Study on the High Precision Relative Orbit Control Strategy for FFAST mission

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ABSTRACT

JAXA is planning the Formation Flying All Sky Telescope (FFAST) mission that will cover a large sky area in relatively high energy X-ray. It consists of two 300 kg class small satellites i.e. one is an X-ray telescope satellite and the other is a detector satellite. The two satellites fly on near circular orbits in which the detector satellite (Chaser) rounds near circularly around the telescope satellite (Target). Figure 1 shows the diagram of the relative circular orbit.

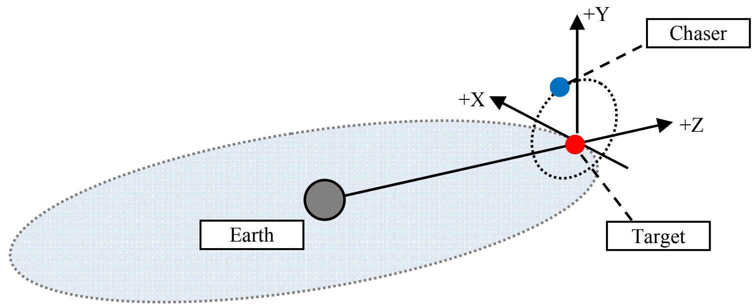


Figure 1. Diagram of the relative circular orbit

The relative distance between the two satellites is required to be kept within 20 m ± 5 cm. To realize the ultra accurate requirement within sufficiently small delta-Vs, a high precision relative orbit control strategy is constructed and proposed in this paper.

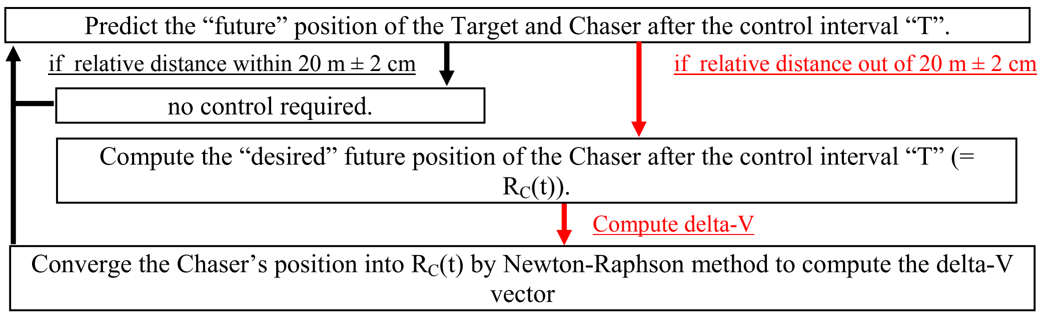


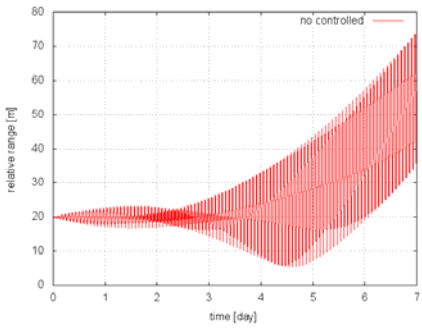
Figure 2. Flow-chart of the relative orbit control algorithm

Figure 2 shows the flow-chart of the main algorithm of the relative orbit control strategy constructed in this paper. In this algorithm, at first the "future" state vectors of the Target and Chaser after the pre-determined control interval "T", are predicted. If the relative distance between them is out of the pre-determined range i.e. 20 m ± 2 cm, the algorithm predicts the "desired" future position of the Chaser in the Target-centered rotational coordinate system (= $R^*_C(t)$) by computing the phase angle φ_T after the interval "T" in the relative circular orbit plane. The phase angle and the angular velocity of the relative circular orbit ω^* are described as follows;

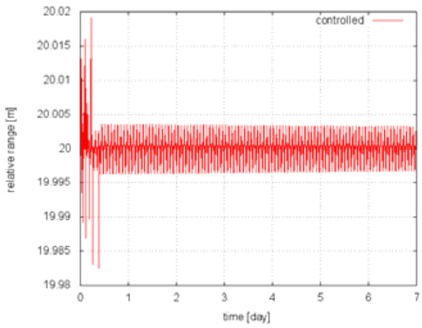
$$\varphi_T = \omega^* T + \varphi_0 \qquad\qquad \omega^* = k\frac{\omega_T + \omega_C}{2}$$

where φ_0 is the phase angle at initial time of control, "k" is a constant, ω_T and ω_C are angular velocity of the Target's and Chaser's orbit, respectively. In this algorithm, the total amount of delta-Vs for the formation keeping is highly sensitive in the control interval "T" and the constant "k". In this paper, the "T" and "k" are found through heuristic approach as follows; T = 300 seconds, k = 20.05/20. The computed "desired" future position of the Chaser in the rotational coordinate system is then converted into the Earth-centered inertial coordinate system (= $R_C(t)$). The delta-V vector for the formation keeping is computed by the Newton-Raphson method in which the delta-V vector is found by converging the Chaser's position into the "desired" future position by controlling the three velocity components of the Chaser.

The aforementioned algorithm is evaluated under "real-world" dynamics which include the perturbed forces caused by the Earth's oblateness i.e. J_2, the air drag, the solar radiation pressure and the disturbing forces by the other celestial bodies i.e. the Sun and Moon. For the calculation of the air drag, Harris-Priester air density table of $F_{10.7}$ = 250 is used. Besides, the eccentricity of the orbit into which the two satellites are injected is not zero i.e. 0.003 which is derived from the specification of JAXA's Epsilon rocket. The altitude of the satellites is 550 km, and the inclination is 31^o. The control interval "T" is set to 300 seconds.



a) no control



b) controlled

Figure 3. Relative range

As you can see, the relative range increases up to about 70 m by the perturbations, especially by the air drag. On the other hand, the relative range of the "controlled" case is within the range of 20 m ± 2 cm, which satisfy the FFAST's mission requirement. The total amount of delta-V for one-year formation keeping is about 13.4 m/s/yr, which is sufficiently small value. Further improvements are anticipated through setting optimized "T"and "k" through optimization approach.