Flash Lidar for Planetary Missions

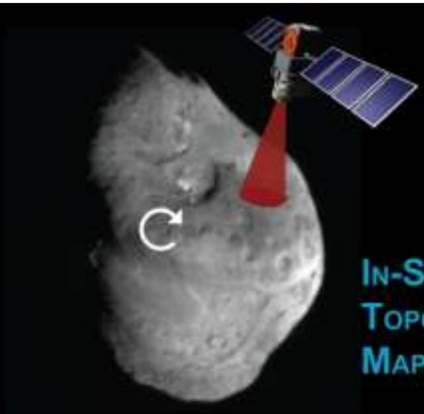
Rich Dissly, Carl Weimer, Jim Masciarelli, Jonathan Weinberg
Kevin Miller, Reuben Rohrschneider

Oct 11, 2012

Agility to Innovate, Strength to Deliver

Ball Aerospace
& Technologies Corp.

Planetary Applications for Flash Lidar



In-Space Topographic Mapping

- Topographic mapping from orbit about a planetary body or in a following orbit with a small body
- 3-D surface information available real-time under any lighting condition and while in motion

Ranging

- Long Distance (100s of km) Targeting and Ranging (3-DOF mode)

Surface Operations

- 30 Hz data rate to detect hazards during real-time operation
- High resolution maps of terrain and rock surfaces

Autonomous Rendezvous and Docking

- Docking with a carrier spacecraft or rendezvous with an asteroid or other non-cooperative target

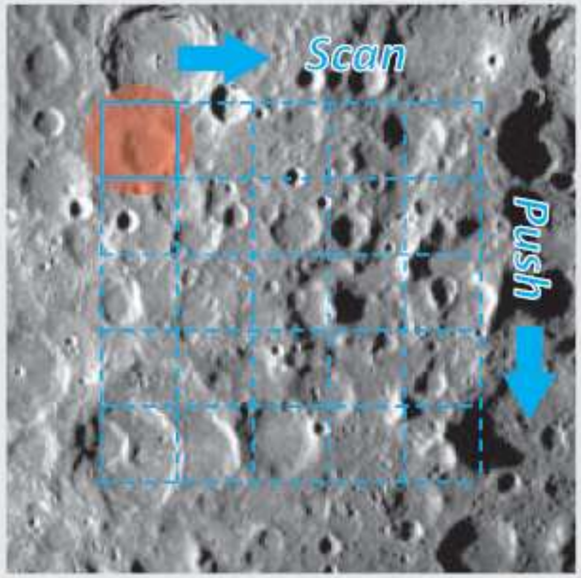
Entry, Descent and Landing

- *Initial Entry* : LIDAR used for altimetry and velocimetry. With addition of an imager , Terrain Relative Navigation may be performed, even under low light conditions.
- *Terminal Decent* : LIDAR beam diverted to illuminate entire field of regard. Allows addition of Hazard Detection and Avoidance for landing.

Scanning vs. Flash Lidar

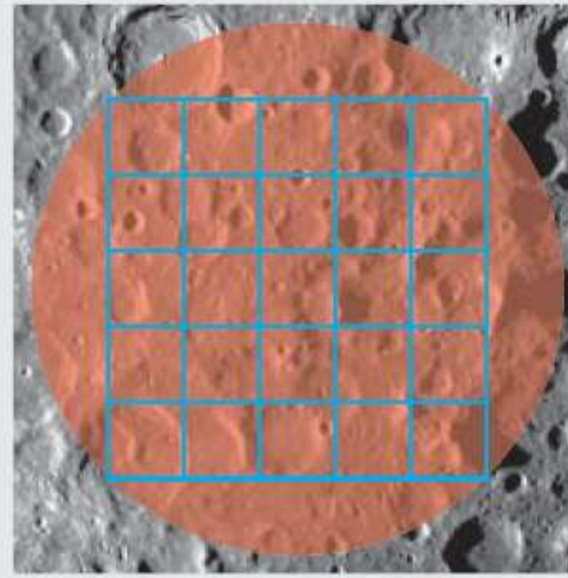
- **Range to target is determined by measuring the time of flight of a laser pulse from source to target and back to detector**
- **Intensity of returned light is also measured**
- **Difference between scanning and flash lidar lies in illumination and detection approach**

