Seeing Beyond the Surface with Optical Techniques for Munition Response

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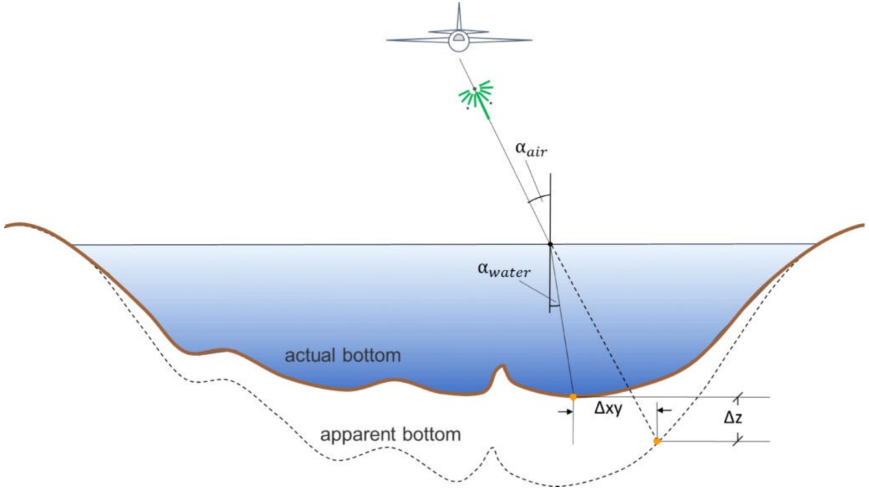
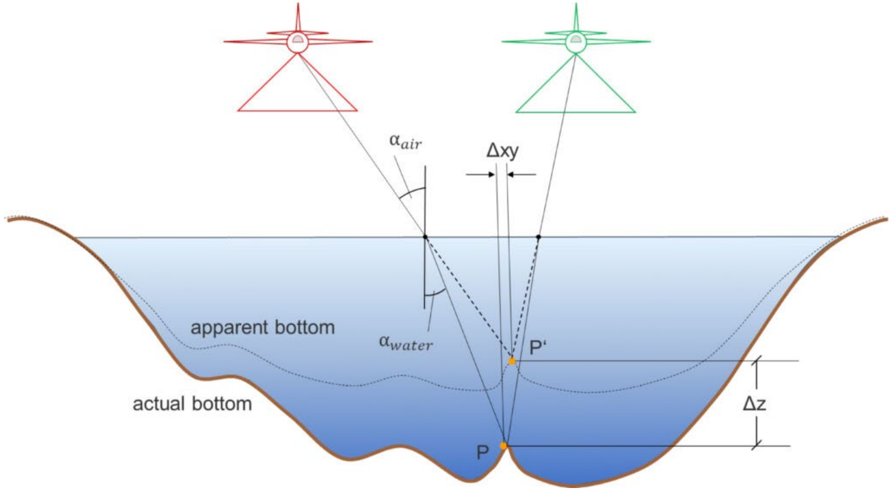
Optical Remote Sensing for Shallow Water Munitions Response

Optical methods can contribute to shallow water bathymetry and proud munition DLC for depths from 0-60 m depending on **water clarity**, **bottom reflectivity**, and **sea surface state**

Active Remote Sensing: LiDAR



Passive Remote Sensing: Photogrammetry



Mandlburger, Gottfried: A REVIEW OF ACTIVE AND PASSIVE OPTICAL METHODS IN HYDROGRAPHY. International Hydrographic Review (28), 8-52 (2022). https://doi.org/10.58440/ihr-28-a15

SERDP/ESTCP Optical Efforts for Shallow Water (0-10 m) Munitions Response

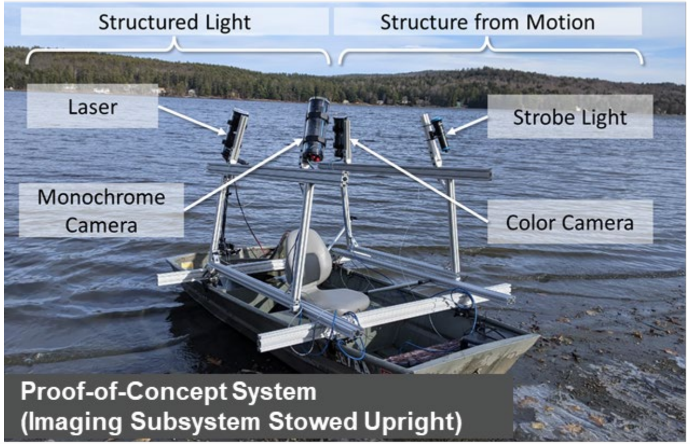
UAS LiDAR Payload

- LiteWave Technologies / CU Boulder
- SERDP/ESTCP ongoing project

EDGE[TM] Topo-Bathy LiDAR

USV / UUV Imaging Payload

- Creare LLC / Scripps Institution of Oceanography
- SERDP/ESTCP ongoing project

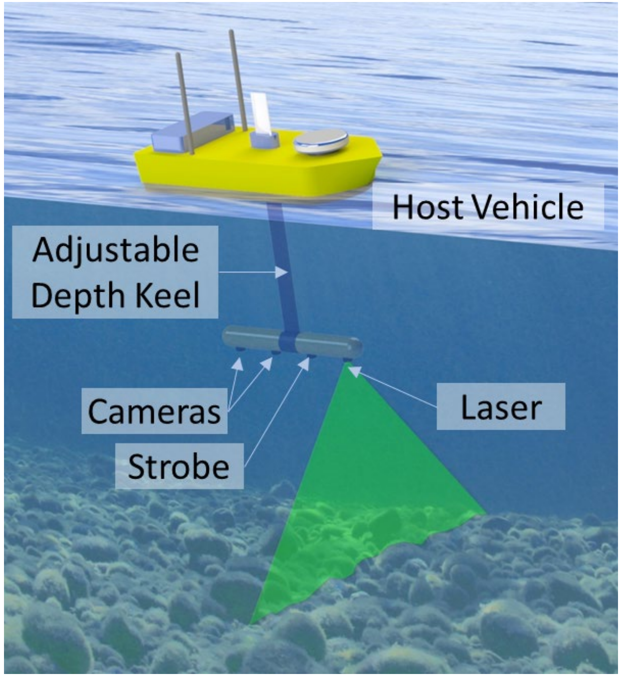


Proof-of-Concept System
(Imaging Subsystem Stowed Upright)

