IMAGE NAVIGATION AND REGISTRATION IMPROVEMENTS USING GPS

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1. ABSTRACT

With recent advancements in GPS receiver technology, particularly the Navigation receiver from NASA-GSFC and TOPSTAR 3000 from CNES, it will now be possible to receive GPS signals at geostationary orbit. As INR (Image Navigation and Registration) requirements become tighter for the next generation weather satellites, due in part to increased spatial resolution, orbit knowledge will play a significant role in the pointing error budget. This paper presents a multi-sensor and multi-spectral approach to image navigation for the next generation geostationary weather satellite programs. The sensors include GPS and imaging radiometers. The science requirements for these programs are driving significant advancements in multi-spectral instrument design. These programs require increased angular resolution and increased radiometric resolution, with detector resolution on the order of 14 μrad.

2. INTRODUCTION

INR is comprised of image navigation, image registration and image co-registration. The objective of image navigation is to determine and control the parameters that influence the pointing of the line of sight (LOS) of the instrument in such a way that each pixel from each image is geo-located to within an accuracy comparable to the finest resolution of the instrument. Image registration is the relative alignment within the same image and from one image to the next. Co-registration is the relative alignment between radiometric channels. These instruments scan the full disk earth with a plane scan mirror mounted on a two-axis gimbal system. Very large focal plane arrays are needed to increase duty cycle and reduce the time needed to scan the earth. This paper examines a number of pointing disturbances, occurring under various scenarios, to the instrument's line of sight and evaluates the impact to pointing performance.

Table 1 shows the evolution in the INR requirements for the GOES program. GOES 8-12 was the first 3-axis spacecraft series procured by NASA for NOAA. (The first generation, GOES 1-7, was spin stabilized). To cope with the major spacecraft control system disturbances and the severe thermal environmental effects of the instruments, a novel Image Navigation and Registration (INR) System was developed by one of the authors [1] suitable for 3-axis controlled spacecraft. GOES-13, O, and P [2] series used star trackers and continuously operating gyros on board the spacecraft to meet more stringent INR requirements. GOES-R [3] using star trackers and continuously operating gyros on board the spacecraft and pixels remapping to a fixed grid were performed on ground instead of using Image Motion Compensation (IMC) onboard the Spacecraft to meet more stringent INR requirements. The fourth generation GOES will employ GPS. As a result of these developments, orbit knowledge and maneuver perturbations are playing a significant role in the pointing error budget for image navigation [4].

Table 1. INR requirements for three generations of the GOES program

Requirement	GOES 8-12 (μrad)	GOES 13, O,P (μrad)	GOES R (μrad)
Navigation Non Eclipse Eclipse	 112 N/A (Imager off)	 56 N/A (Imager on)	 21 32
Within Frame Registration	42	42	21
Frame-to-Frame Registration	28	28	16
Channel-to-Channel Registration	28	28	5.3
Line-to-Line Shear	28	20	5.3

4. APPROACH AND INNOVATIVE STEPS

An Extended Kalman Filter (EKF) is developed for integrating GPS measurements with star and landmark measurements derived from a imaging radiometer. The orbit and instrument attitude will be solved in a coupled fashion, an approach that was used on GOES 8-12 . The advantage of a coupled system is that the complete state vector can still be estimated when there are fewer than 4 GPS satellites in view [5]. This approach also guarantees that the orbit solution will be consistent with navigating the LOS of the instruments. At the geostationary altitudes, the application of GPS is due in part to receiver improvements that allow for side-lobe tracking, a finding that has been demonstrated in recent missions [6-8]. Satellites below the GPS constellation are guaranteed continuous tracking coverage, which allows for dynamic orbit determination without modeling the underlying physics. Since geosynchronous orbits are fairly benign, most of the forces can be easily modeled, with the exception of solar radiation pressure and spacecraft maneuvers. Thus, geosynchronous orbit determination has traditionally been geometric and not dynamic. However the next generation of weather satellites very well may require dynamic orbit determination, especially after orbit maneuvers. Recovery from orbit maneuvers must be quick and robust , since these satellites are used during critical periods of storm tracking. In this paper we explore the design of a EKF and evaluate its performance relative to a batch least squares filter using traditional S-band tracking observations.

