Twenty-Five Years of INR

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Abstract

Image Navigation and Registration (INR) is the engineering discipline that deals with the problem of calibrating and stabilizing image geometry, particularly in the domain of geostationary weather satellites where the term appears to have first come into use within the GOES program. GOES I-M represented the transition from spin-stabilization to three-axis control within the GOES program. A spin-stabilized spacecraft, with its large gyroscopic stiffness, is a stable platform for supporting challenging Earth-observation missions from geostationary orbit. Unfortunately, a telescope deployed on a spin-stabilized spacecraft looks towards the Earth only about 5% of the time. NASA and NOAA were justifiably concerned in the GOES I-M epoch by the idea of adapting what was essentially communications satellite attitude control technology to host precision-pointed scanning instruments and accorded special attention to these concerns within the GOES I-M specifications under the heading of INR. The technology and performance of INR systems have evolved considerably since then and the field has found application in a host of non-U.S. systems, including Meteosat, MTSAT, and COMS. This paper looks back at the field beginning with GOES I-M and traces its evolution through Meteosat Second Generation (MSG), MTSAT, COMS, and GOES N-P with advanced stellar-inertial attitude control. It concludes with an analysis of where the field is likely to be heading for the next generation systems, in particular, GOES-R and Meteosat Third Generation (MTG).

Introduction

INR is an acronym that stands for “Image Navigation and Registration.” INR started as just an acronym but has since developed into an engineering discipline on its own with particular application to geostationary weather satellites. The author does not know who first coined the term “INR.” Some of the pioneers in the field, including Dr. Markley, were polled for this article but no clear attribution has emerged. The term may have originated at NASA or NOAA within the Geostationary Operational Environmental Satellite (GOES) program at the time that the GOES I-M system requirements were being prepared or at Ford Aerospace (now Space Systems/Loral) and ITT, the industrial team responsible for the GOES I-M system where INR started emerging as an engineering discipline under the leadership of Dr. Ahmed Kamel. The term “image navigation” is known to have been used

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with NOAA polar weather satellites [1, 2] prior to or concurrent with GOES I-M, so it is possible that “INR” is derived from such usage. Using landmarks or “ground control points” to navigate spacecraft and register imagery to geographic reference frames certainly predates GOES I-M and references to such appear in early works of Dr. Markley [3–5] and others [6] and in the Landsat program [7]. This paper is titled “Twenty-Five Years of INR” because it looks back roughly twenty years, starting at the time when the GOES I-M system was being engineered, and examines how the discipline has evolved and the applications of INR. At the end, we consider how INR is likely to evolve over the next five years when America, Europe, and Asia start building their next generation weather satellite systems.

INR is essentially about calibrating, controlling, and stabilizing the geometry of images, particularly those captured from geostationary orbit (GEO). Those who have worked on other Earth observation programs that fly sensors in low-Earth orbit (LEO) may not recognize the term INR, but nonetheless should understand its concepts and should recognize its methods. Indeed, the author came to the INR field from the Landsat-4 program, where we spoke of “geometric correction” using photons-in-to-pixels-out models of the imaging system. This brings up the question of whether INR is really different enough from its LEO cousins as to merit its own name. Indeed, there are two features to the INR problem particular to a GEO weather satellite. First, there is an urgency to disseminate meteorological image data to the user community because of its importance for operational weather forecasting. Information about severe weather is only actionable in the present and becomes stale quickly. With lives and property at risk, all calibration processing that is needed to support the quality of end-user products must be completed in as close to real time as possible. Second, weather remote sensing from GEO is really akin to movie production, compared to LEO remote sensing, which is more akin to still photography. Weather is dynamic; tracking and quantifying this dynamism is important to the end users. We can say that INR enables multi-temporal products that are stable from frame-to-frame and in which the geographic locations of pixels are known with high accuracy. Navigation in near real time and multi-temporal stability are the two hallmarks of INR.

**INR Is Multidisciplinary**

INR engineering is inherently multidisciplinary simply because many aspects of the system contribute to overall INR performance (Fig. 1). While in detail the INR problem can be quite complicated, in principle it is simply following rays of light from points on the Earth to the focal plane of the sensor. Following step-by-step, an object on the Earth emits or reflects radiation, which travels to the GEO spacecraft in a time equal to the range to the object divided by the speed of light. The apparent direction of arrival of this light is modified when transformed into the satellite rest frame (a velocity aberration). The spacecraft orbit and the geographic position of the object obviously figure into this calculation. The orientation of the instrument, which is attached to the body of the spacecraft, involves the Attitude Control System (ACS). As light enters the instrument aperture, it is redirected by a scan mechanism that orients the field-of-view using a servo control system. As the light makes its way to the detectors on the focal plane, it may deviate from its nominal path as a result of various tilts of the optical components that can be calculated in a Structural Thermal Optical (STOP) analysis.