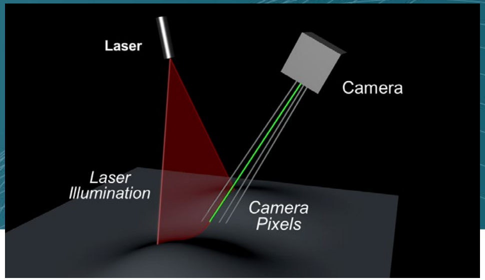
Creare Optical Munitions Detector (OMD)

Evaluating an OMD for Optical Detection and Classification of Unexploded Ordinance (UXO) in Shallow Water

- OMD deployment is agnostic
  - Keel of unmanned surface vehicle (USV)
  - Unmanned Underwater Vehicle (UUV)
  - Human-operated vehicles
- Current OMD Applies Two Optical Methods
  - Structured Light Imaging (SLI) and Structure from Motion (SfM)
  - May down-select in the future to one method
- An OMD demonstration test is in development

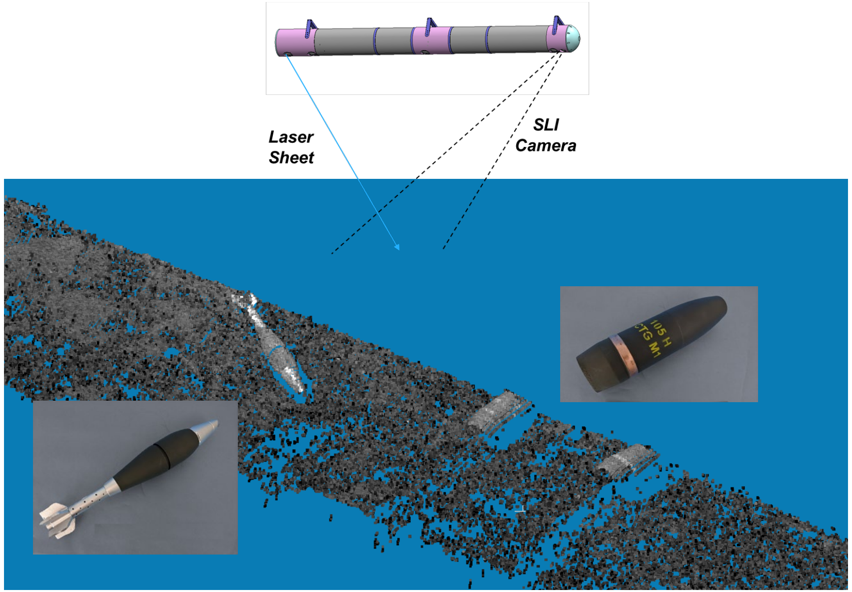


OMD Technical Approach: SLI

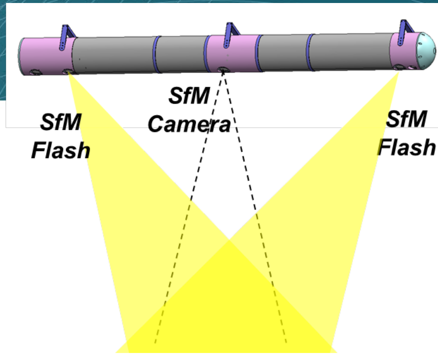


Structured Light Imaging (SLI)

- Also known as laser scanning
- Laser line “painted” on bottom
- 3D point cloud triangulated by offset camera
- Provides high-resolution 3D point cloud
  - Monochromatic (no color)

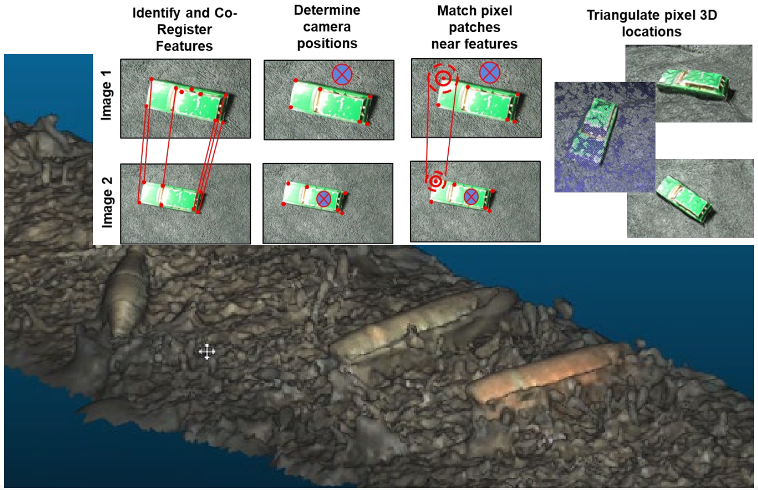


OMD Technical Approach: SfM



Structure from Motion (SfM)

- Bottom is illuminated using a white light and imaged from multiple views as the vehicle moves
- Features in subsequent images are registered to triangulate 3D locations
  - Requires knowing the relative position of the camera in each image
- Produces high-resolution 3D image of the bottom
- Preserves color and contrast

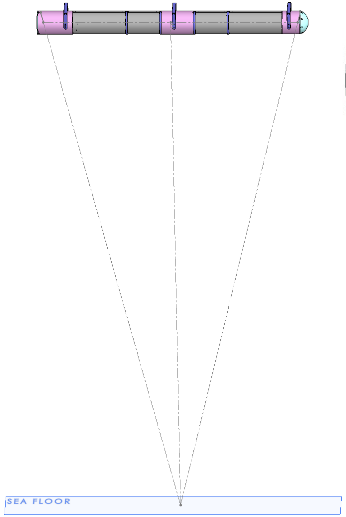


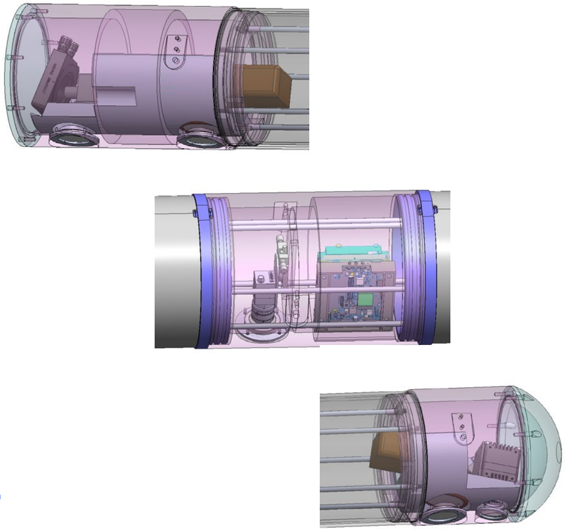
SLI and SfM use different cameras and illumination methods

