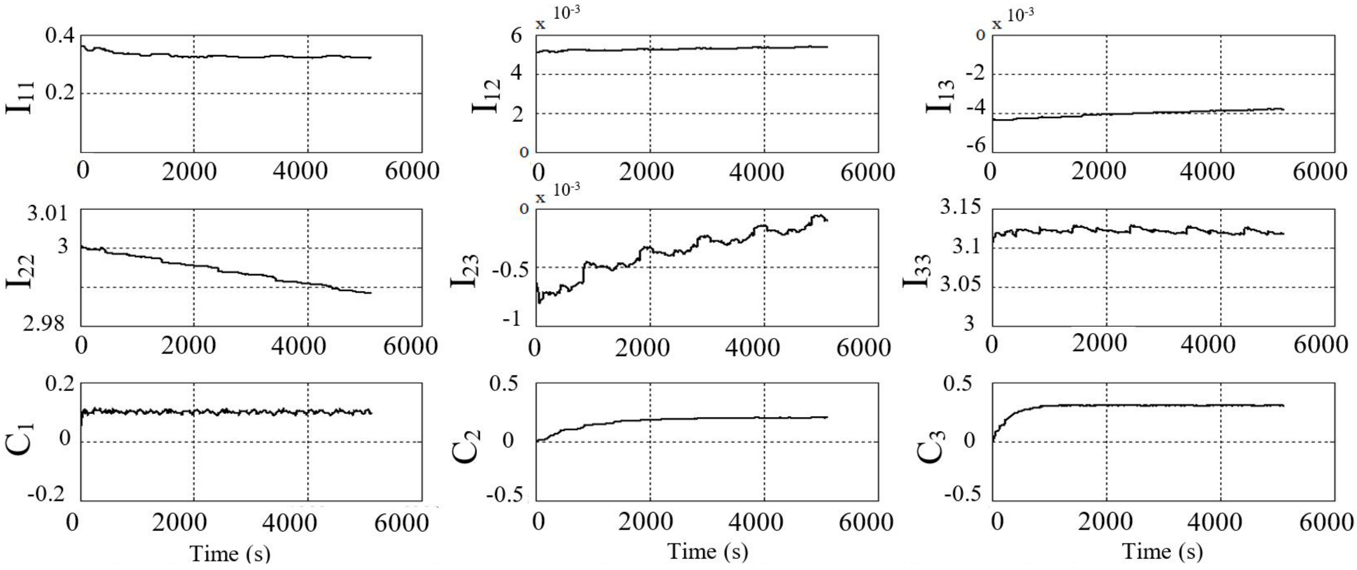

Figure 2. Estimated parameters of moments of inertias and friction coefficients of attitude simulator

After simulating the designed adaptive control algorithm, results were obtained for estimated parameters which are shown in Fig. 2.

As shown in Fig. 3, the attitude error is approximately 0.02 degrees which is an acceptable value for an attitude error.

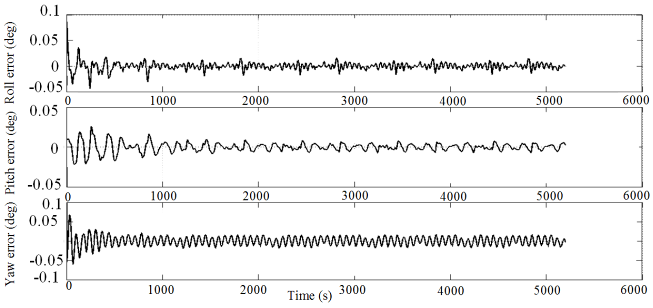

Figure 3. Simulator's attitude error

4- Conclusions

In this paper, the dynamics of Amirkabir University of Technology's attitude simulator was obtained in the robotic form and an adaptive control algorithm was designed afterward. This adaptive control algorithm is capable of estimating parameters such as the moments of inertias of the simulator and bearing's friction forces. Simulating the adaptive control algorithm shows that this algorithm is an appropriate algorithm to be implemented on the attitude simulator.

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