P2.34 GEOLOCATION OF THE GEOSYNCHRONOUS IMAGING FOURIER TRANSFORM SPECTROMETER (GIFTS) DATA

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ABSTRACT

The data to be acquired from Geosynchronous Imaging Fourier Transform Spectrometer (GIFTS) instrument, under development for the NASA New Millennium Program, presents a shift from the scanning approach to global coverage used almost exclusively by current and recent instruments. The focal plane array detector and the bore sighted CCD camera will cover the earth in 512 x 512 km sized "frames". The GIFTS sensor itself is equipped with servo-controlled pointing mirrors to help in the data acquisition process. We describe below the approach for the post-fact geo-location of the acquired data.

1. INTRODUCTION

First images of the earth from space by an orbiting spacecraft were taken by the Television Infrared Observation Satellite (TIROS) in 1960 (Figure 1), a frame camera (Stroud 1960; Fritz and Wexler, 1960). Subsequent weather satellites used a different technique to acquire the images, scanning instruments in polar or geosynchronous orbits with cross-track scanning (polar orbit) covering the earth through orbital motion, or letting spacecraft spin enabling a telescope to sweep West-East across the earth (GOES–1 through GOES-8) or scanning mirror in the telescope sweeping the earth (GOES-9 and later) and pointing of a telescope (geosynchronous orbit) in the North-South direction.

The imaging mode is generally critical in interpretation of the weather satellite imagery only through the acquisition time required to cover the globe and the process used to determine the earth location of the image data. Although there are many similarities, the process of navigation of images (forward and reverse coordinate transform between earth and image coordinates) is different for those acquired from framing cameras and those acquired from scanning instruments.

The data to be acquired from the Geosynchronous Imaging Fourier Transform Spectrometer (GIFTS) instrument, under development for the NASA New Millennium Program, presents a shift from the scanning approach to global coverage used almost exclusively by current and recent instruments and thus a different approach to the geolocation process. GIFTS will obtain interferograms with a 4 km/pixel at nadir, 128 x 128 Focal Plane Array. As conceived, the spacecraft carrying GIFTS will also carry a visible imager bore-sighted with the interferometer. The CCD will have a nominal 1 km pixel size at the sub-spacecraft point.

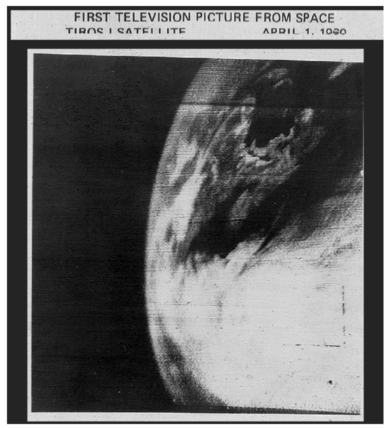

Figure 1. After more than four decades, the proposed GIFTS instrument will acquire earth observations with a framing camera again. This is the first television image of the Earth acquired from the TIROS I satellite on 1 April 1960. The spatial and digital resolution of the GIFTS will far exceed that of this image by acquiring an interferogram at each of its 128 x 128 pixels covering the spectral range from 4.4 – 15 µ. A bore sighted 512 x 512 Active Pixel Sensor CCD imager will obtain visible images in the 0.725 – 0.875 µ spectral band.

The focal plane array detector and the bore sighted CCD camera will cover the earth in 512 x 512 km size "frames". The GIFTS sensor itself is equipped with a servo-controlled pointing mirror to achieve spatial coverage through multiple frames by pointing the mirror to pre-selected locations such that the resulting frames achieve seamless coverage of the desired area. We

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describe below the approach for the post-fact geo-location of the acquired data and the software development effort we have undertaken.

2. GIFTS INSTRUMENT

The GIFTS instrument incorporates some novel features. For the first time that we are aware, a star tracker is being incorporated as a critical pointing component instead of relying on the mother spacecraft pointing information. As yet, it is not known which spacecraft GIFTS will get a ride on, except that it will be in a geosynchronous orbit. The incorporation of the star tracker provides real-time pointing information for the GIFTS instrument to maintain pointing over the duration of the interferogram image that can be as long as 10 seconds required for the mirror motion of the interferometer to traverse the path delay.

