ORBITAL MANEUVERS OF A LUNAR ARTIFICIAL SATELLITE, UNDER THE ACTION OF GRAVITATIONAL AND NON-GRAVITATIONAL PERTURBATION FORCES

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Abstract:

An artificial satellite orbiting the lunar surface is subject to disturbances that can cause changes in their orbital motion. These disturbances can be of gravitational origin, as the lunar gravitational potential and the gravitational attraction of other bodies, like the Earth and the Sun; or non-gravitational origin, like lunar albedo and solar radiation pressure.

All perturbations are studied, modeled and implemented in a simulator called Spacecraft Trajectory Simulator - STRS, which allows controlling the trajectory so that deviations and errors in the state variables are minimized.

The simulator operates with a few specific characteristics: considers a closed loop control system, operating in a discrete manner in order to reduce to the maximum the state errors (position and velocity), utilizing continuous low thrust. Thus, the state is determined and controlled at every simulation step to accomplish the orbital maneuver as required by the guidance subsystem.

The proposed work is divided into three stages: the first makes an analysis of the mentioned perturbations, aiming to study the magnitude of such forces and their ability to disturb the satellite and vary the orbital elements. In the second step, a calculation of an orbital maneuver is done by connecting the satellite from an initial position to the final desired position using the two point boundary value problem. A comparison is made between the situation in which correction maneuvers are performed by the control system in order to minimize perturbation effects and the situation where such corrections are not performed.

The orbital motion can be determined by solving Kepler's equation at each step defined as an input parameter in the simulator (STRS). Given a initial state, and a period of time by solving the inverse problem of a satellite positioning it is possible to determine the elements of the keplerian orbit. Using Kepler's equation the propagated elements are obtained. From the new keplerian elements, it is possible to obtain the state propagated, solving the direct problem of satellite positioning.

The lunar gravitational potential can be expressed by the expansion of normalized spherical harmonic coefficients, as a function of gravitational constant, of lunar equatorial radius, of distance from the satellite to the Moon, of the latitude and longitude and of the normalized Legendre associated polynomials.

The model used to study the lunar gravitational potential was presented by Konopliv. The model provides the components x, y and z for the gravity acceleration at each instant of time along the orbit of an artificial satellite, and allows considering the spherical harmonics up to degree and order 100. Through a comparison made between the gravity acceleration from a central field and the gravity acceleration provided by the Konopliv model, the velocity increment due to the perturbing term is obtained. The perturbing velocity increment is applied to the space vehicle, allowing, by means of the inverse problem, determine the keplerian elements of the perturbed orbit, so that an analysis is made of the orbital motion.

The dynamics of the movement of a n-body system, as well as the disturbing accelerations due to the gravitational attraction of the bodies, can be studied and derived from the Newton universal gravitation law. The gravitational attraction of the bodies is obtained from the equation of the gravitational potential due to the presence of the third body, as a function of the gravitational constant, of the third body mass, and of the position of the bodies.

The lunar albedo is the fraction of solar energy reflected diffusely from the lunar surface into space, measured from the Moon's surface reflectivity. This value can range from 0 (completely opaque) until 1 (completely brilliant) and depend of the surface conditions.

The perturbation model caused by the perturbations was based on the reflectivity of the Moon surface, due to variations in the lunar soil composition. The Moon's surface is divided into cells, whose dimensions and quantities may vary between a minimum of 1 cell (in which is considered the average albedo) and 51840 cells (in which each cell has one degree of latitude and 1.25 degree of longitude), to thereby study the solar radiation incident and *reflected by each cell. Each cell is assigned a reflectivity value, where 1 is the total reflection of the incident light and 0 is the total absorption, i.e. cells with similar color to white receive values close to 1, and cells with similar color to black receive values close to 0.*

Thus, to load the Moon's image, as well to make its division and assignment of reflectivity values for each cell, it is first necessary to modify the Moon's image to contain only color tones between black and white. Then a calibration of the Moon's figure was made, considering the image as a single cell, and adjusting the reflectivity exactly equal to the average albedo of the Moon, which is 0.12. The calibrated image was divided into cells and using a routine that provide the average of the pixels in each cell, a value corresponding to the albedo of each cell was determined and assembled into an array which represent the reflectivity of the surface of the Moon.

The perturbation model due to solar radiation pressure has been developed based on the albedo model. Considering that for the albedo model is necessary the modeling of the movement of the Sun, as well as the radiation that reach the spacecraft, and also the motions of the Moon and the satellite, some routines were implemented to provide these parameters to the albedo model and also to the solar radiation pressure model. However, it should be considered that the solar radiation reaches directly the satellite surface, instead of considering that solar radiation was reflected by the Moon's surface before reaching the satellite, such as considered in the albedo model.

In the proposed study, which analyzes the magnitude of the main disturbances that act on an artificial satellite around the lunar surface, was adopted an approach using the integration of forces alone, but simultaneously. Thus, the contributions of each disturbance are determined and then added to obtain the total disturbance acting on the satellite. Thus, it was possible to analyze the variation of the satellite orbital elements over the time. The control system used in the simulation was able to minimize the effects caused by disturbance, performing correction maneuvers and also performing the transfer maneuver, allowing analyses related to time and to the fuel consumption, for cases with an without correction maneuvers.

Keywords: *Astrodynamics, Orbital Maneuvers, Continuous Thrust, Perturbations.*