Demonstration of UAS-Based Topobathymetric Lidar for Shallow-Water Munitions Response

Project Number: MR22-EO-7964

Principal Investigator: Alexandra Wise

PI's Organization: Orion Space Solutions – an Arcfield company

(formerly: LiteWave Technologies, Inc.)

In Progress Review Meeting

13 Aug 2025

Project Team

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Orion Space Solutions
Systems Integration & Testing Engineer II, P.I.

Dan Knight
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Dr. Jeff Thayer
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Project Team

Bryce Garby
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Lead LiDAR Engineer

Martine Bissonnette
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Host Installation P.O.C.

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Bottom Line Up Front

- What technology or methodology is being evaluated during this demonstration?
  - Demonstrate the detailed survey capabilities of the EDGE LiDAR for Munitions Response (MR): first in a relevant environment (Panama City Beach, FL); then with improved sensor capabilities (Coconut Island [Moku o Lo‘e], Hawaii); finally, in a live environment (Vieques – or similar).
- What's been going well?
  - Orion team is coming up to speed after project leadership transition.
  - ESTCP engineering test on Shell Island at Panama City Beach, FL provided complete LiDAR data set that produced georeferenced points across land. Lessons learned and analysis (by Co-I's team) have led to improved CONOPs/system requirements.
  - EDGE system design updated to meet new requirements; Prototype high-definition MR LiDAR system build & validation in progress.
  - Additional funding received for R&D validation tests of the prototype MR system and 2nd Engineering Test.

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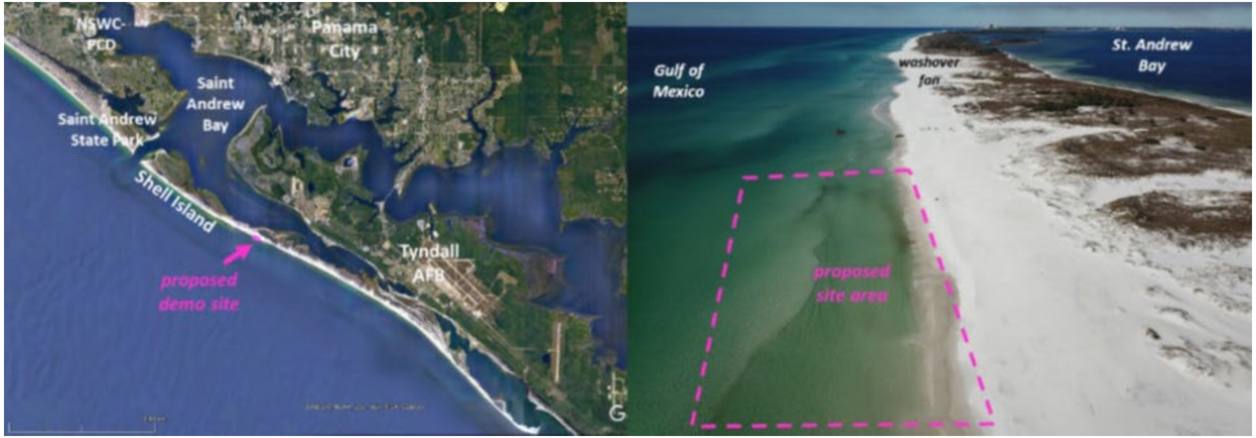
Bottom Line Up Front

- What's not working?
  - Object detection and classification solutions have been hindered by the limited level of information content from the observations made by eye-safe EDGE system.
  - Current resolution of system (dictated in part by eye safety concerns) and georeferencing of points due to surface roughness are limitations of commercially available LiDAR system for MR applications.
    - Simulations suggest that our prototype system will have required information content but will not be eye-safe, requiring administrative controls at test sites.

- What support do you need?
  - Remaining project funds used to build MR-tailored R&D EDGE system.
  - Received additional funding for R&D validation tests of the Prototype MR system and 2nd Engineering Test to validate performance in relevant environment (UHI ARL site).