(a) Scanning Push-broom Lidar



- Spot size matches single pixel or detector field of view
- Spot scanned to make multiple measurements at adjacent locations to build up a swath
- Process is repeated for the next swath

(b) Flash Lidar



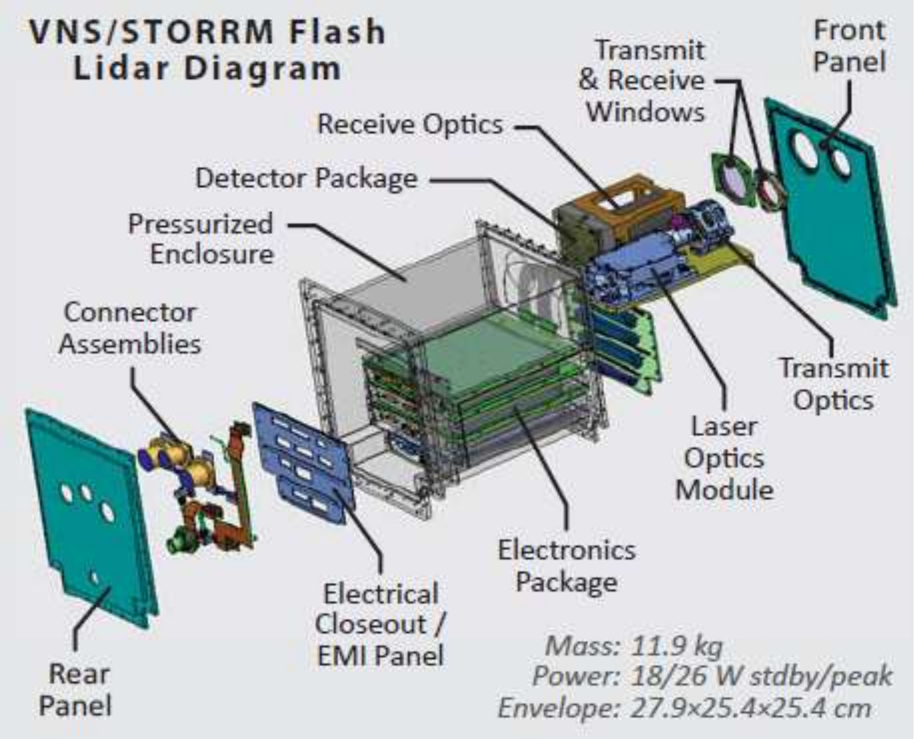
- Spot size matches 2-D array detector field of view
- Entire scene is mapped with one laser pulse

Flash Lidar Advantages

- Fast Frame Rate → *Insensitivity to target motion, stray light and glint*
  - Entire scene imaged at once – no scanning required
  - Entire array of pixels (frame) is correlated in space and time with each laser pulse
  - Each pixel is read out in parallel via special Read Out Integrated Circuit (ROIC)
- Large Dynamic Range → *High resolution imagery of rough surfaces*
  - Each pixel is triggered and read independently, allowing a large dynamic range
- High Reliability → *Low risk, long life*
  - No moving parts
  - Long life lasers rated for over 2 billion shots
  - Large array offers detector redundancies
- Lower Mass and Volume
  - No scanning mechanisms
- Simplified Integration and Test
  - No precision alignment required