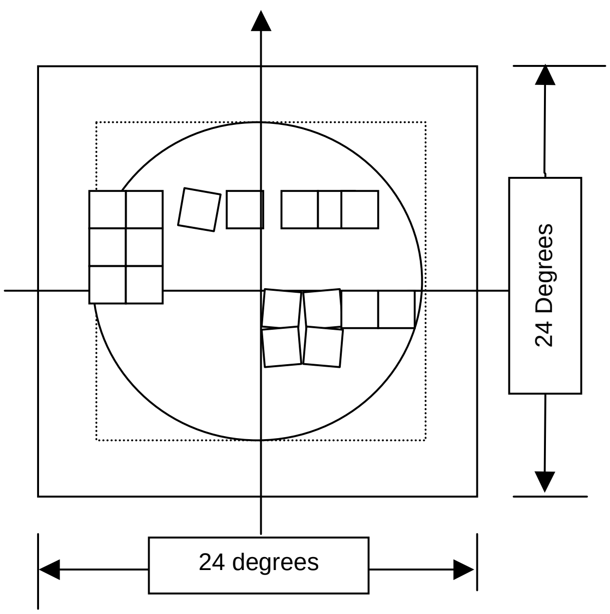

Figure 2. GIFTS instrument spatial coverage. The Field of Regard (24º x 24º) allows the Star Tracker to find stars in around the Earth for pointing updates. The "roll" angle of individual frames about the instantaneous pointing for some frames is exaggerated as is some overlap or underlap, whether intended or unintended. For clarity the frame size is exaggerated.

3. NAVIGATION MODEL

At this time, the GIFTS instrument is a work in progress. However, the geo-location task is general enough so that the basic navigation model can be defined and adapted once the final parameters are known. Figures 2 and 3 illustrate a schematic view of covering the visible disk of Earth from a known orbit with multiple frames of known angular size. The procedure for determining the geo-location of the GIFTS data frames is based on the following assumptions:

(1) GIFTS instrument is mounted on a three-axis stabilized spacecraft in a geosynchronous orbit, with the instrument pointed nominally at the earth center.

(2) The GIFTS instrumentation consists of a sensitive visible CCD imager (512 x 512), and a bore-sighted imaging Fourier Transform spectrometer with a 128 x 128 Focal Plane Array detector in two infra-red bands (long and mid), with the interferogram providing spectral radiances sampled at 2048 channels.

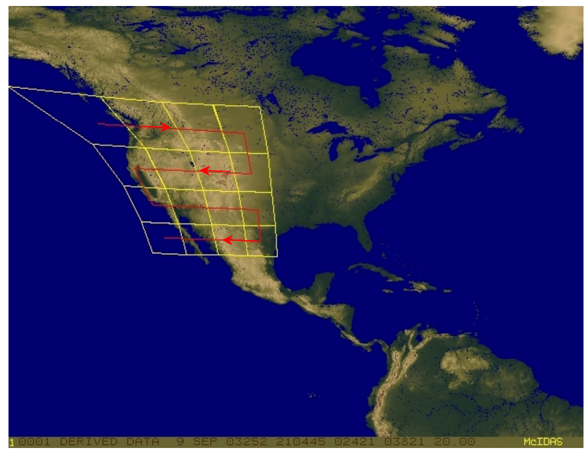

Figure 3. A typical GIFTS mapping sequence pattern for global or wide area coverage may use a 4 x 4 pattern for limited area. Larger areas can be covered by repeating this pattern or by increasing the frames.

(3) The optical design of the GIFTS instruments includes a 25 cm telescope with a 24º x 24º field of regard with a pointing mirror capable of focusing a nominal 512 x 512 km footprint (at nadir, equator) on the earth. The nominal resolution is this 1 km x 1 km for the visible CCD imager and 4 km x 4 km for the Imaging Fourier Transform Spectrometer (IFTS).

(4) The instrument pointing (frame center latitude and longitude) will be controlled by commands sent by a ground station to the S/C carrying GIFTS, and will be available as engineering data sent back with the observations.

(5) It is assumed that the instrument alignment with the spacecraft axes will be known prior to launch. Nominally it is assumed that the optic axis of the GIFTS at zero azimuth and elevation pointing mirror of instrument will be aligned with one of the axes of the spacecraft that will be pointed towards the nadir direction which will pass through the center of the earth.