1st Engineering Test - Site Description

- Shallow nearshore areas along the southern part of Shell Island near Panama City Beach, Florida
- Provides optically clear waters, uniform bottom substrate, little natural clutter, and excellent support infrastructure



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2nd Engineering Test - Site Description

- Boat channel and/or surrounding shallow nearshore areas along Coconut Island (Moku o Lo‘e), Hawaii
- Provides optically clear waters, uniform bottom substrate, little natural clutter, and excellent support infrastructure

Technology

- Orion/LiteWave **EDGE LiDAR** is a TRL 9 innovative technology providing unprecedented capability in topo-bathymetric mapping for commercial surveying applications of nearshore and riverine environments
- Agnostic to **UAS airframe** as long as CONOPs capable (5kg mass for >12 min flight time). UAS used included the ISS aerospace Sensus L8, Skyfront Perimeter 8 and another traditional 6-rotor platform.

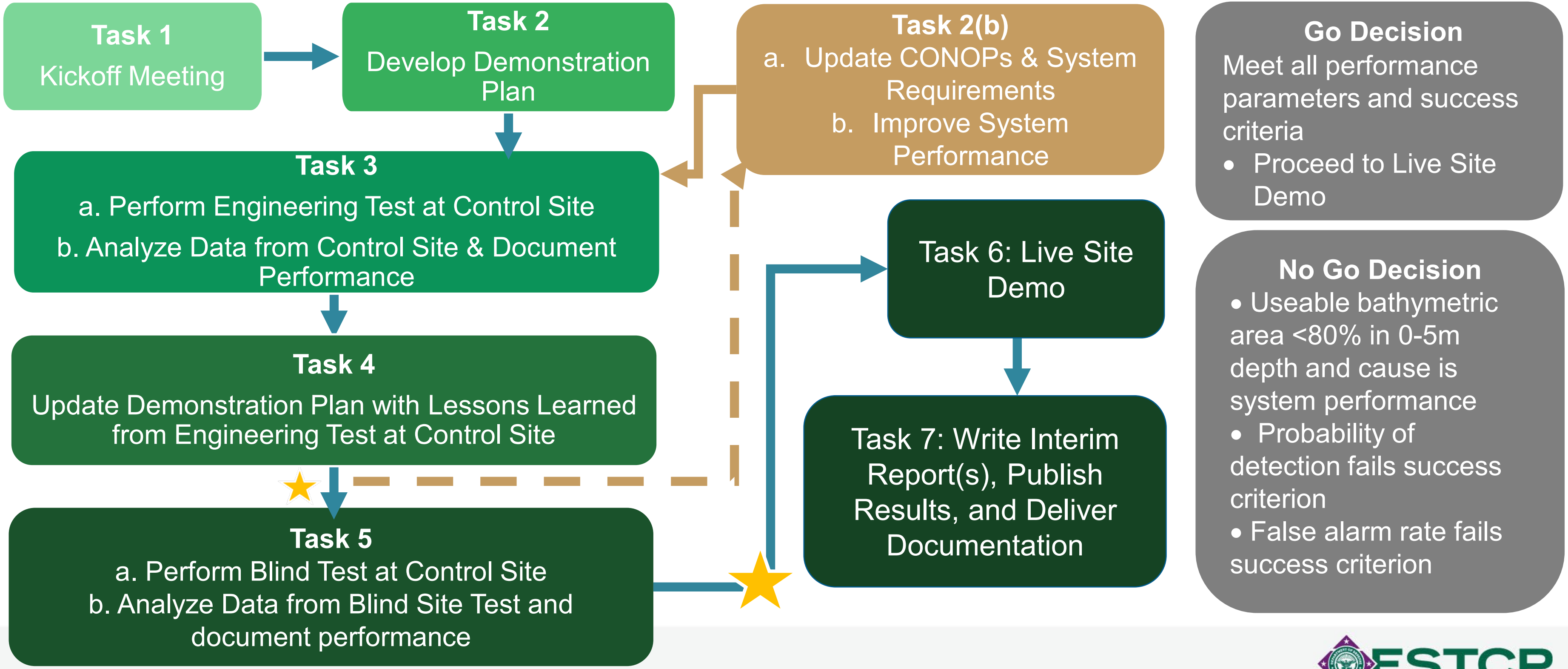
Technical Objectives

1. **Perform a field demonstration at a controlled ESTCP test site** to demonstrate the ability of a UAS-mounted topographic-bathymetric LiDAR to rapidly carry out *both wide-area and detailed bathymetric surveys* in an actual environment with munition surrogates and other targets of interest.

