Perceptual Modeling of Icy Surfaces: A Probabilistic Approach to Visualizing Challenging Environments

Simon J. Bloch, *Swarthmore College* | Joe Bartels, William "Red" Whittaker, *Carnegie Mellon University*

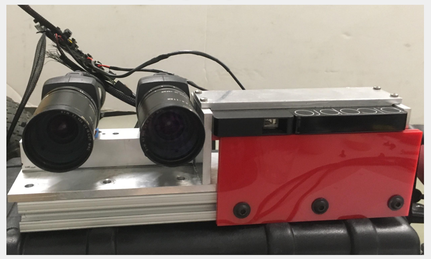
Introduction

- In space exploration, it is important to create robust 3D maps
- Icy moons of Jupiter and Saturn might contain water
- Ice is difficult to model due to light absorption and internal reflection

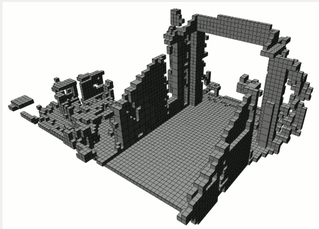
"Penitentes": Ice spikes which could be found on the surface of Europa

- **Solution:** Perceptual model
  - High resolution occupancy map with robust sensor model
  - Shows ice/non-ice probabilities
  - Uses data from a stereo depth sensor
  - Adapt existing occupancy mapping software to accommodate model

Tools

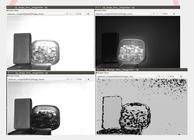


- Episcan3D[1]:
  - Stereo depth sensor
  - Direction sensitive light-capturing method
  - Different modes register only direct reflected light, "global" or indirect light, or full-intensity light
- Octomap[2]:
  - Open-source occupancy grid modeling software
  - Base OcTree class used as foundation for perceptual model

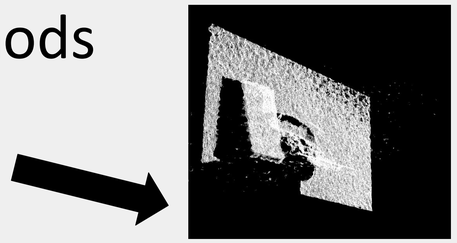


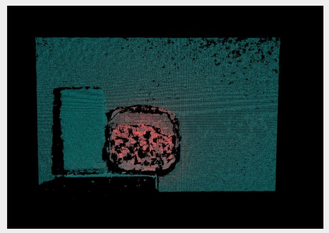
Methods

Matte "control" surface, next to tray of ice



Episcan-generated images, left to right, top down: Intensity image, Global image (indirect light), Direct image, Depth map (for 3D Point Cloud)

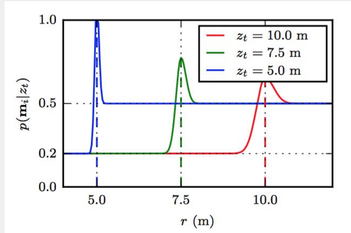


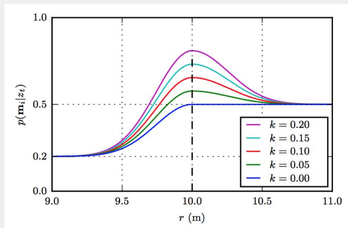


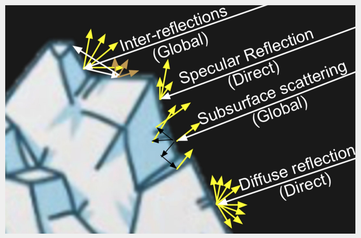
Colored 3D Point Clouds, where each point contains Direct, Global, and Intensity image data

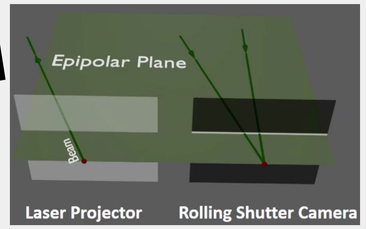
Stereo Sensor Model

- We want to address sensor error and remove incorrect depth values
- Sensor model relates distance measurements to occupancy probabilities
- Andert's inverse stereo sensor model[3]
  - Error scales proportionally to measurement distance
  - Tunable constants useful for implementation in perceptual model









Ice Probability

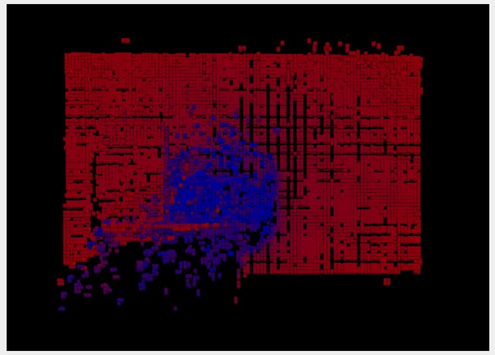
- The global light image contains indirect light from internal reflection
- Direct light visible in "current" projected pixel row
- Global light visible in non-current pixel rows
- Ice probability approximated by taking a ratio of the global light to the full-intensity light in each pixel

References

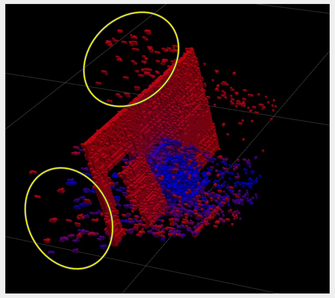
1. M. O' Toole, S. Achar, S. G. Narasimhan, K. N. Kutulakos, *"Homogeneous codes for energy-efficient illumination and imaging"*, 2015.
2. A. Hornung, K. M. Wurm, M. Bennewitz, C. Stachniss, W. Burgard, *"Octomap: An Efficient Probabilistic 3D Mapping Framework Based on Octrees"*, 2012.
3. F. Andert, *"Drawing stereo disparity images into occupancy grids: Measurement model and fast implementation"*, 2009.

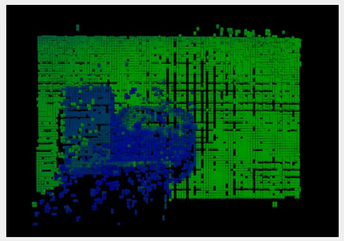
Results

8 mm resolution 3D Occupancy map, with each voxel (3D pixel) colored by the probability that ice lies at that spot (red is low probability, blue is high probability)



- Most error is attributable to all scans being taken from one direction
- Image scans taken from multiple angles, when passed through the stereo sensor model, will be filtered for inconsistent and noisy points
- Additional viewing modes: direct/global/indirect





Future Work

- Machine learning algorithms can be applied to improve ice probability estimation algorithm
- Outdoor trials in a non-control environment
- Alternate modeling applications
  - Thermal data
  - Radiation

Acknowledgments

- NASA Research Grant - Autonomous Navigation for Exploration on Icy Moons
- Shantanu Vyas - Sensor calibration and infrastructural support for Episcan software