PRECISION CLOSED-LOOP ORBITAL MANEUVERING SYSTEM DESIGN AND PERFORMANCE FOR THE MAGNETOSPHERIC MULTISCALE FORMATION

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Abstract: *The Magnetospheric Multiscale (MMS) mission is the fourth mission of the Solar Terrestrial Probe (STP) program of the National Aeronautics and Space Administration (NASA) which launched on March 13, 2015. The MMS mission consists of four identically instrumented spin-stabilized observatories that function as a constellation to provide the first definitive study of magnetic reconnection in space. The need to maintain sufficiently accurate spatial and temporal formation resolution of the observatories must be balanced against the logistical constraints of executing overly-frequent maneuvers on a small fleet of spacecraft. These two considerations make for an extremely challenging maneuver design problem—one that is explored in depth in several companion papers submitted to this conference. The current text focuses on the design elements of a 6-DOF spacecraft attitude control and maneuvering system capable of delivering the high-precision adjustments required by the constellation designers. Specifically, the maneuvering control-system flown on MMS utilizes a micro-gravity resolution accelerometer sampled at a high rate (100 KHz) in order to achieve closed-loop velocity tracking of an inertial target with arc-minute directional and millimeter-per-second magnitude accuracy. Techniques for correcting of bias-drift, sensor-head offsets, and centripetal aliasing in the acceleration measurements are discussed. The nature of the on-board pre-maneuver calibration and compensation algorithms are explained and demonstrated with both simulated and flight-recorded data.*

Compounding some of the difficulties in precise pointing and maneuvering is the arrangement of the MMS instrument suite. The observatories consist of no less than eight independent deployable booms—six radial and two axial—the most striking of which are the four symmetric Spin Dual-Probes (SDP) deployed on independent 60-meter tethers. The SDP utilize the gyro-dynamics of spacecraft spin (nominally 3.1 RPM) to both deploy and maintain their relative positions. New analytical expressions are derived and presented for an effective dynamic system suitable for on-board processing. Attitude and rate estimates are generated using measurements from four independent star-camera heads and combined efficiently in a (gyro-less) Multiplicative Extended Kalman Filter developed for the mission. The use of thrust-feedback for improved rate estimation, an iterative (predictor-corrector) targeting scheme, and an interleaved 6-DOF momentum/velocity controller are also covered in depth.

Due the complexity of multi-body response to discrete pulse-width-modulated thrusting, Monte Carlo analysis methods were essential to the design process. Specific instances of how these tools helped to refine the design by exposing modeling, algorithmic, and implementation flaws are given. A proper sampling size is established, and systemic/quasi-static biases are carefully delineated from other error sources. Both simulation and flight results are used to demonstrate the effectiveness of implementation approximations, and highlight some of the critical design sensitivities.

Keywords: *Formation flying, maneuver/attitude dynamics, determination and control.*