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On-Board Limb-Based Shape Modeling For Small Body Navigation

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Introduction

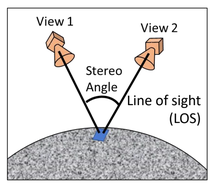
- Space mission to small targets may benefit from further use of autonomy
  - Reduction of: cost, downlink data, and time
- Shape models usually created by image stereo-pairs, laser range measurements, or other advanced techniques
- Limb-based shape modeling may provide adequate initial shapes for navigation purposes

Objectives

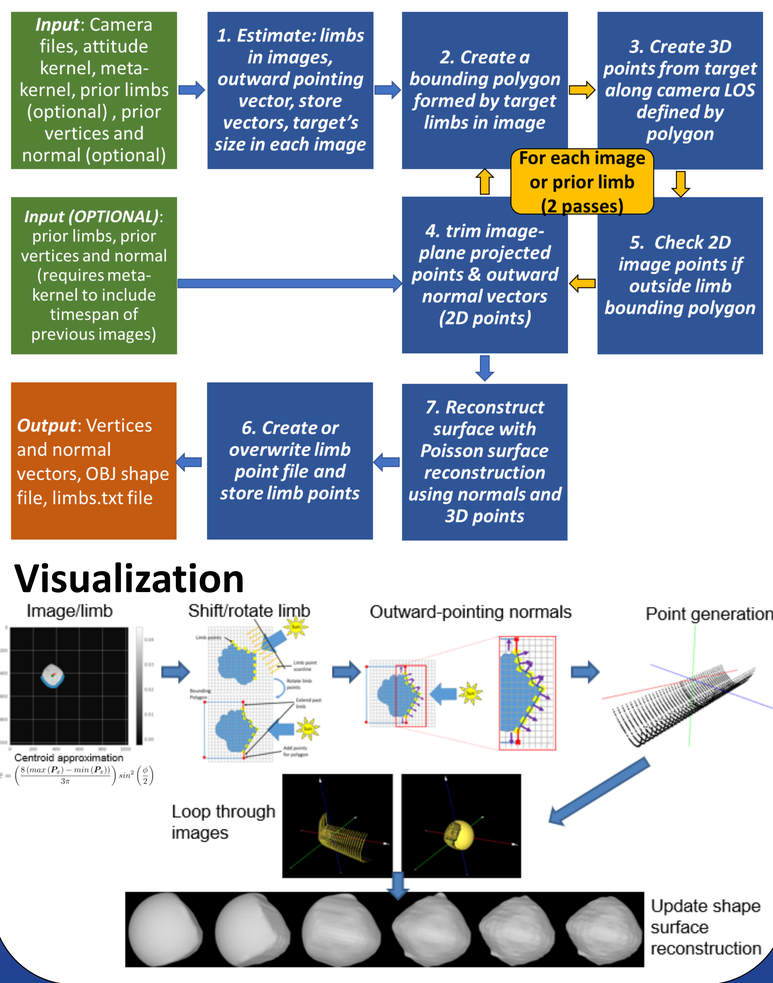
- Create a shape modeling approach that uses limb information that can be updated with new images
  - No need for stereo-pairs or near zero phase angles
- Investigate use for on-board applications
  - Run on a RAD750 processor (BAE systems) or equivalent
- Reduce the need for data downlink for early portions of a mission

Background

- Typical and advanced ground-based shape modeling
  - Space carving and photoconsistency
  - Shape from silhouette
  - Laser ranging altimetry reconstruction
  - Clinometry or Stereophotoclinometry (SPC)
- Limb-based shape modeling derived from shape-from-silhouette
  - Cannot capture concavities if not in silhouette



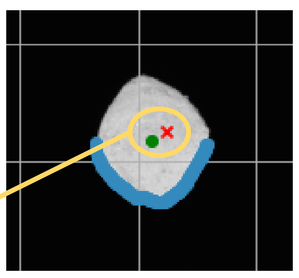
Method Flow



Visualization

Assumptions

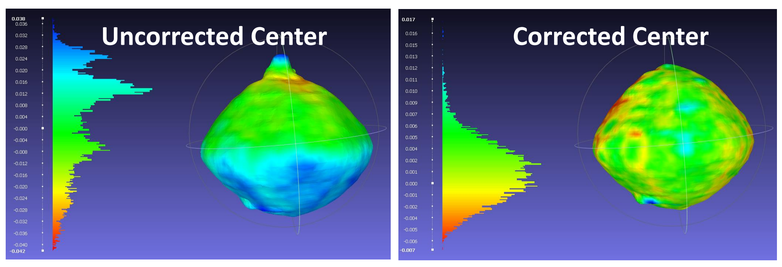
- Camera parameters
- Target relative state to camera/spacecraft
  - Range more specifically
- Target orientation
- No large areas of self shadowing