SERDP ESTCP

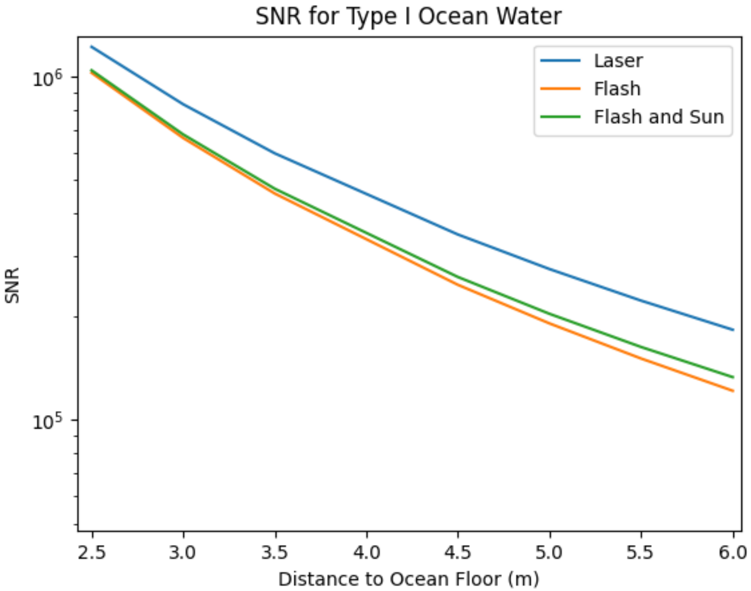
Optical Modeling of OMD System Performance

OMD Optical Design





Optical Modeling



UAS-LiDAR: 3D Point Cloud Generation

Time-of-Flight Measurement

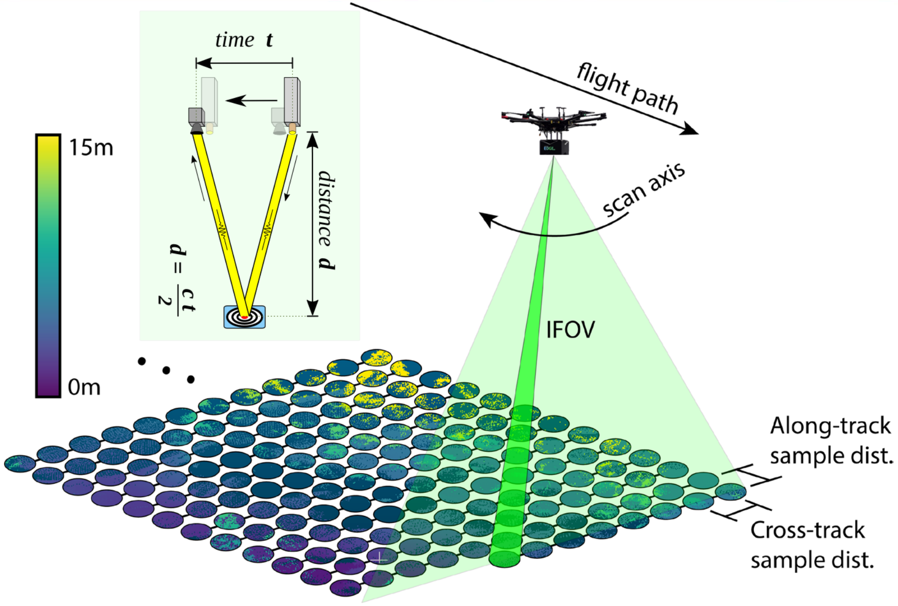
- Range to target determined by laser pulse two-way travel
- Scanning and platform motion provide x-y positioning of beam

Concept of Operations

- Drone Platform: motion, attitude, altitude
- Conditions: sea state, turbidity, bottom reflectance

