Spacecraft Autonomous Navigation for Formation Flying Earth Orbiters Using the Global Positioning System

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ABSTRACT

This paper extends earlier analysis for computing maneuver times and magnitudes autonomously for Earth orbiting spacecraft with a groundtrack repeat requirement [1]. By analogy, nearly identical autonomous navigation strategies can be used for two spacecraft flying in formation. Tracking and orbit determination functions are performed using the Global Positioning System (GPS) and spacecraft along track separation drift behavior is examined with a simple empirical model todeduce required maneuver limes and magnitudes. Thus, this technique dots not require the conventional tools of orbit determination (i.e., numerical integrator for state/state partial propagation and Kalman filter for observation noise filtering). The simplified empirical model also reduces the complexity of the orbit propagation /prediction task required by the maneuver decision and design functions.

Simplifying and automating routine spacecraft operations is increasingly desirable to reduce space science missions costs. This paper presents a simplified approach to autonomously navigate Earth orbiting spacecraft flying in near circular orbits with a minimum along track separation of approximately 10 km. This technique is a candidate for validation in NASA's New Millennium Earth-1 mission to demonstrate autonomous navigation of a low cost land imaging spacecraft. The New Millennium spacecraft will fly in formation with LANDSAT-7 to validate a new lightweight, low cost imaging, system.

Elements of this autonomous navigation system include: Global Positioning System (GPS) tracking and orbit determination, maneuver decision, maneuver design, and maneuver implementation. This memorandum proposes a strategy encompassing all elements except the maneuver implementation function.

Tracking System and Orbit Determination

For [his simplified autonomous navigation strategy, only the spacecraft position is required; thus, the minimum set of observations consists of four simultaneous GPS pseudorange measurements and the GPS space vehicle ephemerides. Point position solutions (navigation solutions) are obtained with a least squares adjustment of the observations to produce estimates of the spacecraft Earth-Fixed cartesian position and GPS receiver clock offset.

GPS provides two levels of service: a Standard Positioning Service (SPS), available to all users on a continuous, worldwide basis with no direct charge and an encoded Precise Positioning Service (PPS) intended primarily for military use. SPS is intentionally degraded with a process called Selective Availability (SA) and has an advertised positioning accuracy of 100 meters horizontal and 140 meters vertical (95 percent probability) [2]. For TOPEX/Poseidon, the three-dimensional accuracy of the navigation solutions using SPS is 60 to 70 meters RMS over 1 day.

An important aspect of this simplified method is to use the along track separation for maneuver parameter determination. Along track separations between the GPS navigation solutions and a truth models are expected to be accurate to approximately 50 meters RMS over 30 days.

Maneuver Decision and Design

For the planned New Millennium Earth-1 mission, an along track separation from the LANDSAT-7 spacecraft is expected to be maintained to ±10 kilometers. Fig.1 shows a simulated history of the LANDSAT to New Millennium along track separation. An important feature to note is the quadratic nature of the change in the along track separation. Between each maneuver, a quadratic (2nd degree polynomial) fit to the along track separation produces an empirical model that can be used to predict the next maneuver time and magnitude. This behavior has been noted for use in more complex formation flying control algorithms [3].

Maneuver times are computed by propagating the quadratic and monitoring the forward and aft boundaries for violations. By examining the maximum forward excursion of the groundtrack from the quadratic model the maneuver magnitude can be optimized to maximize the time interval between maneuvers

Conclusions

A simplified approach to autonomously computing maneuver parameters for two spacecraft flying in formation, at an approximate separation of 10 km, appears to be feasible. This approach will provide for faster and cheaper development and operations costs to support formation flying science missions.

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References

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Fig. 1 - Simulated Along Track Seperation of Two Spacecraft Flying in Formation