5. PERFORMANCE EVALUATION

To evaluate the performance, an end-to-end simulation of the space and ground segments has been developed. For the space segment, important contributors to the image navigation performance are the spacecraft attitude control system (ACS) and the instruments. The baseline approach assumed for the ACS model will be a three-axis stellar inertial control system with zero-bias momentum. Disturbances from scan mirror stepping, solar array stepping, and reaction wheel jitter will be included. For the instruments, the main drivers that are included are optical thermal distortion, which directly influence the LOS pointing errors and scan mechanism control noise and jitter [10] . In addition the GPS constellation must be determined and propagated along with error models for the GPS orbit elements, ionosphere and troposphere, and receiver.

Ground system processing is included in the simulation and will specify models for the star and landmark measurement errors. The landmarks are derived from both the visible and infrared channels and are acquired at prominent features in the image (primarily coastlines but can also be taken at lakes and rivers) by the use of a similarity measurement between image sobel and the coastline map [11].

6. EXPECTED RESULTS

The simulation results will compare the image navigation performance of the EKF with a batch least squares filter, using traditional tracking measurements. The EKF will improve image navigation and increase the instrument's duty cycle. The approach will also be shown to be robust in recovery from orbit perturbations.

7. REFERENCES

[1] Kamel, A. A., "GOES Image Navigation and Registration System", SPIE Proceedings, Vol. 2812 (GOES-8 and Beyond Conference), August 1996.

[2] Slafer, L.,"The Next GOES Satellite Designed with Advanced Technology to Improve the Quality of NOAA's Weather Date", 85th AMS Annual Meeting, 12 January 2005.

[3] Ellis, K., Igli, D., Gounder, K., Griffith, P., Ogle, J., Virgilio, V., Kamel, A., "GOES Advanced Baseline Imager Image Navigation and Registration", P1.27, 5th GOES Users'Conference, New Orleans, January 2008, http://ams.confex.com/ams/88Annual/techprogram/paper_136060.htm

[4] Chu, D., et al., GOES-R *Stationkeeping and Momentum Management*, 29th Annual AAS Guidance and Control Conference , Vol. 125, 2006, pp. 277

[5] Crassidis, J. L., *Sigma-Point Kalman Filtering for Integrated GPS and Inertial Navigation*, IEEE Transactions on Aerospace and Electronic Systems, Vol. 42, Issue 4, 2006

[6] Moreau et al. *Preliminary results of the gps flight experiment on the high earth orbit AMSAT-OSCAR 40 spacecraft*. 25th Annual AAS Guidance and Control Conference , Vol. 111, 2002, pp. 45

[7] Ruiz, J., L., Frey, C., H., *Geosynchronous Satellite Use of GPS*, ION GNSS 18th International Technical Meeting of the Satellite Division, 13-16 September 2005, Long Beach, CA, pp. 1227

[8] Laurichesse, D., et al. *Use of GNSS-based pseudo-acceleration measurements and orbital constraints to initialize spaceborne receiver orbit solutions*, Journal of The Institute of Navigation, Vol.50, No.2, 2003, pp. 95

[9] van der Merwe, R., Wan, E., A., Julier, S., I., *Sigma-Point Kalman Filters for Nonlinear Estimation and Sensor-Fusion -Applications to Integrated*, AIAA Guidance, Navigation, and Control Conference and Exhibit, 16 - 19 August 2004

[10] Harris, J., Carr, J.L., Chu, D., *A Long Term Characterization of GOES I-M Attitude Errors*, Proceedings of the Flight Mechanics/Estimation Theory Symposium (Greenbelt, MD), NASA-Goddard, June 2001.

[11] Madani, H., Carr, J.L., Schoeser, C., *Image Registration Using AutoLandmark*, Proceedings of the 2004 IEEE International Geoscience and Remote Sensing Symposium, September 2004.