LiDAR Sampling Scheme

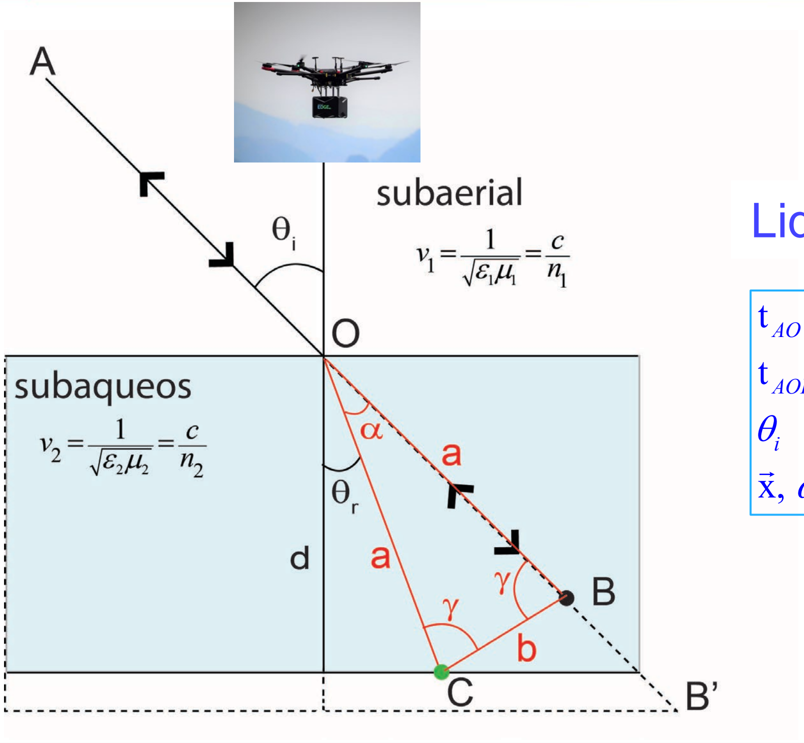
- System specifics
- Drone flight plan



For LiDAR images, height is the contrasting signal for 3D analysis

SERDP ESTCP

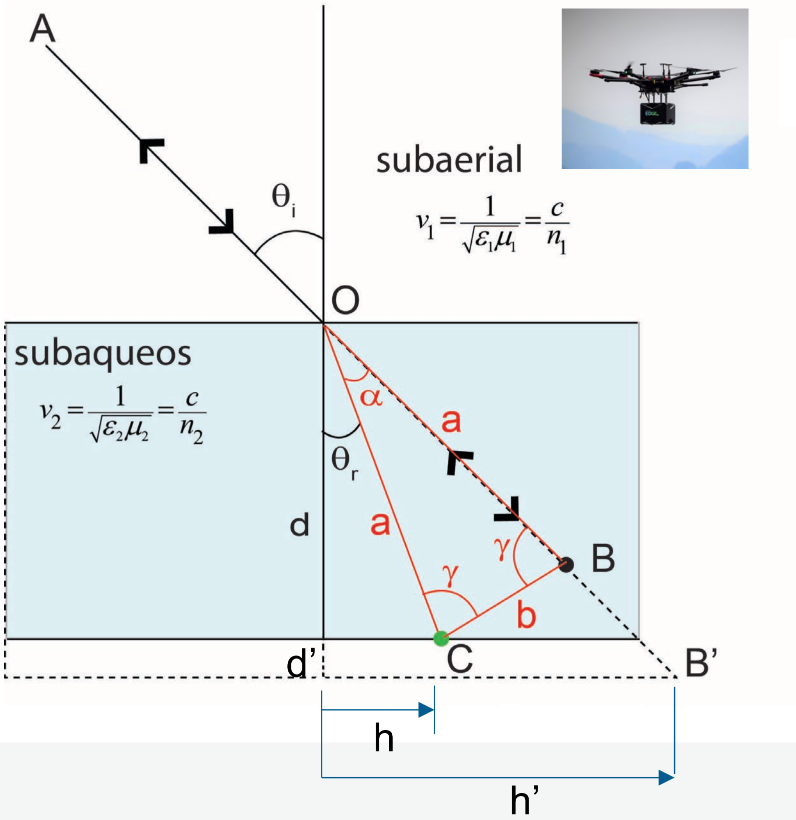
Light Travels the Path of Least Time



Lidar Observables:

t_{AO}	→ Two-way time from Lidar Tx to water surface
$t_{AOB'}$	→ Two-way time from Lidar Tx to water bottom
θ_i	→ Lidar pointing angle assuming nadir is normal to water sfc
$\vec{x}, \vec{\omega}$	→ Platform position and attitude information

Light Travels the Path of Least Time



Lidar Bathymetric Derivables:

Water surface range: $$AO = r_1 = \frac{ct_{AO}}{2n_1}$$

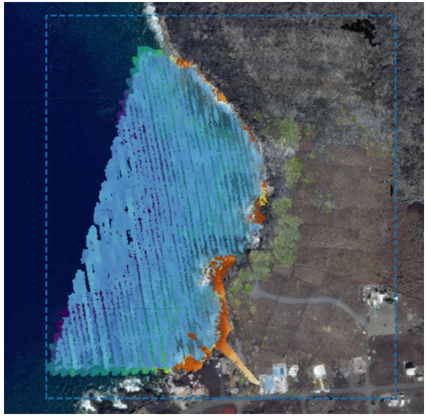
Water path length: $$OB = r_2 = \frac{c(t_{AOB'} - t_{AO})}{2n_2}$$

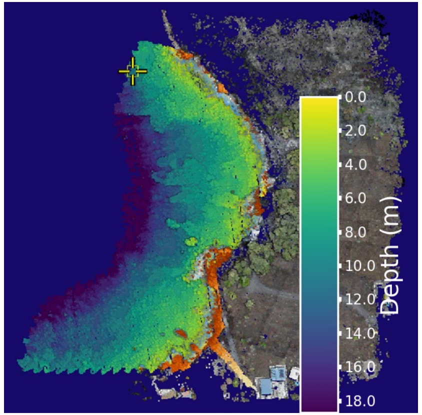
Water depth: $$d = r_2 \cos(\theta_r) \approx r_2 \left(1 - \frac{\theta_i^2}{4}\right)$$

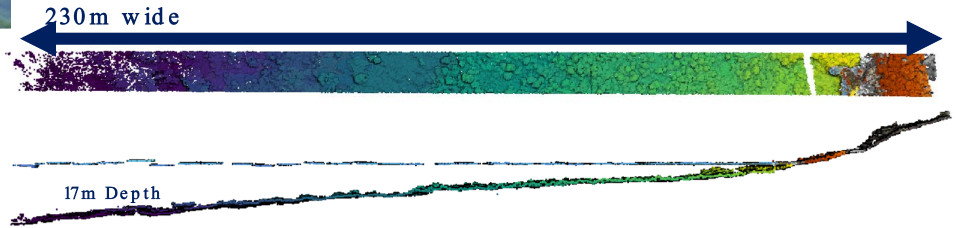
Point position: $$h = r_2 \sin(\theta_r) \approx \frac{3r_2\theta_i}{4}$$

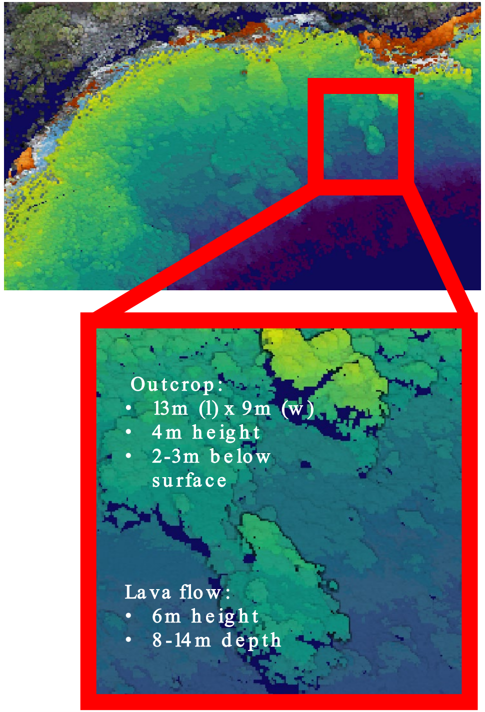
UAS-based Scanning LiDAR for Topographic-Bathymetric Mapping

