Stereo Data Products, DTMs Orthoimages and Anaglyphs

Stereophotogrammetry is a time intensive image processing technique that can be used to generate terrain models from stereo-image pairs and then orthorectify the stereo-images. The technique requires careful data preprocessing, sophisticated software, specialized training, as well as considerable computing and human-operator resources. The goal when developing stereo-image products is to create the most accurate terrain model as possible. Creating stereo-image products is intended to increase scientific productivity by making valuable data publicly and freely available that would be difficult for the average scientist to produce.

The acronyms DTM (Digital Terrain Model) and DEM (Digital Elevation Model) are used interchangeably in the literature to describe raster data products that provide elevation as a function of geospatial extent. We use DTM to describe our gridded elevation data products throughout this document. DTMs are Level 4 derived products stored in PDS IMG format. DTMs are derived from a set of stereo-images that have comparable resolution and illumination, using ISIS and SOCET SET stereo-photogrammetry software. Values of elevation are extracted every ~ 4 pixels, depending on the stereo strength of the image set and are controlled to OLA altimetry data. Elevation is reported in units of meters from either the body center or relative to a predefined planetary geoid. DTMs are generated from both MapCam and PolyCam stereo-images for up to 2 candidate sample sites from Reconnaissance imagery.

An orthoimage (or orthophoto) is an image that has been geometrically corrected ("orthorectified") such that scale is as uniform as possible. Orthoimages are Level 4 derived products stored in the Map interchange FITS file format. Orthographic rectification uses topography measurements (e.g. DTMs) to reproject images as though they were taken at nadir conditions, thereby removing any distortion due to topography, oblique camera angles, or artifacts of lens distortion. The uniform scale allows orthoimages to be used as map products when latitude/longitude information has been associated with each pixel. Orthoimages are generated from each stereo-image in a set according to the highest resolution DTM. Orthoimages are produced from MapCam and PolyCam stereo-images for up to 2 candidate sample sites from Reconnaissance imagery and are paired with a DTM.

Overview

What is the Data Type?

- Digital terrain models
- Orthoimages
- Anaglyphs

What MRD does this data product satisfy or contribute to satisfying?

None at present time.

What observations are required to provide the input data needed to make the data product

PolyCam and MapCam panchromatic images acquired during Reconnaissance for the candidate sample sites at 2 cm resolution.

What is the spectral and/or spatial resolution of this data product?

The required spatial resolution < 2 cm for the 2 site-specific panchromatic mosaics from Reconnaissance for > 80% of a 2-sigma TAG delivery error ellipse.

When in the DRM are the observations that make the data product scheduled to be taken?

Reconnaissance

How long does it take to produce the data product?

A single set of stereo data products (DTM and companion orthoimages) can take anywhere from 1 day to 1 week to generate depending on the number of stereo-images in the set, and the quality of the stereo strength of the images.

Is this product used for sample site selection, science value, or long term science?

Long-term science.

Observation Requirements

Stereo-images must be acquired under the right geometric conditions to be useful. These conditions are well described by the attached "Criteria For Automated Identification Of Stereo Image Pairs" by Becker et al.

Data Product Structure and Organization

What is the structure of the data product (e.g. FITS file with 4 extensions)?

SOCET SET native format for Science Team processing

IMG and FITS files for the PDS archive.

Data Format Descriptions

Header information (metadata) included with data product:

At a minimum the following information will be associated with each DTM and stereo-image. The “Data_Set_ID” keyword will point to a file list that includes all images, SPICE kernels, and the shape model used to support the generation of this product.

/* Identification Information */

DATA_SET_ID = “OSIRIS-REx_B_OCAMS_STEREO_SET_0001_V1.0"

DATA_SET_NAME = "OSIRIS-REx_OCAMS_POLYCAM_WILKOCRATER_001"

PRODUCER_INSTITUTION_NAME = "UNIVERSITY OF ARIZONA"

PRODUCER_ID = "UA"

PRODUCER_FULL_NAME = “MATT CHOJNACKI"

PRODUCT_ID = = "DTbcd_LLLLLL_NNNN_RRRRRR_NNNN_Vnn"

PRODUCT_VERSION_ID = "V1.0"

INSTRUMENT_HOST_NAME = "Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer "

INSTRUMENT_HOST_ID = “OSIRIS-REx”

INSTRUMENT_NAME = “OSIRIS-REx CAMERA SUITE”

INSTRUMENT_ID= “OCAMS”

TARGET_NAME = “BENNU”

SOURCE_PRODUCT_ID = (XSP_LLLLLL_NNNN, XSP_RRRRRR_NNNN)

RATIONALE_DESC = "Brief descriptive text "

SOFTWARE_NAME = “ISIS3.4.11”

OBJECT = IMAGE_MAP_PROJECTION

DATA_SET_MAP_PROJECTION = “TEMPLATE.MAP”