(6) It will take approximately 10 seconds for acquisition of the interferometric data and an additional 1 second for pointing the dual-axis mirror (11 seconds per frame total).

(7) There are at least three different observation modes with different spectral resolution that permit acquisition of imaging and interferometric data at different frame rates to cover a region or the full visible globe. The overlap between adjacent frames is not yet determined or specified.

(8) The instrument pointing location and the UT of data acquisition will be available for each frame. The exact instrument alignment information will not be known until instrument checkout, but nominally, the targeted optic axis intersection with the earth (geographic latitude and longitude) will be known, and presumably this information will be contained in the data header.

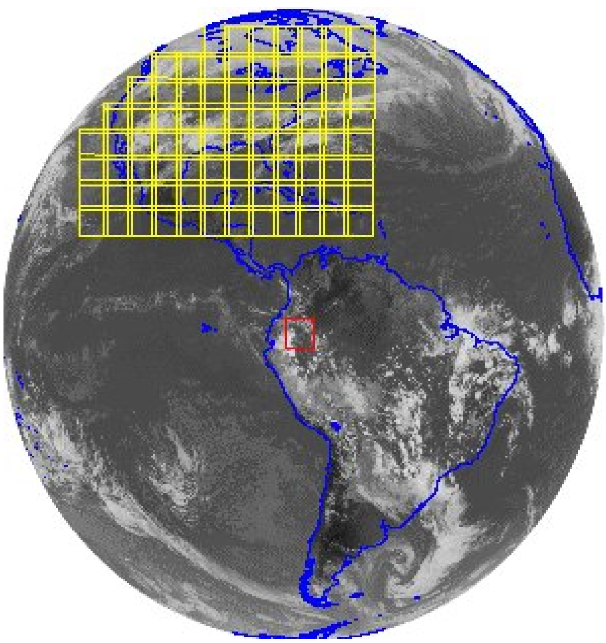

Figure 4. Simulation of the GIFTS coverage using GOES data as proxy. The positioning of adjacent frames in the individual “frames” is software programmable in the simulation of the GIFTS geolocation navigation software.

With this information, it is possible to simulate the GIFTS pointing and generate footprint patterns on the visible disk of the Earth and to understand potential spatial coverage issues (Figures 3 and 4) such as overlap/underlap, frame rotation, etc. For determining cloud or water vapor tracer motions, generally large area coverage, even full disk, is desirable. Since each frame of data can take as many as 11 seconds to acquire, the 25 x 25 frame pattern required to cover the full disk will take far longer than the current GOES (1.9 hours vs. ~ 10 minutes).

The seamless coverage of the visible disk of the Earth will rely heavily on the knowledge of the spacecraft orbit and instrument pointing. 25 rows of 25 frames will cover the entire visible disk of the Earth. Frame overlap, underlap, are not a problem for geolocation, but only for coverage through redundancy. However, overlap/underlap and frame rotation will impact the cosmetic appearance of the full disk mosaic by compositing individual frames. To generate a visually appealing full disk image, remapping each frame into a composite view is an option as illustrated later. It is understood that the pointing stability over the integration time for each frame is critical otherwise it would produce a smeared image. The current GIFTS strategy includes updating the mirror pointing at 100Hz from the star tracker in two orthogonal directions, but will not correct for roll angle.

<u>Software Development Approach:</u>

(1) In order to meet most potential challenges, the software for geo-location will be general enough to accommodate changes in orbital parameters for the GIFTS spacecraft and instrument specifications. It is assumed that Keplerian orbit information for the GIFTS spacecraft will be available from the GIFTS Project as needed.

(2) The term geo-location or navigation refers to the ability to convert data coordinates (line and sample number for either the CCD or the interferogram image) to earth geographic latitude and longitude, as well the reverse, converting the earth coordinates to data coordinates.

(3) The full disk or a regional "map" will be constructed from individual data frames for a given nominal time by remapping the data into a standard projection of the earth as desired. All of the interferogram channels will be mapped at the same time using the remapping algorithms that are in use (bi-linear splines and either nearest neighbor or average of nearest neighbor data values).

(4) In regions of overlap, there will be a choice of oldest data, latest data or an average. The frame number or the Space Craft Event Time (SCET) for each pixel will be saved as an additional pixel of information for each pixel of the output map.

