Acta Astronautica 118 (2016) 308–315

Contents lists available at ScienceDirect

Acta Astronautica

journal homepage: www.elsevier.com/locate/actaastro

MicroASC instrument onboard Juno spacecraft utilizing inertially controlled imaging

David Arge Klevang Pedersen*, Andreas Härstedt Jørgensen, Mathias Benn, Troelz Denver, Peter Siegbjørn Jørgensen, Jonas Bækby Bjarnø, Alessandro Massaro, John Leif Jørgensen

Technical University of Denmark DTU Space, Division of Measurements and Instrumentation Systems, Elektrovej 327, 2800 Kgs. Lyngby, Denmark

ARTICLE INFO

Article history:
Received 4 March 2015
Received in revised form
19 September 2015
Accepted 1 November 2015
Available online 10 November 2015

Keywords:
Juno
Earth fly-by
Star tracker
Attitude
Image processing

ABSTRACT

This contribution describes the post-processing of the raw image data acquired by the microASC instrument during the Earth-fly-by of the Juno spacecraft. The images show a unique view of the Earth and Moon system as seen from afar. The procedure utilizes attitude measurements and inter-calibration of the Camera Head Units of the microASC system to trigger the image capturing. The triggering is synchronized with the inertial attitude and rotational phase of the sensor acquiring the images. This is essentially works as inertially controlled imaging facilitating image acquisition from unexplored perspectives of moons, asteroids, icy rocks and planetary rings.

1. Introduction

The Juno spacecraft, one of NASA's New Frontiers missions, was launched on August 5th 2011 and set its course towards Jupiter, planned for arrival on July 2016. On the 9th of October 2013, en route to Jupiter, JUNO successfully executed the Earth fly-by (EFB) maneuver and gained velocity in order to reach Jupiter. When preparing for the Earth approach it was discovered that a unique opportunity to record images of the Earth and Moon system from afar presented itself. The Earth and Moon would enter the Field of View (FOV) of the micro Advanced Stellar Compass (microASC) Camera Head Units (CHU).

The effort to capture and process the raw image data from the microASC system during the EFB is presented in detail leading to a perspective of future possibilities for the microASC system.

2. The microASC instrument onboard JUNO facilitating inertial controlled imaging

The microASC system onboard Juno consists of four CHUs (denoted CHU A-D) and a double Digital Processing Unit (DPU). A detailed description of the system is found in [1]. The microASC system is a part of the magnetic field investigation package (MAG) onboard Juno [2] and is designed to autonomously deliver high accuracy attitude measurements of the magnetometers on the basis of stellar sky images, see Fig. 1. An overview of the Juno mission is given in [3]. For the purpose of performance analysis, the microASC instrument is capable of capturing and downloading images from any of the four CHUs for analysis on ground.

The Juno spacecraft is spin stabilized, rotating at approximately 2 rpm, so CHU D will only have Earth and Moon in the FOV during a small phase of the rotational sequence. Commanding CHU D to a very low exposure time meeting the expected brightness of Earth and Moon

* Corresponding author. Tel.: +45 45253609; fax: +45 45887133.
E-mail address: dakp@space.dtu.dk (D.A.K. Pedersen).

http://dx.doi.org/10.1016/j.actaastro.2015.11.001

prevents CHU D from delivering attitude solutions as no stars are detectable at this level of exposure.

There is a need to inertially control the triggering of image acquisition exactly when the Earth and Moon are in the FOV as well as knowing both the timestamp and attitude of the sensor at the time of capture. Utilizing the inter-calibration of the independent CHUs, CHU C is commanded to trigger the microASC system to acquire an image from CHU D at the correct phase of the rotation, once every 5 rotations. This setup ensures that the acquisition of the images occurs at the correct phase of the rotation as well as providing an accurate attitude estimate of CHU D when acquiring the image. The image acquisition with CHU D is based on the real-time attitude measurements from CHU C, operating as a fully autonomous inertially controlled imager. Onboard JUNO, the microASC system operates at 4 Hz. With the optical sensor being an analog interlaced video signal the time between the First Field (FF) and Second Field (SF) is 125 ms. Due to the spinning of the spacecraft the objects in the FF and SF will be offset corresponding to the angular motion of the CHU.

