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Daily-repeat stereo monitoring from formation flying

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ABSTRACT

Three satellites in formation flying have the flexibility to monitor the target on the ground and the vicinity in the space, and can even achieve stereo view for any object. We consider each satellite orbit is slightly different with a daily-repeat circular Sun-synchronous orbit in the inclination, the right ascension of ascending node, the argument of perigee, and the mean anomaly. According to the linearized orbit equation, a formation of a tilted triangle with respect to the equatorial plane can be constructed. A Sun-synchronous formation is then obtained through a rotation. We investigate the maintenance cost through the evaluation of the delta-V for the triangle formation under perturbation by the PID autonomous control of the nonlinear equation of motion. With reference to the relative position with respect to the formation centroid, the formation configuration can be maintained with less delta-V.

1. Introduction

Solutions for daily revisit may have three categories: a GEO to continuously monitor for large events, a daily-repeat LEO to focally monitor for specific regions, and a constellation to intensively monitor for international cooperation [1]. For international cooperation to develop satellites, there are various scenarios for the roles and responsibilities, including breakdown in systems, components, manpower, cost, schedule, and data distribution.

Imaging satellites utilize optical, infrared, or radar sensors to conduct the Earth observations, which are now extensively applied to our daily life. In the beginning we considered one-satellite mission, which is required to implement with high-resolution sensors, short revisit cycle, and global coverage. Now we considered mission conducted with multiple satellites, which may be operated by same or different countries, to increase the spatial coverage and to reduce the revisit cycle. An example is the RapidEye mission using five satellites to achieve daily revisit [2], and another example is GEOSS to integrate the existing and planning satellites and related systems worldwide for the seamless Earth observations [3].

Three satellites in formation flying have the flexibility to monitor the Earth and the vicinity in space, and can even achieve stereo view for any object. We consider each satellite orbit is slightly different with a daily-repeat circular Sun-synchronous orbit in the inclination, the right ascension of ascending node, the argument of perigee, and the mean anomaly. According to the linearized orbit equation, a formation of a tilted triangle to the equatorial plane can be constructed. A near Sun-synchronous formation is then obtained through a rotation. We investigate the maintenance cost through evaluation of the delta-V for the triangle formation under perturbation by the PID autonomous control.

The linearized orbit equation governs the relative position of the satellite with respect to the reference object in small distance, and provides the exact solution for a circular reference orbit [4]. But it has constraints for general cases like eccentric reference orbit and oblateness effect, and it will be complicated to make transformation between the orbit reference frame and inertial reference frame. In this paper we consider the equation of motion in

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the inertial reference frame for each satellite in formation flying. The idea is original, and we investigate the control of formation flying in the inertial frame to avoid the tedious formulation in the linearized orbit equation.

2. Orbit parameters

According to the linearized orbit equation [5], a formation of regular triangle tilted at 60° with respect to the equatorial plane can be constructed from Fig. 1 like LISA mission [6].

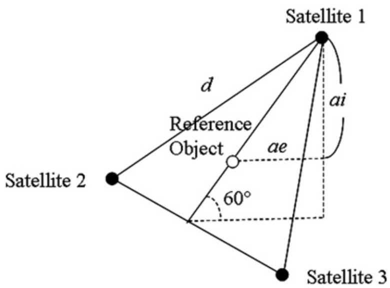

Fig. 1. Formation geometry from linearized orbit equation.

For a regular triangle, one has the following relations.

$$ae = d/(2\sqrt{3}), \quad ai = d/2 \tag{1}$$

Given the distance between the satellites d and the semimajor axis of the orbits a, the eccentricity e and the inclination i can be obtained.

The orbit parameters of the three satellites in the equatorial formation are selected as shown in Table 1, in which the semimajor axis a is 7272 km and the distance d is 1215 km. The three satellites are different in RAAN and mean anomaly only.

In this paper, we use the Earth centered inertial (ECI) frame XYZ, in which the origin is at the center of the Earth, Z points to North, X points to the vernal equinox, and Y completes the right-handed orthogonal system. The x,y,z are the components of a satellite's position in ECI, and the u,v,w are the components of its velocity.

Apply a rotation of 99.1° about X axis, and we can then have a near daily-repeat Sun-synchronous formation as shown in Table 2. The three satellites are different not only in RAAN and mean anomaly but also in inclination and argument of perigee. The 3D view of the equatorial formation and the Sun-synchronous formation are shown in Fig. 2, in which the normal vector of the triangle

Table 1
Orbit parameters of the equatorial formation.

Satellite	1	2	3
Mean motion (rev/day)	14.	14.	14.
Eccentricity	.04825	.04825	.04825
Inclination (degree)	4.785	4.785	4.785
RAAN (deg)	90.	210.	330.
Argument of perigee (degree)	90.	90.	90.
Mean anomaly (degree)	0.	240.	120.
Apogee altitude (km)	1245.	1245.	1245.
Perigee altitude (km)	543.	543.	543.

Table 2
Orbit parameters of the Sun-synchronous formation.

Satellite	1	2	3
Mean motion (rev/day)	14.	14.	14.
Eccentricity	.04825	.04825	.04825
Inclination (degree)	99.068	94.949	103.235
RAAN (deg)	4.846	357.601	357.544
Argument of perigee (degree)	180.766	299.706	59.524
Mean anomaly (degree)	0.	235.355	124.645
Apogee altitude (km)	1245.	1245.	1245.
Perigee altitude (km)	543.	543.	543.

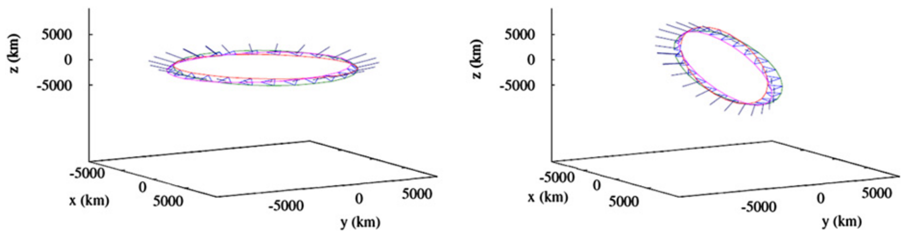

Fig. 2. 3D view of the equatorial formation (left) and the Sun-synchronous formation (right).