Caviar: a software package for the astrometric reduction of spacecraft images

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Introduction

Caviar is an IDL-based software package for the display and astrometric reduction of images taken by optical imaging cameras on spacecraft. The software will shortly be made available via the NASA PDS website: http://pds-rings.seti.org/cassini/iss/software.html .

The current version supports images recorded using the narrow and wide angle cameras (NAC and WAC) of the Imaging Science Subsystem (ISS) on the Cassini spacecraft. Future versions will support other space missions.

The package has two main functions:

- Correcting errors in the camera pointing direction
- Measuring the astrometric positions of natural satellites

A working version of the package has been in use since 2004 and has to date generated more than 12 000 published astrometric observations of the main and smaller inner moons of Saturn from Cassini ISS images. This work has included the discovery of new satellites of Saturn, such as Polydeuces (Murray et al. 2005) as well as recent work on the tidal evolution of the Saturn system (Lainey et al. 2016).

A graphical-user-interface (gui) allows images to be displayed with overlays showing reference star positions and positions of known satellites.

The various options and function parameters within the package may be selected on-screen via the gui (Figure1).

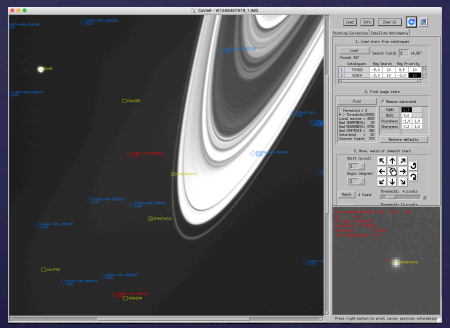

Figure 1

Positions of references stars used for the camera pointing correction are obtained using the Vizier online web-server. An active internet connection is therefore needed to run Caviar. Currently, the TYCHO2 and UCAC4 star catalogues are used.

The positions of known natural satellites are obtained from JPL ephemerides using the IDL version of the NAIF SPICE package (Acton 1996).

Camera Repointing

The nominal camera pointing direction from the star trackers on the Cassini spacecraft has a typical accuracy of approximately 10 NAC pixels (Figure 2). This nominal pointing orientation is encapsulated in a SPICE C-kernel and may be extracted as a C-matrix or quaternion.

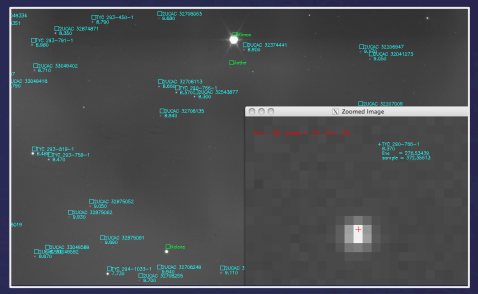

Figure 2

Caviar uses an iterative technique to improve the nominal pointing accuracy by comparing the positions of reference stars, taken from an appropriate star catalogue, to their imaged positions. After correction, an accuracy of the order of 0.1 NAC pixel can typically be achieved.

The positions of star-like objects in the images are estimated by locating gaussian-type signals, using the DAOPHOT 'Find' algorithm (Stetson, 1987). These imaged positions are then visually correlated with actual stars from a reference catalogue, and the pointing direction is iteratively adjusted until the catalogue positions match the imaged positions. The revised pointing direction, together with information relating to the reference stars used in the computation may be saved to a text file.

Satellite Astrometry

The second key function of the software is the measurement of the positions of any natural satellites present within a given image.

Two options are currently available:

- For unresolved satellites (such as the image of Epimetheus shown in Figure 1), a centroiding technique may be used. The algorithm is fundamentally the same as that used to measure the positions of stars during the camera repointing step.
- For fully resolved satellites (for example, the image of Enceladus in Figure 3), a limb-fitting technique is used.

The limb-fitting technique is a multi-stage process: firstly, the limb of the imaged satellite must be detected. Two algorithms are currently available: a simple gradient-based edge-detection algorithm, or the Canny algorithm (Canny 1986). Secondly, a model of the limb of the satellite is projected on to the image and the position of the model iteratively adjusted until it matches the position of the imaged limb. The astrometric position of the centre of the satellite is then taken to be the centre of the adjusted shape model.

Currently, shape models are obtained from the SPICE software package in the form of triaxial ellipsoids, projected on to the image. Plans for future development include the option to use irregularly-shaped digital terrain models, when available.

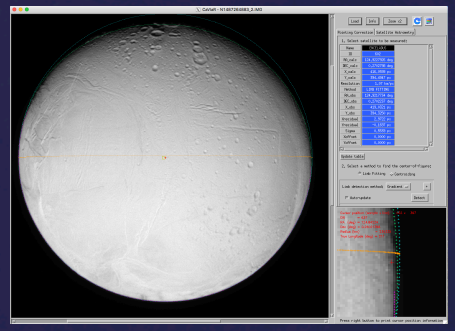

Figure 3

Observed-minus-computed residuals for Cassini ISS SATELLORB and MUTUAL EVENT image sequences, processed using the Caviar software, are shown below in Figure 4. Mean line and sample residuals are 0.14+/-0.82 and -0.09+/-0.66 pixels, respectively. The mean image resolution is approximately 13.4 km/pixel.

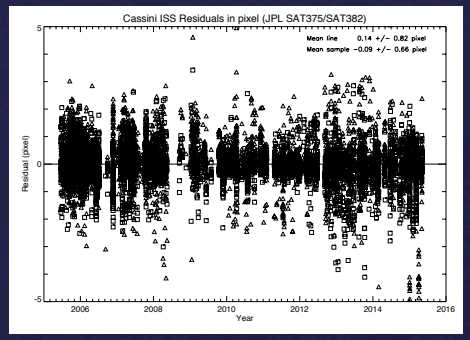

Figure 4

Future Development

The first release of the software via the NASA PDS website will have functionality for Cassini ISS images. Future planned developments will include:

- The ability to process images from other space missions, including: New Horizons, Galileo, Voyager 1 and 2, Mariner 9 and Viking
- Option to use digital terrain models for satellite limb-fitting
- Sub-pixel limb detection
- Batch processing
- Reference star positions from the GAIA catalogue, when available

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References

Acton, C. H. 1996. Ancillary data services of NASA's navigation and ancillary information facility, Planet. Sp. Science, 44, 65-70

Canny, J., 1986, A Computational Approach To Edge Detection, IEEE Trans. Pattern Analysis and Machine Intelligence, 8(6):679–698, 1986

Murray, C.D., Cooper, N.J., Evans, M.W., Beurle, K., 2005. S/2004 S 5: A new co-orbital companion for Dione, Icarus, 179, 222-234

Stetson, P.B., 1987, DAOPHOT - A composite program for crowded-field stellar photometry, Pub. Astron. Soc. of the Pacific, 191-222

V. Lainey, R. A. Jacobson, R. Tajeddine, N. J. Cooper, C.D. Murray, V. Robert, G. Tobie, T. Guillot, S. Mathis, F. Remus, J. Desmars, J-E Arlot, J-P De Cuypers, V. Dehant, D. Pascu, W. Thuillot, C. Le Poncin-Lafitte, J-P Zahn, 2016, A new constraint on Saturn's tidal parameters from astrometry with Cassini data, Icarus, submitted