Orion Vision Navigation System (VNS) Flash Lidar

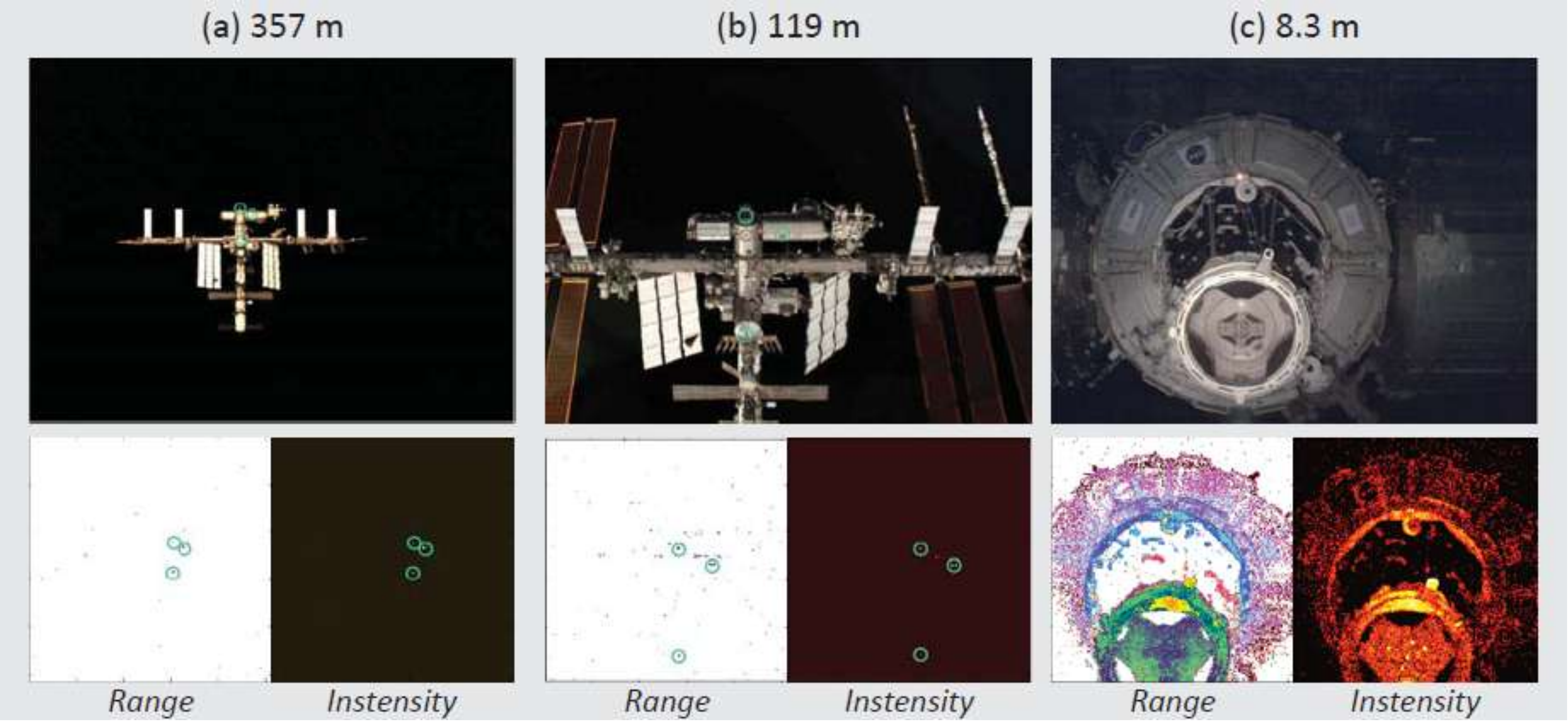
- Developed as a docking sensor for the Orion/MPCV capsule with the ISS
- Full frame flash lidar, max 30 Hz frame rate
- CMOS InGaAs PIN detector array (256x256)
- Optically switchable diffusers to create 12 or 20 deg beam divergence
- 2.5 mJ Nd:YAG passively Q-switched pulsed laser
- Optical parametric oscillator to create eye-safe 1572 nm output
- 33 mm receive aperture; 20 deg FOV



VNS/STORRM Flight Unit

Sensor Test for Orion Relative-navigation Risk Mitigation (STORRM)

- VNS flew on Space Shuttle mission STS-134 in May 2011
- VNS mounted in the cargo bay was activated as the shuttle approached the ISS
- VNS successfully acquired the ISS at a range of 5.6 km, exceeding 5.0 km requirement
- The lidar never lost lock the entire time the ISS target was in the field of view
- Provided real-time range and bearing information, proved the conceptual approach and elevated the hardware to TRL 7