2. **Perform a field demonstration at a live munitions site** to rapidly provide a detailed geophysical description of submerged areas that may contain proud UXOs, and assess the ability of the EDGE LiDAR system to locate and identify those UXOs.

3. **Determine Operational parameters**: the ease of use, operational costs, applicability, resolution requirements, flight hours, and other required resources to perform both wide-area and detailed surveys.

Technical Approach



Test Design Goals

The goals of the engineering test involve evaluating:

1. The operability of a UAS-based scanning topobathy LiDAR for shallow-water munitions response
2. The resolvability and characterization of emplaced proud MR objects on land
3. The detectability, resolvability, and classification of emplaced proud MR objects in waters of 0-5m depth.

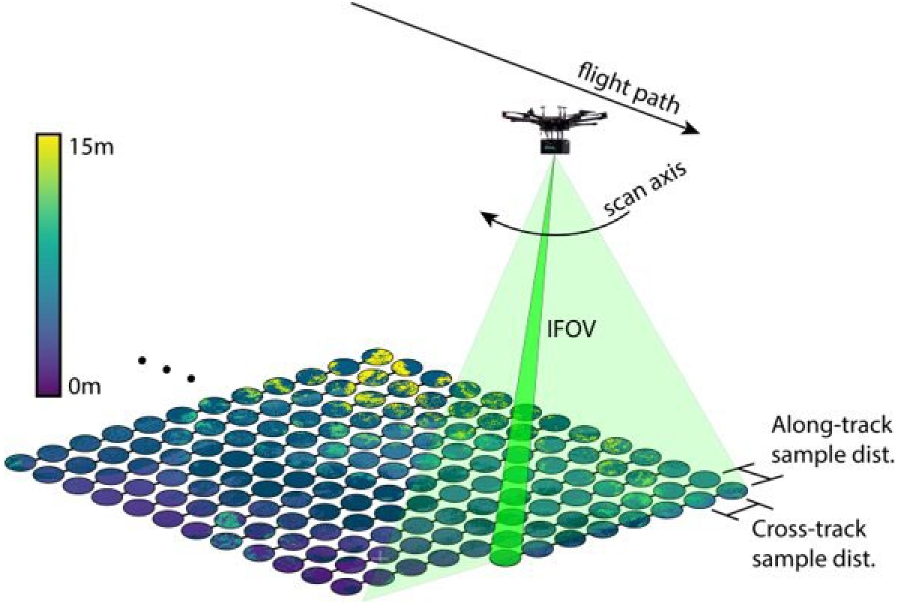
2nd Engineering Test Design - Overview

- Perform Engineering Test at Control Site – Coconut Island (Moku o Lo‘e), HI
  - Place targets of interest and clutter objects to fully demonstrate EDGE LiDAR’s ability to map features in bathymetric environments
- Conduct Observations of IVS zone, calibration zone, control zone, and blind control zone to compare to standard baseline/current testing methodologies.
  - This approach was taken to establish the current limits of resolvability for MR response of the improved EDGE LiDAR.
- Sampling plan includes a range of CONOPS parameters:
  - Flight heights (AGL), UAS platform velocities, and flight planning (side laps and crosshatching) to identify the limits of MR resolvability.
- Test to be performed 9-13 Feb 2026

2nd Engineering Test Design – Overview, cont.