MAP_PROJECTION_TYPE = "EQUIRECTANGULAR"

ROJECTION_LATITUDE_TYPE= PLANETOCENTRIC

A_AXIS_RADIUS = nnnn.nn <M>

B_AXIS_RADIUS = nnnn.nn <M>

C_AXIS_RADIUS = nnnn.nn <M>

COORDINATE_SYSTEM_NAME = PLANETOCENTRIC

POSITIVE_LONGITUDE_DIRECTION = EAST

KEYWORD_LATITUDE_TYPE = PLANETOCENTRIC

CENTER_LATITUDE = nn.0 <DEG>

CENTER_LONGITUDE = nnn.nn <DEG>

LINE_FIRST_PIXEL = 1

LINE_LAST_PIXEL = nnnnn

SAMPLE_FIRST_PIXEL = 1

SAMPLE_LAST_PIXEL = nnn

MAP_PROJECTION_ROTATION = nnn.nn <DEG>

MAP_RESOLUTION = nnnnnn.nnnnnnnn <PIX/DEG>

MAP_SCALE = n.nnnnnnnnnnnn <METERS/PIXEL>

MAXIMUM_LATITUDE = nnn.nnnnnnnn <DEG>

MINIMUM_LATITUDE = nnn.nnnnnnnn <DEG>

LINE_PROJECTION_OFFSET = nnnnnnnn.n <PIXEL>

SAMPLE_PROJECTION_OFFSET = nnnnnnnn.n <PIXEL>

EASTERNMOST_LONGITUDE = nnn.nnnnnnnn <DEG>

WESTERNMOST_LONGITUDE = nnn.nnnnnnnn <DEG>

END_OBJECT = IMAGE_MAP_PROJECTION

END

Data Product Generation

By whom is the product generated?

The product will be generated by Sarah Sutton and Matt Chojnacki of the Planetary Image Research Lab (PIRL) on campus.

What are the input products needed to produce the product?

The following data are needed to create panchromatic mosaics:

- L2 Calibrated PolyCam and MapCam panchromatic images in units of I/F
- L2 OLA data
- SPICE kernels
- Bennu shape or terrain model (DSK)

Are there format expectations for the input products?

All input images will need to conform to the OCAMS SIS for Level 2 products.

The asteroid shape model will need to be in DSK format or a terrain model in ISIS3 cube format.

The photometric model will need to conform to the RADF SIS

What algorithms are used to generate products?

Stereo data products are generated using a workflow defined by the OCAMS SOCET SET Standard Operating Procedure (SOP). This SOP will be completed by the end of August 2016.

What calibration data are used to generate products?

PolyCam and MapCam L2 images are used to create this product. These products will be radiometrically calibrated by the OCAMS pipeline prior to use by the IPWG. In ISIS3, the products will be geometrically corrected using the PolyCam and MapCam camera models.

Has a specific Science Team Member been assigned to produce this product?

Sarah Sutton and Matt Chojnacki of the Planetary Image Research Lab (PIRL) on campus have been assigned the generation of this data product.

Will multiple versions of the product be generated?

No, unless major changes to the OCAMS calibration become necessary.