3D LiDAR Point Cloud of Papa Bay, HI







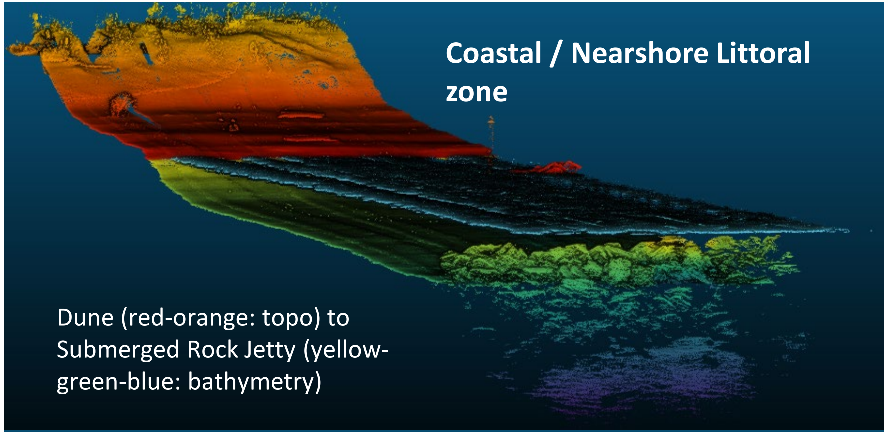


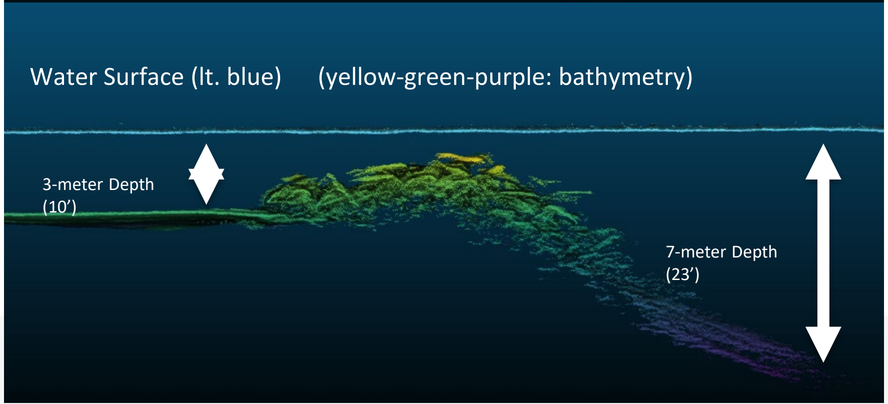
Jetty reconstruction project

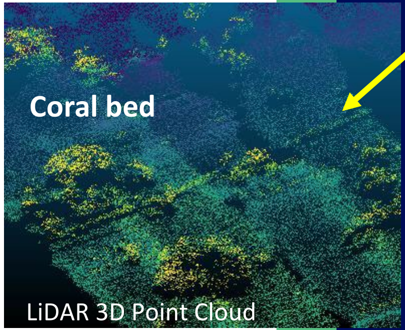
Detailed 3D Resolution

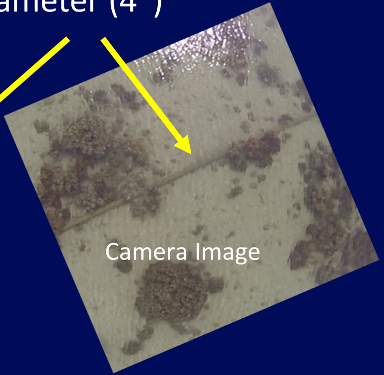
LiteWave TECHNOLOGIES

Cable: 100 mm diameter (4”)

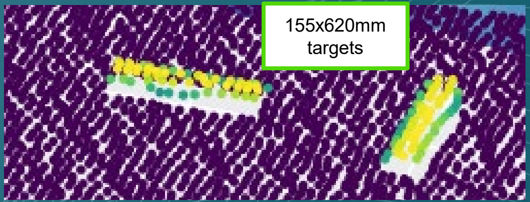




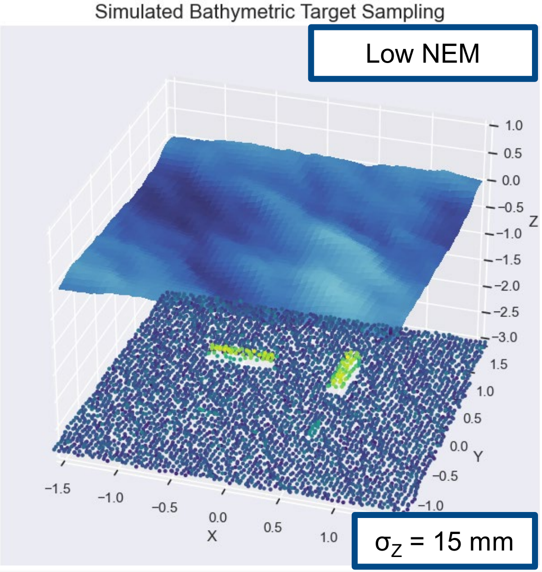


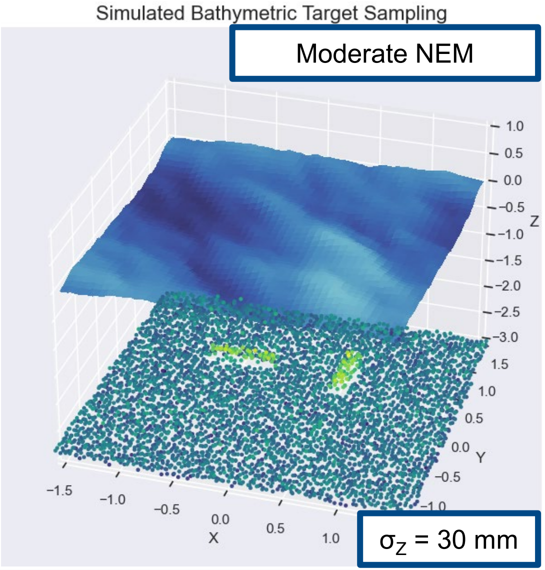


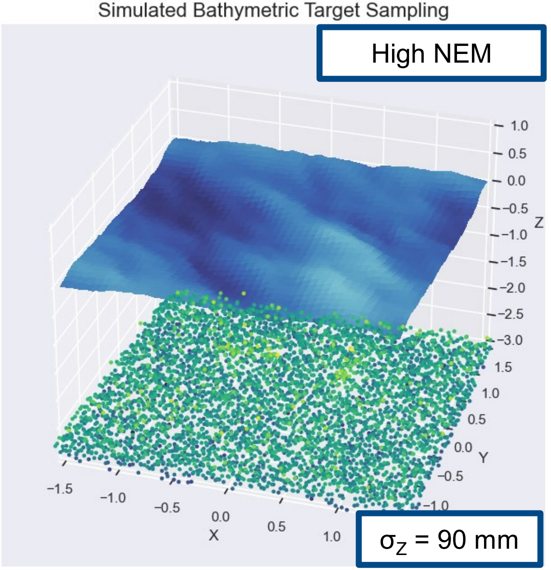
UAS LiDAR for UXO DLC: Noise and System Modeling



Ex: Surface sea state treated as Noise-equivalent modulation (NEM) in simulated point cloud







Water surface simulated using method detailed in J. Tessendorf. Simulating Ocean Water. Technical report, SIGGRAPH Course Notes, 2004.