(5) It is assumed that all data frames will have radiance calibration available and the output map will use these calibrations in the remapping and data merging process.

<u>Geo-location software capabilities needed</u>:

1. Determine the location of the GIFTS S/C in orbit for each time-tagged frame.
2. Determine the earth coordinates of the four corners and the center point of each (128 x 128 or 512 x 512) data frame from the pointing information.
3. Determine the sun and viewing angles for each pixel as needed.

4. Determine the footprint size of each pixel in sq. km

5. Support determination of cloud motion vectors

6. Software will be modular, utilize NAIF modules as much as possible and be able to support multiple environments provided they can interface to compiled FORTRAN or C libraries.

7. All code written shall meet NAIF standards and use revision control system or some acceptable control system.

8. Instrument bore sight offsets between the CCD and the IFTS will be utilized when known to determine congruency information.

9. Code to be developed will be capable of handling the following main sources of errors in geo-location:

   Instrument Optical (geometry) distortions (if any)

   Instrument/spacecraft pointing errors

   Spacecraft orbit location deviations from nominal values

In essence, the post-fact geo-location process is exactly the reverse of the one used to determine the GIFTS instrument mirror angles commanded from ground to cover a specific area on the earth with known latitude and longitude. This requires that the spacecraft location or ephemeris be known in advance. In an ideal situation, the pre-fact knowledge and the actual location of the spacecraft in orbit would be identical. In reality, as illustrated by the experience of the current operational GOES spacecraft, the actual position of the spacecraft in orbit varies noticeably from the predicted location, and hence the process of geo-location involves using the post-fact orbit information to determine the true location of the observations acquired. At this point how this information will be acquired is not known. If need be, the orbital position of the spacecraft can be refined from the measurements of landmarks or fiducial geographic reference locations seen in the image data as is done currently for GOES operations at the ground control facility of NOAA/NESDIS.

The GIFTS pointing is controlled by a bi-axial mirror, nominally assumed to be in a plane orthogonal to the s/c nadir direction, nominally pointed at the center of the earth. For the sake of simplicity, one of the axes about which the pointing mirror will scan the earth (east-west direction) can be assumed to be parallel to the earth rotation axis and in the plane normal to the nadir direction, assumed to be the optic axis of the CCD/IFTS telescope. The other axis about which the scan mirror will scan the earth (North-South) disk is normal to the E-W scan axis and in the plane normal to the nadir direction.

Any deviations in S/C and instrument pointing from this ideal geometry can be handled for the sake of geo-location through appropriate rotations or small angle corrections as the case may be. These deviations will affect the appearance of large area or global mosaic however as illustrated in Figure 3. With the GIFTS pointing mirror restricted to move in two orthogonal directions, the instrument is susceptible to roll angle changes about the optic axis of the instrument due to spacecraft motions that cannot be compensated for by the pointing updates from the star tracker. Fortunately, the impact of even relatively large roll angle changes of ~ 1 milliradian will amount to only about 0.5 km shift in the corners of an individual frame.

4. PROTOTYPE GEO-LOCATION SOFTWARE DEVELOPMENT

Although somewhat new for earth applications, the geolocation of data from framing cameras has been routinely done for planetary data and many software tools have been developed. We have previously developed tools for navigation of data from planetary images acquired from missions such as Mariner 10, Voyager and Galileo (Limaye, 1994). The Jet Propulsion Laboratory has also developed an excellent software toolkit that is particularly attractive for this purpose – the Navigation Ancillary Toolkit Facility (Acton, 1996). Given the NAIF Toolkit's capabilities and wide applications in solar system missions, we have chosen to use it as much as possible in the development of the GIFTS data navigation or geo-location software.

The test software has been developed in the form of library modules written in C that call specific NAIF navigational toolkit modules that perform the forward and reverse navigational transforms as well as other necessary geometry related functions. Spacecraft location is determined from "known" orbital elements and the approach is general enough to handle any known orbit, besides a near circular geosynchronous orbit. The NAIF navigational toolkit is being used extensively for navigational calculation as well as supplemental ephemeris data. Input requirements include; (i) orbital and attitude information for the satellite, (ii) the time that the image was taken, and (iii) instrument pointing mirror angles

Knowledge of telescope focal length, S/C alignment angles, offset with the CCD sensor will be required and obtained after assembly and is essential for geo-location. It is also anticipated that telescoping pointing information derived from the star tracker will be available, independent of the spacecraft pointing knowledge.