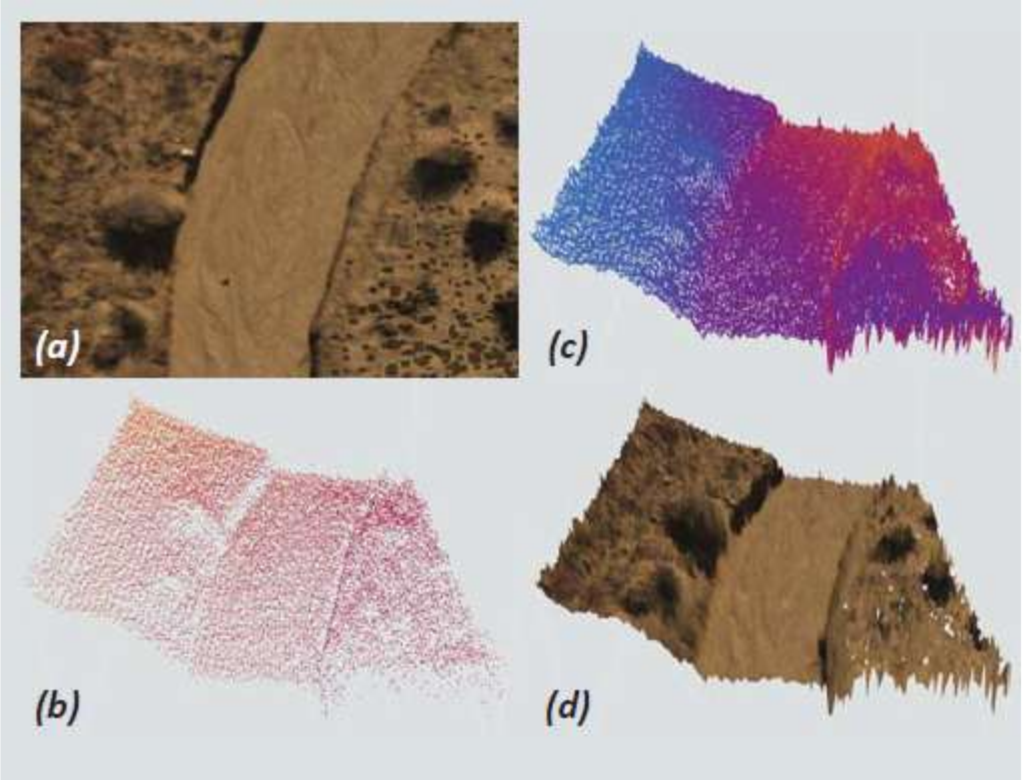


VNS/STORRM: Changes for Planetary Missions

- **ISS docking targets are ~95% reflective, while planetary targets have ~3-20% albedo**
- **More signal is needed to use VNS/STORRM for planetary missions**
- **Low cost, low risk modifications**
  - — Remove OPO *1064 nm laser output with 60% more light output*
  - — Change diffusion filters on laser output ⟶ *more laser energy per area (pixel)*
  - — Increase receive optics aperture → *more light received per pixel but more mass*
- **Medium Cost & Risk modification**
  - — Increase laser power⟶ *more light on target but more power and mass*

Advanced Real-Time Processing

- To provide true utility for advanced applications such as hazard avoidance, lidar data must be processed in real-time
- Flash has an advantage in that data is acquired quickly and the format is well suited for fast FPGA processing
  - (b) xyz-positions for each pixel (point cloud) are generated at 30 Hz
  - (c) a surface grid is generated for the frame



  - (d) surface grid may be draped with a visible image from a camera or database for terrain relative navigation
- The resulting DEM can be fed to GNC algorithms for landing or hazard avoidance
- Entire process takes only milliseconds
- TRL 5 (system demonstrated on aircraft)

Summary

- Mature Flash Lidar technologies are available to provide important data for planetary missions
- Flash Lidar is particularly well suited for applications requiring fast data acquisition and read-out such as: descent and landing, hazard avoidance, rendezvous, encounters and docking, terrain relative navigation
- Ball is continuing to mature techniques and hardware for increased functionality

Flash Lidar Performance Factors

- Radiometry
  - Target is actively illuminated with laser light and a narrow band filter on the detector → *insensitivity to ambient and stray light*
  - Integration time for detector is fixed by laser pulse width
  - Radiometry determined by: (1) laser power (2) beam divergence (3) target albedo (4) aperture of receive optics (5) detector sensitivity
- Ranging
  - Each pixel has a minimum threshold detection (# photons) to register a signal
  - As long as the light incident on the detector is above the pixel threshold and below the pixel saturation, a range will be calculated → *range accuracy is NOT a function of brightness*
  - Thresholds are determined by adjusting detector gain
  - Different detector gains may be determined during calibration and commanded in flight operation
- Ranging Accuracy
  - Contributing factors include: ground calibration accuracy, repeatability, laser jitter, laser rise time jitter, digitization, mounting accuracy and thermal and structural distortions
  - Errors are dominated by calibration accuracy and [pixel to pixel] repeatability