Benefits for Shallow-Water Munitions Response

Creare Optical Munitions Detector

- Low power (order 10s of W)
- High resolution (sub-mm is possible)
- Sensitive to optical contrast and color
- Preserves geometric shape and size
- 3D point clouds for post processing
- Support for multiple USV and UUV platforms

LiteWave Topobathy LiDAR

- Above-water sensor
  - Access to non-navigable waters
- High resolution (cm-level resolution)
- Swath area independent of water depth
- Preserves geometric shape and size
- 3D point clouds for post processing
- Support for multiple UAS and USV platforms

Complementary capabilities for Munitions Response

Limitations for Shallow-Water Munitions Response

Creare Optical Munitions Detector

- Detection sensitive to water turbidity
- Limited swath width
- Water surface contact required
- Some weather dependencies

LiteWave Topobathy LiDAR

- Detection sensitive to water turbidity
- Classification sensitive to water surface structure
- No intensity information
- Some weather dependencies

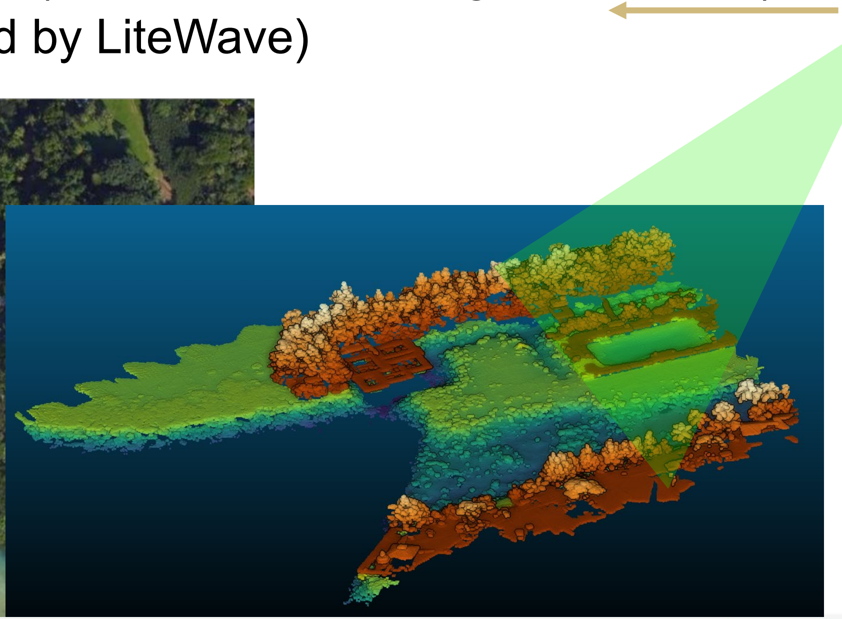
Neither technology can detect buried UXO

… but both can be used to characterize seafloor topology / spectral roughness to inform traditional sub-bottom sonar imaging

Demonstration Test Planning

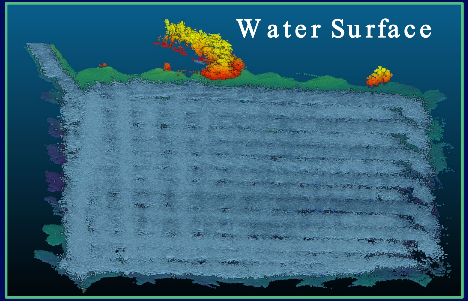
Tests are planned for the UXO Test Bed Site on Coconut Island, Oahu HI

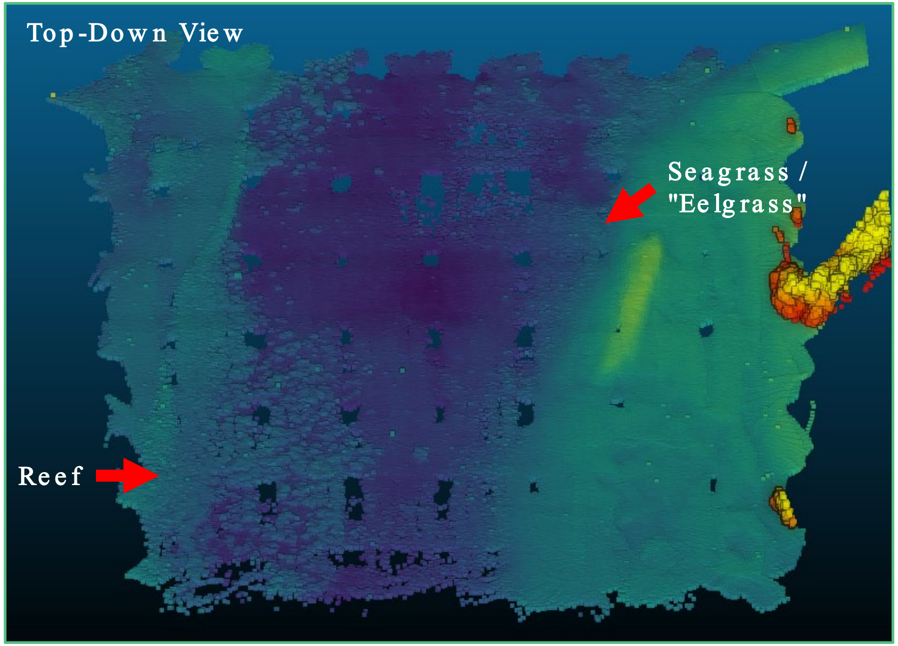
- WAM-V Autonomous Surface Vehicle (OMD mounted using custom keel)
- UAS Hi-Res LiDAR system (modified by LiteWave)