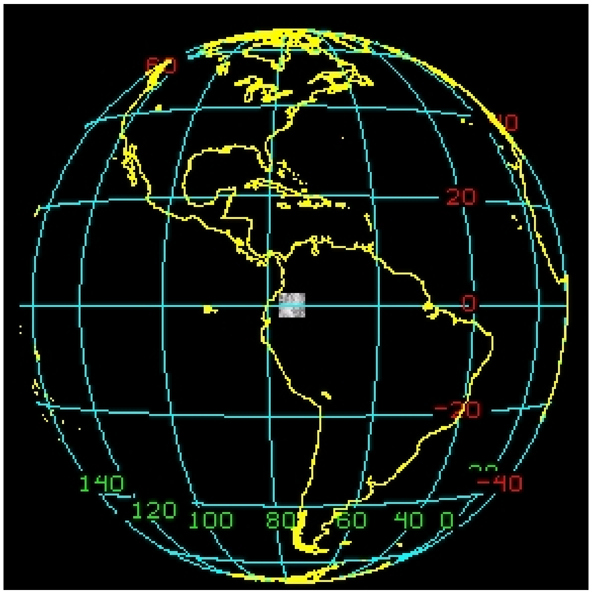

Figure 5. Simulation of the GIFTS navigation by substituting existing GOES images for GIFTS CCD imager and using the GIFTS navigation module. This shows a single frame acquired at nadir.

Currently GIFTS geo-location software tests are being done using the orbital parameters of the GOES-EAST spacecraft. The input of this information into the navigational software is being handled through a NAIF kernel text file but this method is expected to change, as more information concerning the operational functionality of the instrument/spacecraft is determined and is not integral to the operation of the software.

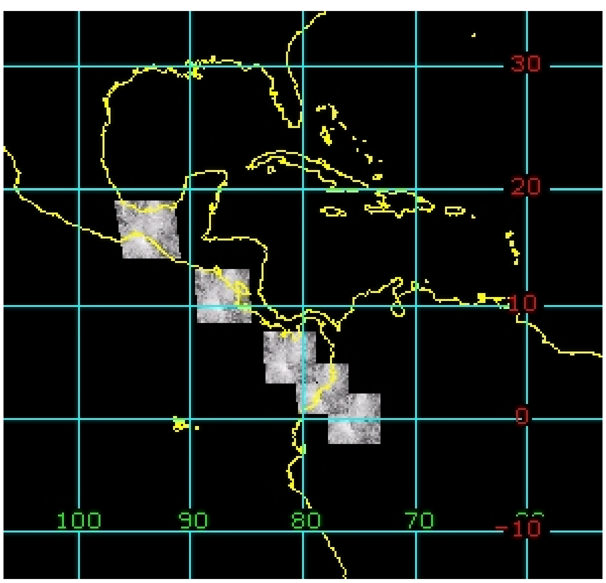

Figure 6. Remapped and merged simulated GIFTS frames into a single mosaic. The software can simulte random pointing errors as desired and for generating global mosaics.

A new navigation module specific to the GIFTS instrument was introduced in a McIDAS (Suomi et al., 1984) environment that enabled all the existing McIDAS applications to be readily used for GIFTS data.

Figure 5 was generated using McIDAS software and the new GIFTS navigational code. The square in the center of the image is a 128x128 pixel GOES-EAST image that has been modified to simulate GIFTS data. Figure 6 shows a set of five simulated GIFTS frames that have been merged into a single image file and remapped into a Mercator projection. The remapping and merging of the data was done using standard functionality in the McIDAS software package. This is a preliminary test and proof of concept for the methods that will be used operationally to merge multiple GIFTS images into mosaics that cover large areas.

SUMMARY

A model for geo-location or navigation of data from framing instruments has been developed by incorporating the NAIF toolkit that is available both in C and Fortran and has been used extensively in navigation of data from other solar system objects. The code for GIFTS is fairly general and can be readily adapted for operational use once the final instrument alignment and orbital parameters are known.

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