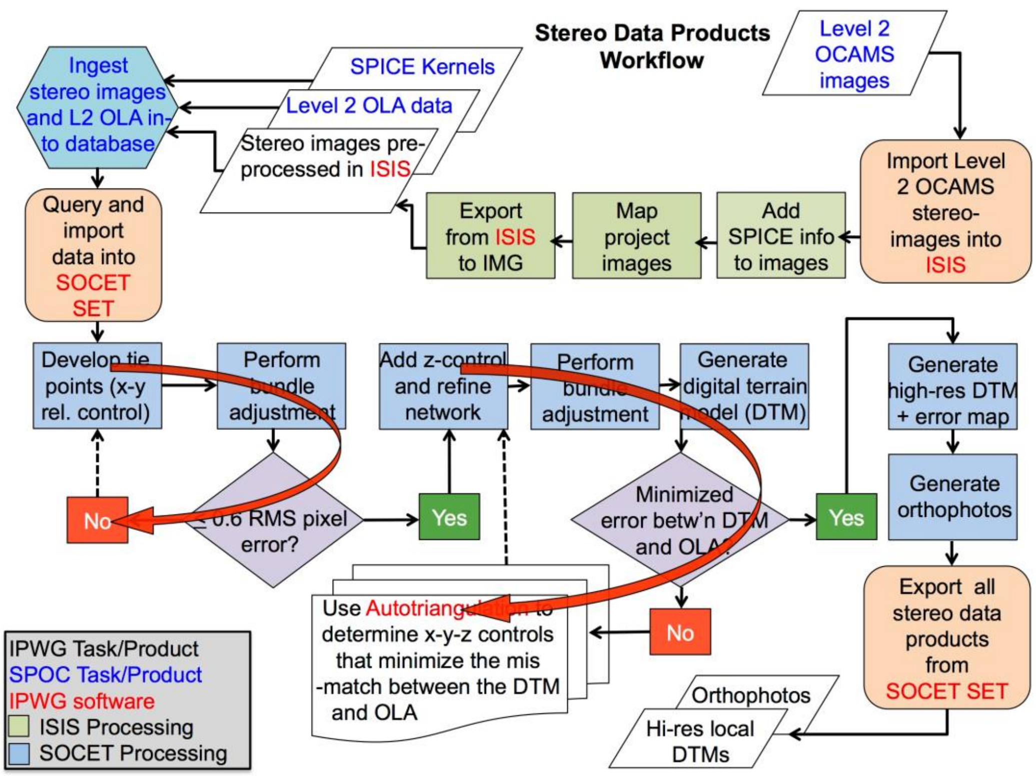
Data Product Validation

How will the product be validated to ensure contents and formats are correct?

This data product will need to pass an IPWG acceptance test before being delivered to the SPOC. The IPWG acceptance test will ensure that format is correct.

The IPWG lead will review the content of the data product and the data provenance before it is delivered to the SPOC.

Data Flow



Standards used to generate data product

Cartographic Standards

Stereo products will be generated in either equirectangular or polar stereographic cartographic projections. The equations describing these projections are included in the Image Processing Software Interface Specification (SIS) document.

CRITERIA FOR AUTOMATED IDENTIFICATION OF STEREO IMAGE PAIRS.
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Introduction: Stereo imaging forms the basis for much of the 3-D terrain analysis conducted by researchers in the planetary science community. Identifying the data on which to conduct stereogrammetry can be complicated and time-consuming [1-3]. While some instrument teams maintain databases of deliberately targeted stereo-pairs (e.g., Mars Reconnaissance Orbiter (MRO) HiRISE [4] and Lunar Reconnaissance Orbiter (LRO) Camera (LROC) [5]) there is no tool to locate fortuitous stereo overlaps, especially for images from different instruments.

Here we provide recommended methods and constraints for locating stereo pairs. Many of these recommendations can be tested using a new interactive solution provided by the USGS via the web-based Planetary Image Locator Tool (PILOT) application [6].

Overview: The main criteria to be used in identifying stereo images include:

- Image overlap and similar spatial resolution.
- 3-D stereo imaging "strength" as computed from emission and spacecraft azimuth angles.
- Illumination similarity as computed from incidence and solar azimuth angles.
- Similar solar longitude (i.e. it is best to avoid seasonal variations, such as differing frost patterns on Mars).
- Compatible spectral wavelength range to achieve similar contrast.

Recommendations are separated into two main categories of evaluation: (1) individually identify all candidate images that are suitable for stereo analysis and (2) identify images with common surface coverage that satisfy stereo pairing criteria. For both evaluation categories, the range of acceptable values depends on the intended use and thus most recommendations provided below are not absolute. While we provide specific "recommended" values, one should not take these as necessarily the "optimal" value because there can be a broad range of values that give similar quality without a sharp optimum in usefulness.

Image Suitability for Stereo Analysis (1): Generally, criteria for finding useful stereo image candidates are generated for the center pixel of all possible images, although a more robust solution might compare only areas where images share common surface coverage.

Incidence Angle. This angle is measured between the local surface normal vector at the surface intercept point (evaluated on a smooth representation of the global shape) and the vector to the Sun (for radar images, replace the sun vector with the radar source).

- Limits: Between 40° and 65° depending on smoothness (shadows to be avoided) [7].
- Recommended: Nominally 50°

Emission Angle. The angle is measured between the spacecraft-to-surface intercept vector and the local surface normal vector at the intercept point (evaluated on a smooth representation of the global shape). The goal of this criterion is to exclude images with extreme foreshortening (high emission angles for optical, low for radar).

- Limits: Between 0° and the complement of the maximum slope (conservatively 45°, greater for smoother terrains) for optical images. Greater than the slope (≥15° even for smooth surfaces) for radar.
- Recommended: No recommendation.

Phase Angle (optional). Measured as the angle between the spacecraft-to-surface intercept vector and the illumination source (typically the Sun). Surface appearance can vary with phase angle, especially at low phase, so it may be useful to exclude low phase images.

- Limits: Between 5° and 120°.
- Recommended: ≥ 30°

Ground Sampling Distance (GSD). The width of the pixels projected to the surface.

- Limits: GSD is chosen based on the desired GSD of the output digital terrain model (DTM). Because typical stereo matching methods do not produce independent height estimates over distances smaller than about 3 to 5 image pixels, the image GSD needs to be 3 to 5 times smaller than the desired DTM GSD.
- Recommended: Better than 1/3 of target DTM GSD.