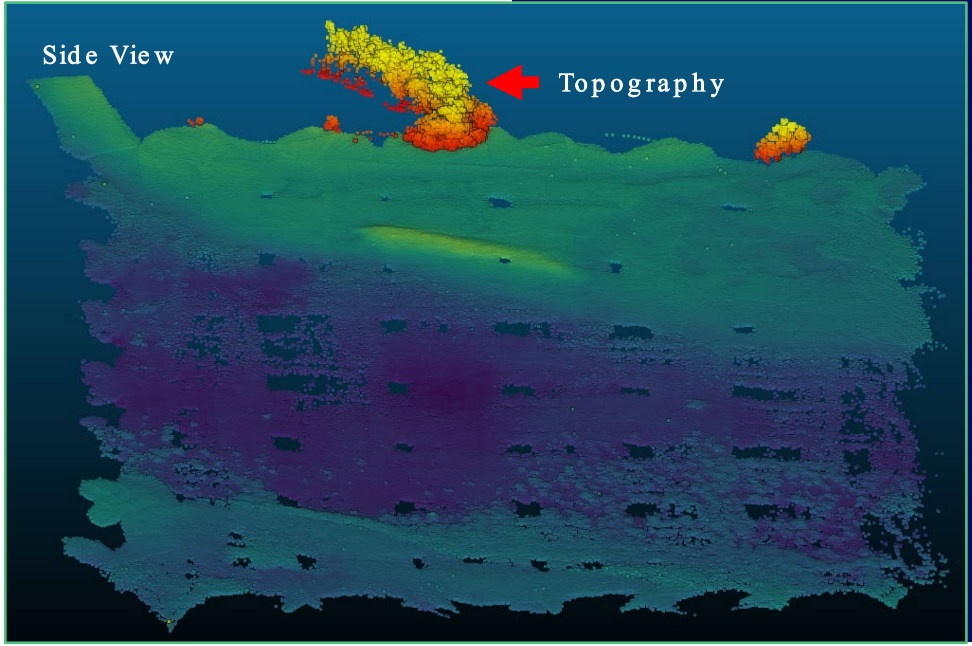


Backup Slides

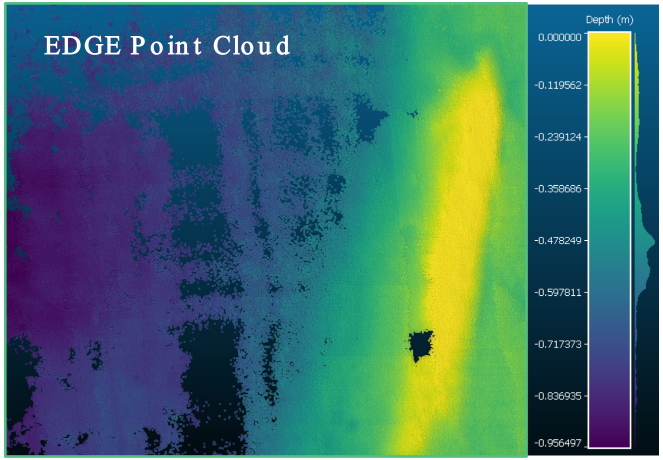
Biomass Mapping

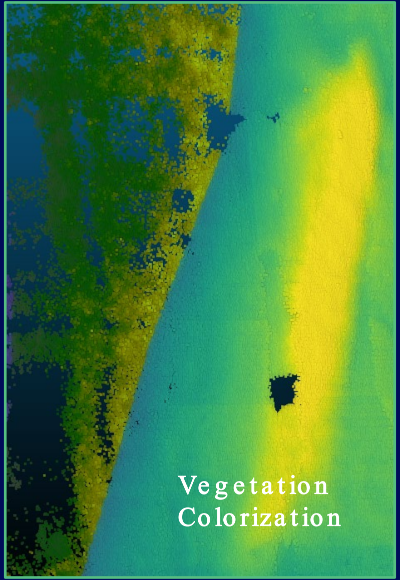


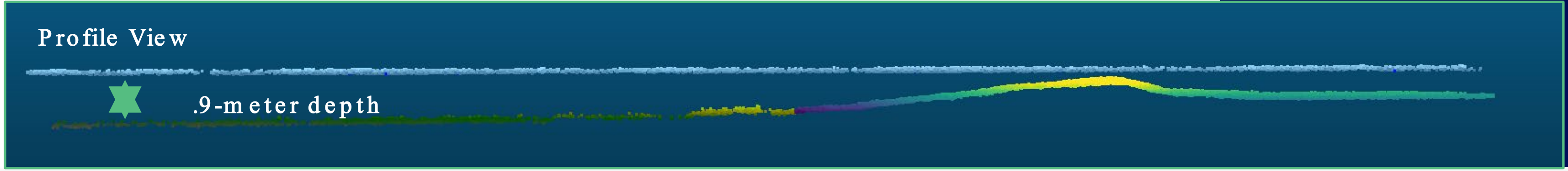




Biomass Example





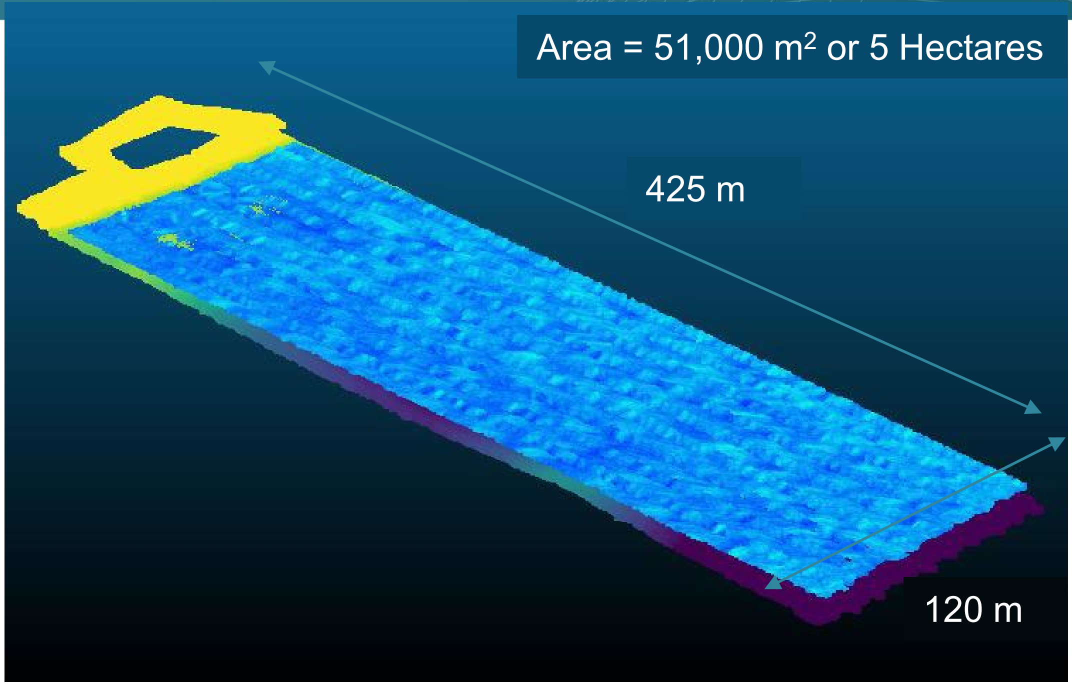


Detection: Point Cloud Processing

MR22-EO-7964 : Demonstration of UAS-Based, Topo-Bathymetric Lidar for Shallow-Water Munitions Response