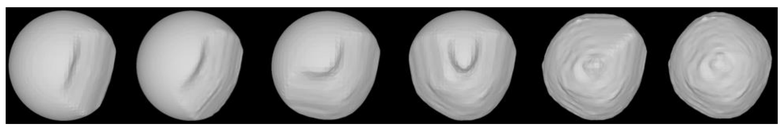
Center-of-mass (COM) from pointing and ephemeris (red) and blob centroid (green) discrepancy

Results

OSIRIS-REx Approach



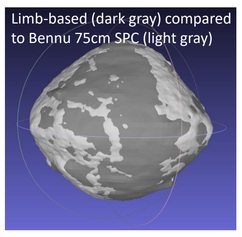
Comparison to Bennu 75cm SPC shape model



Shape model generation by using 110 images over 6 update steps. From left to right: +5 images, +5 images, +20 images, +20 images, +30 images, +30 images

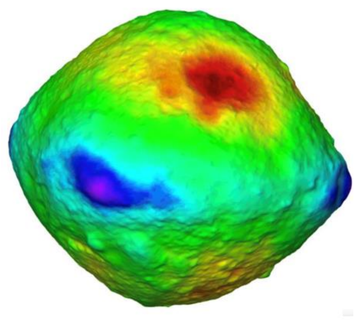
Center correction comparison with 75 cm SPC model

Parameter	Difference without $\bar{c}$ correction	Difference with $\bar{c}$ correction
Mean dif. [m]	3.368	1.122
RMS [m]	16.949	3.219
Min dif. [m]	-42.364	-7.047
Max dif. [m]	37.994	17.347

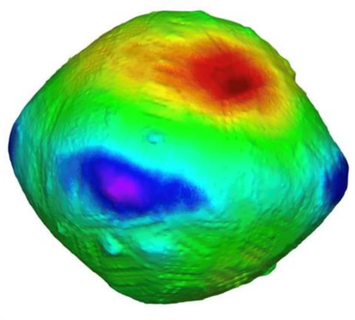


OSIRIS-REx Detailed Survey

300 NavCam images with ground processing, 12 cores and a complete time of 15 minutes



Operational SPC 75 cm model



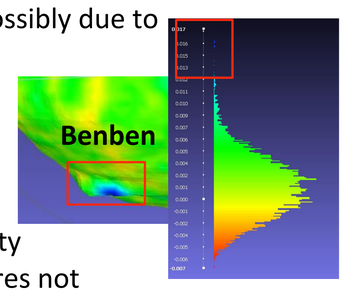
Limb-based shape model, generated with new GIANT automated process

Raspberry Pi 1 Comparison

Parameter	Throttled Pi 1 D	Computer
Processor speed	70 MHz	2.5 GHz
Cores	1	8
# images	10	222
Loading Kernel	60-120 seconds	~10 seconds
Process images	4-5 minutes	~5.5 minutes
Construct surface	530 seconds	~4 seconds
Total time	14-16 minutes	~6 minutes

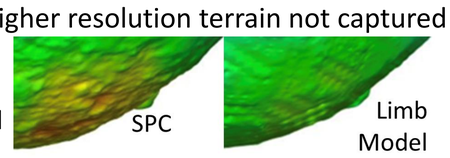
Discussion

- OSIRIS-REx approach images
  - COM of Bennu incorrect possibly due to pointing not ephemeris
  - Shape constructed well with blob centroid and phase angle correction
  - Largest error around Benben, lack of observability
  - Smaller features and textures not present, lower resolution images and limb points not representing the surface



- OSIRIS-REx Detailed Survey images
  - Reconstruction performed well
  - Many different viewpoints present within images
  - No correction was applied, assumed pointing and ephemeris were correct
  - Small surface artifacts present
  - Not all images had a low phase angle
- On-board equivalent
  - Throttled Pi 1 is comparable to RAD750
  - May be possible to create sufficient resolution models on-board autonomously, help with orbit determination
  - Shape model updating will help with processer load, update during processor downtime
- Overall
  - Reconstruction requires good estimation of COM
  - Method may help reduce the required downlink data
  - Technique not suitable for landing purposes

Higher resolution terrain not captured



Conclusion

- Method produced a reasonable shape model for Bennu
  - Approach and Detailed Survey
  - Shape model updates with new batches of images
- Initial implementation on a 70 MHz processor is promising
  - Able to update shape
  - Times are slow and may need further optimization
- Method provides a means for further autonomy for small body missions and non-science image downlinks

Future Work

- Test irregular shape objects (example: comet 67 P/CG)
  - Incorporate any modifications to generalize tool
- Test algorithm on DART images
- Shape model use in proximity operations simulation
  - Compare to flight data and trajectories
- Range uncertainty to incorporate any scale errors
- Center-of-mass and orientation/pole estimation
  - Go beyond blob centroid and phase correction
- Terminator point ellipsoidal estimate constraint
- Investigate non-IAU standard rotation scenarios