Image-Pairs Suitability for Stereo (2): In general, these comparative parameters are evaluated based on the properties of the two images as measured at a common ground point.

GSD Ratio. The ratio of the larger to the smaller GSD of the two images at a common point.

- Limits: Image pairs with GSD ratios larger than 2.5 can be used but are not optimal, as details only seen in the smaller scale image will be lost. If required, images with ratios greater than ~2.5 should be resampled to the GSD of the lower scale image.
- Recommended: Between 1.0 and 2.5.

Strength of Stereo. The strength of a stereo pair is measured as the angle between the emission vectors of the two images. This parameter can be generalized (e.g., to cover cases in which both images are oblique) in terms of the *Parallax/Height Ratio* (*dp*) computed as shown in **Figure 1** and can also be generalized to apply to radar. Physically, *dp* represents the amount of parallax difference that would be measured between an object in the two images, for unit height.

- Limits: Between 0.1 (5°) and 1 (~45°).
- Recommended: 0.4 (20°) to 0.6 (30°).

Figure 1. Computation of *dp*

scazgnd = spacecraft azimuth ground
emi = emission angle

X component of parallax vector:
px = -tan(emi)*cos(scazgnd)
Y component of parallax vector:
py = tan(emi)*sin(scazgnd)

$$dp = \sqrt{(px1 - px2)^2 + (py1 - py2)^2}$$

where 1 & 2 refer to the images of the pair.
Note: For radar, substitute cot(emi) for tan(emi).

Illumination Compatibility. Variations in illumination degrade matching to some extent even if there are no shadows, but the effect becomes severe if there are shadows and these differ. Compatibility of the images can be measured in terms of the *Shadow-Tip Distance* (*dsh*) computed as shown in **Figure 2**. This is defined as the distance between the tips of the shadows in the two images for a hypothetical vertical post of unit height. The "shadow length" describes the shadow of a hypothetical pole so it applies whether there are actually shadows in the image or not. It's a simple and consistent geometrical way to quantify the difference in illumination. This quantity is computed analogously to *dp*. These criteria should also apply to radar, but appropriate limits have not been determined.

- Limits: 0 to 2.58.
- Recommended: 0

Delta Solar Azimuth Angle (optional). In practice, *dsh* alone does not guarantee similar illumination. The absolute difference in solar azimuth angle between stereo pairs can be optionally constrained.

- Limits: 0° to 100°.
- Recommended: ≤20°

Common Image Stereo Overlap. Amount of common surface coverage between the stereo pair images expressed as a percentage of the smaller area to the larger. Note that stereo convergence obtained by targeting some images off-nadir to increase overlap does not weaken the stereo.

- Limits: Between 30% and 100%.
- Recommended: 50% to 100%.

Spectral Range. This is the image color as determined by band, filter, or wavelength. Substantial differences in wavelength may degrade stereo matching.

- Limits: This is very dependent on the filters, the target, and how colorful the target is.
- Recommended: Same or within a spectral difference which is instrument and target dependent.

Figure 2. Computation of *dsh*

sunazgnd = solar azimuth ground
inc = incidence angle

X component of solar vector:
shx = -tan(inc)*cos(sunazgnd)
Y component of solar vector:
shy = tan(inc)*sin(sunazgnd)

$$dsh = \sqrt{(shx1 - shx2)^2 + (shy1 - shy2)^2}$$

where 1 & 2 refer to the images of the pair.

Application of Method: The incidence, emission, phase and GSD limits are applied to winnow out non-stereo image candidates. Image lists that satisfy these individual image suitability requirements are then used to find stereo image sets. Stereo image sets are determined by finding all complements that satisfy the stereo paring constraints first for *Common Image Stereo Overlap* and then for the constraints on *GSD Ratio, Strength of Stereo* and *Illumination Compatibility*. The output results are a set of stereo complement images (one or more) for each image in the seed list (including the seed image, of course), preferably ranked by the *dp* and *dsh* criteria. For flexibility, all search parameters (for single image and image pairs) should be enterable as a range of values, allowing the same value in the upper and lower limit to winnow on a single value.

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References: [1] Cook, A., et al. 1996, *Planet. Space Sci.*, 44, no. 10, 1135-1148. [2] Kirk, R. L., et al. 2008, *JGR*, 113, E00A24, doi:10.1029/2007JE003000. [3] Kirk, R. L., et al. 1999, *LPS XXX*, Abstract #1857. [4] Mattson, S. et al (2011) *LPSC LXII* Abstract #1558. [5] Burns, K.N., et al (2012) *ISPRS XXII*, v. XXXIX-B4-483. [6] Balien., M. B., 2015, this conference. [7] Kirk R. L. et al (2015) this conference.