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New attitude control approach for satellites in elliptic orbits using solar radiation pressure

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Abstract

The paper proposes the use of solar radiation pressure for satellite attitude control in elliptic orbits. The system comprises of a satellite with two-oppositely placed solar panels. A simple approximate analytical approach has been adopted to develop control law for suitably rotating the solar panels so as to neutralize the adverse effect of eccentricity normally responsible for a considerable deterioration in the attitude control performance of the conventional passive or semi-passive methods. The detailed numerical simulation of the governing nonlinear equation of motion of the system establishes the feasibility of the proposed control strategy. The proposed controller is found to improve the satellite attitude performance significantly by simply rotating the solar panel by fraction of a degree only. Thus, the semi-passive nature of the proposed control strategy makes it attractive for future space applications requiring modest attitude accuracies.

1. Introduction

The attitude stability of satellites is of considerable importance for successful completion of a space mission. Unfortunately, even though a satellite may be precisely oriented in the beginning, it deviates in time from its preferred orientation under the influence of environmental torques caused by gravity gradient, solar radiation pressure, magnetic, aerodynamic, and free molecular reaction forces [1]. However, these forces if properly utilized may stabilize the attitude of the satellite instead of deteriorating it [2]. The solar radiation pressure (SRP) for attitude control of high altitude satellites and interplanetary probes has been proposed in several studies [3–26]. Various configurations such as trailing cone system [3], weathervane-type tail surfaces [4], reflector–collector system [5], corner mirror arrays [6], solar paddles [7], grated solar sails [8], and mirror-like surfaces [9–24] have been suggested for properly utilizing SRP torque. These concepts have been applied to sun-pointing satellites [7,8] and gravity-oriented satellites [9–24]. Spinning [6–13] as well as non-spinning satellites [14–24] were also considered. The attitude control of the satellite has been accomplished by translatory motions of single or several control surfaces relative to the satellite body [22–24] or by rotating the control surfaces about satellite body-fixed axes [9–21]. Some missions [25,26] have also been flown to verify these concepts. The Mariner IV mission employed solar vanes

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for achieving passive sun-pointing attitude [25]. The European Space Agency conducted experiments in which the attitude of the geostationary communication satellite OTS-2 was controlled by rotating solar panels [26].

The SRP control torque thus can be utilized to stabilize librational dynamics of a satellite with a desired degree of accuracy. However, if the satellites are in elliptic orbits, the amplitude of satellite attitude oscillations increases rapidly with an increase in eccentricity and the satellite attitude motion may become unstable even though there are no attitude disturbances initially. To overcome the adverse effect of eccentricity, Joshi and Kumar [23] applied the SRP to control the attitude of earth-oriented axisymmetric satellites by regulating translatory motions of the control surfaces relative to the satellite body. However, instead of applying translatory motions of the control surfaces, it would be easy if we can stabilize the satellite by the rotating control surfaces and that too if the angle of rotation is small on the order of a degree or fraction of a degree. Such investigations concerning the attitude control of satellites in elliptic orbits by rotating the control surfaces have not yet been discussed in the literature. In the present paper, we analyze this problem for an earth-oriented non-axisymmetric satellite. We assume satellites having favorable gravity gradient mass distributions as considered in [23].

The major contribution of this paper is the synthesis of open-loop control laws for suitably rotating the single gimbal solar panels to neutralize the excitation caused by eccentricity. The details of the proposed control strategy are discussed in Sections 2–4. The system model and its equations of motion in an elliptic orbit are presented in Section 2. The open-loop control laws using SRP are derived in Section 3. In Section 4, the numerical simulation is carried out for a detailed assessment of the proposed attitude control strategy. The effects of various system parameters as well as the Earth shadow on the performance of the controller are examined.

2. Proposed system model and equation of motion[1]

The system model comprises of a satellite with two-oppositely placed light-weight solar panels along the satellite Y-axis (Fig. 1). The system center of mass S lies on the center of mass of the satellite. The mass of the solar panels and other accessories are ignored. For the system under consideration, an orbital reference frame $S - X_o Y_o Z_o$ is chosen such that the Y_o-axis always points along the local vertical, the X_o-axis lies

[1] Nomenclature is given in the Appendix.

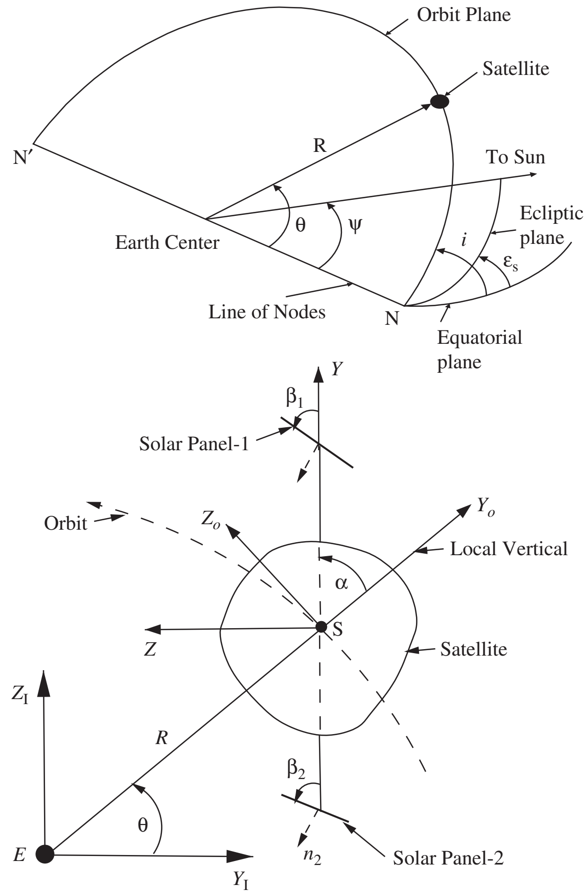

Fig. 1. Geometry of orbit motion and proposed solar controller configuration.

normal to the orbital plane, and the Z_o-axis represents the third axis of this right-handed frame taken. The corresponding principal body-fixed coordinate frame is denoted by $S - XYZ$. For solar panel-j, we consider its axis n_j initially aligned with the Z-axis is rotated by an angle β_j about the X-axis (normal to the orbit plane $Y - Z$). The solar panels are considered to be made of a highly reflective surface (i.e., $\rho_d = 0$; no absorption, specular reflection only). The distances between the system center of mass S and the center of pressure for both the solar panels are assumed to be the same and their cross-sectional areas facing the sun are equal.

For a satellite in elliptic orbit its pitch motion directly gets affected in the first order approximations as compared to its counterparts roll and yaw motions. As our focus in this investigation is to devise a control strategy to counter the adverse effect of eccentricity on the satellite attitude motion, we only consider the control of the satellite pitch motion by rotating the solar panels about the satellite pitch axis (normal to the orbit plane