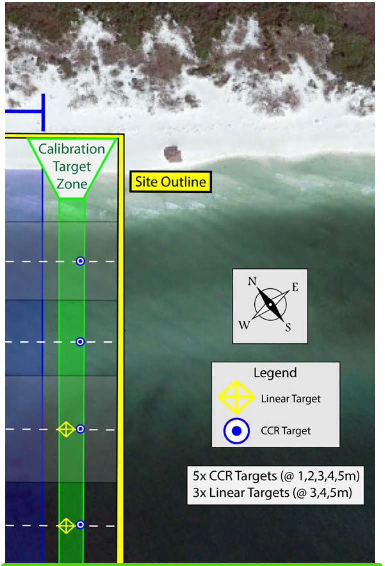
Classified EDGE Point Cloud

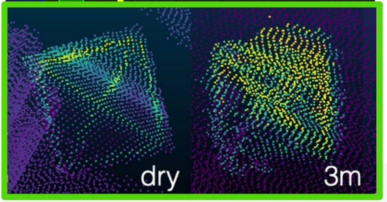
- **Land**
- **Water Surface**
- **Water Column**
- **Bottom Surface**

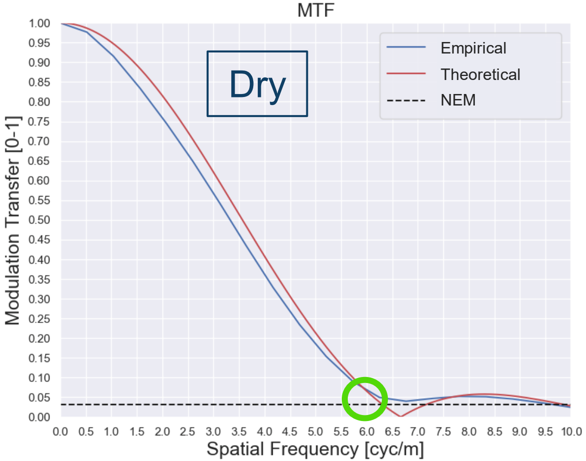


Thanks to NSWC/PCD, NRL, IDA and others for all the support prepping and carrying out the engineering test. Particularly Ray Lim, Amanda Bobe, Chase Graham, Ed Braithwaite, Dan Kolodrubetz, Javier Handal, and the ESTCP Project Office.

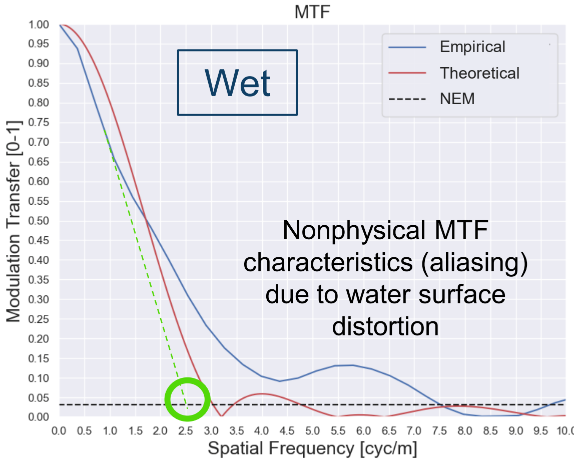
Panama City, FL Campaign Data Analysis





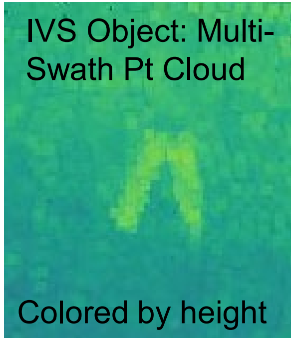


Dry cutoff resolution ≈ 80mm



Wet cutoff resolution ≈ 200mm*

75 mm clutter object



Retroreflector MTFs represent
best-case detectability, **worst-case** resolutions

Single-swath MTF results indicate many munition targets are not resolvable, due in part by the executed sampling strategy

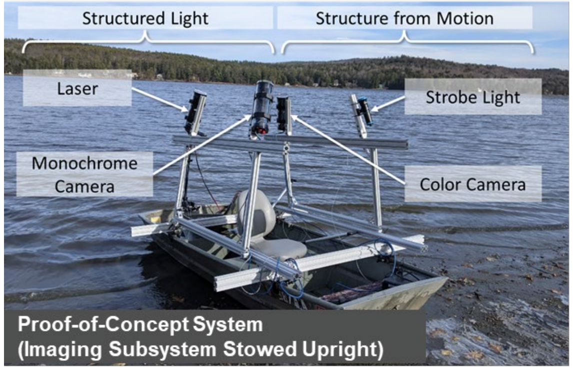
*NEM is inherently higher for bathymetric data, but is difficult to quantify

Why Two Imaging Modalities?

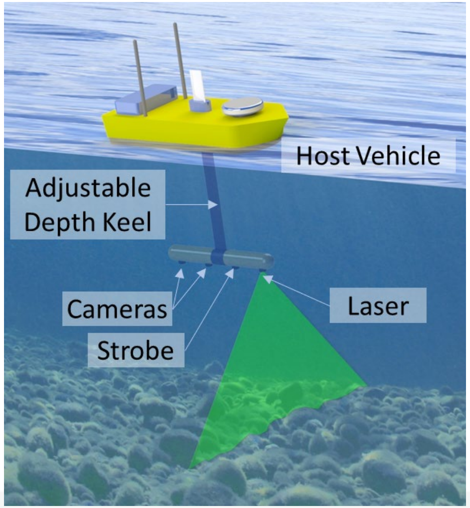
- SfM maintains color information and may be more useful for many missions
  - But is more sensitivity to water clarity due to incoherent illumination
  - Also is more computationally intensive
- SLI works better in turbid water
  - Will function over a wider range of real-world conditions
  - Fast and less computationally intensive
  - Better spatial resolution (~1 mm depending on depth)
- The Demonstration Test Will Allow us to Compare Methods Head-to-Head

Recent Creare OMD Progress

- New SERDP/ESTCP Program Started Feb 2024
  - M23-9001 Optical Detection and Classification of Military Munitions
- OMD System will be Reconfigured with Optical Components and Optical Design, and Integrated for Test



OMD Proof-of-Concept



Updated OMD Concept

OMD Design