2.1. Integration time adjustment

The microASC system is specifically designed for star tracking with a very light sensitive sensor. Under normal operations the sensor will over bloom with Earth and Moon in the FOV. The microASC system however allows for adjusting the exposure time settings as a means of overcoming blooming effects. Commands to change the microASC exposure were sent to Juno during the approach. The time of execution are marked on Fig. 2 together with the trajectories of Earth, Moon and Juno during the EFB which are extracted from NAIF kernels [4]. From radiometric considerations and tests from a representative test environment appropriate exposure times could be estimated. Initially the integration time was set to 8 μs. As Juno approached Earth the area of the Earth and Moon in the sensor plane increases, thus increasing image artifacts correspondingly. To compensate for this, the exposure time of the sensor was reduced to 6 μs, and later to 4 μs. This level of exposure time was presumed the lowest feasible as the exposure time was affected by jitter in the synchronization pulse from the spacecraft to the microASC instrument, thus affecting the observed intensity of the objects. The fourth command adjusted the floor and ceiling parameters of the microASC's internal Automatic Gain Controller (AGC) effectively expanding the working range of the controller.

3. Image post-processing

The raw image data is influenced by the settings of the instrument being close to the absolute limitations of the sensor, leaving imaging artifacts in the data. These artifacts are described and corrected for in the post processing of the downloaded image data captured during the Earth fly by. The post processing is divided into five successive procedures:

- Cleaning of blooming and smear residuals.
- Matching of object intensity and sharpening of image, compensating for lens blurring.
- Warping of frames.
- Merging of frames.
- Conversion from grayscale to color.

The image artifacts and these five processes are described in detail in the following sections.

3.1. Image artifacts

Fig. 3 shows a typical case of a raw image from the fly-by data series. The figure shows smear residuals as distinct lines through the objects from top to bottom of the image. These lines become more prevalent as the area of objects increase. The smear residuals are divided into vertical lines and tilted lines. The vertical lines are caused by the blooming of a line segment of the sensor chip. The tilted lines are caused by photons tunneling through the light-shielded area of the sensor, constituting the vertical transfer register, as the bright objects move across the FOV during the readout of the image sensor. Furthermore objects in the FOV induce a ghost shifted upwards and slightly to the right from the position of the object itself. The presence of the ghost is due to the method used to synchronize the microASC to the spacecraft master clock, where the instrument's internal timing is halted, thus also halting the readout process. During the halted period photons from the very bright object leak through the light-shielded area to the vertical transfer register.

These image artifacts are not present under normal working conditions of the microASC. It is only present due to the very bright object in the FOV and the setting of a very low exposure time.

The process of cleaning the image for artifacts is initialized by subtracting the background level of the image. The level of the background is determined as the 50% fractile of the image histogram. Next the cleaning process is divided into three subroutines removing the tilted lines, vertical lines and the ghost.

3.1.1. Smear lines

The time delay of 0.125 ms between FF and SF results in a rotation of $\theta = 1.5^\circ$ around the spacecrafts axis of rotation ω as illustrated in Fig. 4. The offset of the objects between FF and SF depends on the position of the objects along the vertical axis (y axis) of the image, e.g. an object at the top of the image has a small offset from FF to SF as the object is close to the axis of rotation of the spacecraft.

The angle of the tilted smear line directly depends on the position of the object along the vertical axis of the image. The tilting of the line is thus smaller for objects at the top of the image than at the bottom. Each tilted smear line must therefore be treated independently. The line is removed by subtracting a 50% fractile profile of tilted columns from the region where the tilted line is present. The vertical smear lines are removed by the same method as the tilted blooming lines. Only the 50% fractile profile of columns is not tilted and is processed on the whole image frame without considering the position of the objects.