GOES-R ORBIT AND INSTRUMENT ATTITUDE DETERMINATION

Bruce P. Gibbs[(1)]**, James L. Carr**[(2)]
[(1)(2)]*Carr Astronautics Corporation, 6404 Ivy Lane, Greenbelt, MD 20770, (301) 220-7344, bgibbs@carrastro.com*

Keywords: *satellite orbit, instrument attitude, Kalman filter, GOES-R*

ABSTRACT

The current generation of Geosynchronous Operational Environmental Satellite (GOES), designated the NOP series, continuously provide visible and infrared images of the earth that have become essential for weather forecasting, storm tracking and meteorological research. To be useful for these purposes, all images provided by the imaging instruments must appear as if they were obtained at a fixed point in space relative to the earth, and the images must have a fixed attitude alignment with respect to the earth. GOES defines the reference position as a fixed longitude on the equator at the geosynchronous radius (~42164 km), with image origin nadir-aligned and E/W image axis parallel to the equator. Obviously, real satellites and imaging instruments cannot maintain this ideal position and attitude throughout the day, so it is necessary to first accurately determine actual pixel locations on the earth as a function of time (using best estimates of orbital position and image orientation), and then to adjust the received image pixels so that they appear as if obtained at the reference position (image registration). In the legacy GOES NOP system, this Image Navigation and Registration (INR) is performed partially on the ground and partially onboard the satellite, but it will be performed entirely on the ground in the GOES-R series, expected to be first launched in 2016.

The GOES NOP system uses three types of measurements to estimate the satellite orbit and instrument attitude: observed imaging angles to known stars and to known earth positions (landmarks), and 2-way ranges between the ground antenna and satellite. The term "instrument attitude" refers to multiple parameters that define the instrument boresight and rotation: this attitude includes the orientation of satellite relative to the reference attitude, and the effects of internal and external instrument misalignments. All orbit and attitude parameters are time-varying with a dominant diurnal pattern -- caused by orbital dynamics and instrument thermal deformation driven by spacecraft attitude with respect to the sun. For reasons explained in references, the star observations are only a function of instrument attitude, the range measurements are only a function of satellite orbit, and the landmark measurements are a function of both orbit and attitude (O&A). Thus inclusion of all three measurement types in a coupled O&A least squares solution provides high accuracy estimates of the O&A state variables, which include parameters defining the approximately-diurnal model. Those O&A state variables, updated daily, are then used to perform INR for the distributed GOES product images.

The GOES-R series differs in several respects from the NOP series. First, GOES-R will perform image registration in ground software rather than onboard the spacecraft. That is, all GOES-R Advanced Baseline Imager (ABI) detector radiance samples are first "navigated" to determine the observed position on the earth, and then a resampling kernel is applied to small blocks of

pixels to compute the pixel radiance at fixed grid intersections in the reference coordinate system. The satellite orbital position is computed onboard the satellite (from GPS signals), and then sent to the ground as telemetry. Thus the orbital coordinates used for INR are computed independently of star, landmark and range measurements. The time-varying ABI attitude states are computed on the ground in a Kalman filter using ABI star measurements. Spacecraft high-rate angular rate samples are also telemetered to the ground to allow the Kalman filter (and image resampling) to follow spacecraft attitude changes between star observations. To summarize, GOES-R ABI INR is performed on the ground using orbit parameters provided by the spacecraft, and ABI attitude parameters derived from star measurements. Landmark measurements are not used operationally for INR purposes.

The GOES-R approach to image INR has not been previously used for an operational satellite, so there is some risk that either the onboard orbit or the star-based attitude may not be as accurate or reliable as expected. To mitigate this risk and to provide a post-launch analysis capability for anomalous behavior, INR O&A software is included in the GOES-R ground system. This is similar to the GOES NOP Orbit and Attitude Tracking System (OATS) in that star, landmark and range measurements are used to estimate O&A states, but GOES-R continuously (for life of mission) solves for those states using a Kalman filter, rather than using batch least squares. This is practical because the ABI is thermally more stable than the GOES NOP Imager, the spacecraft provides high-rate angular rate measurements to the ground, landmark measurements are computed using L1beta image data (obtained before image resampling), and a stochastic model of ABI misalignments that handles both non-eclipse and eclipse cases was developed.

The INR O&A software provides:

1. A solution for spacecraft orbit that is independent of the GPS-derived onboard orbit solution. The accuracy is expected to be comparable to that of the onboard solution, so it can be used to validate the onboard solution, or if necessary, it can be used as a backup for operational INR purposes.
2. A solution for ABI attitude that is based on both star and landmark measurements, so it should be more accurate than the operational star-based attitude. The INR O&A attitude can be used to validate the operational attitude.
3. Insight on anomalies based on differences between orbit solutions or attitude solutions.
4. The coupled orbit and attitude solution using three data types provides some observational redundancy that will allow insight into operational problems caused by anomalous behavior of components. Furthermore, measurement residuals of the Kalman filter have well-defined statistical characteristics determined from the underlying models. Discrepancies between actual and expected residuals provide much insight on problem sources.
5. An interactive graphical workstation application allowing what-if analyses.

To summarize, the GOES-R INR O&A system is a novel implementation that provides a backup source of orbit data, and also allows insight on operational INR problems during post-launch testing.