Analyze Data from Engineering Test at Control Site and Document Performance

- Transform data to 3D georeferenced point cloud. Assess shallow-water (0-5m depths) mapped area with point densities >900 pts/m^2 (3x point density of previous engineering test)
- Object detectability analysis
- Parameter estimations – bathymetry, point density, useable bathymetric area, probability of detection
- MTF Analysis and Determination of False Alarm Rate



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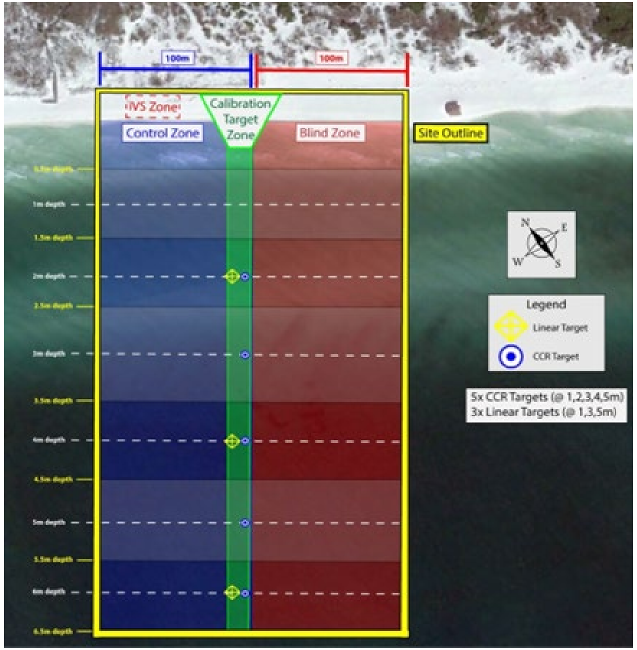
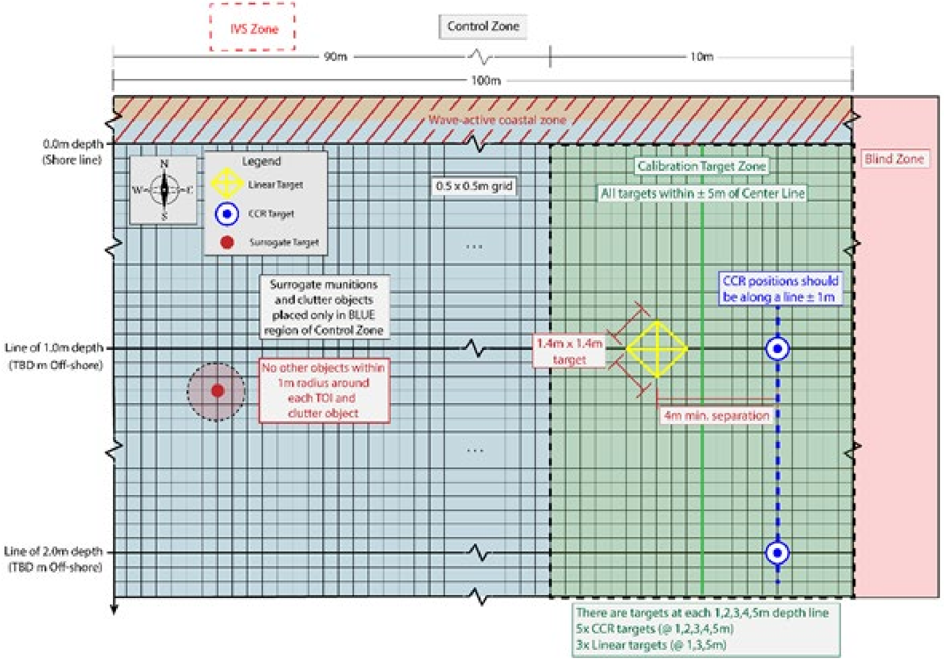
Panama City ESTCP Site and Test Plan





Coconut Island (Moku o Lo‘e) test plan anticipated to be similar.

Performance Objectives

Performance Parameter	Metric	Data Required	Success Criteria
Quantitative Performance Parameters			
Bathymetric Point Density and Useable Bathymetric Area	Number of bathymetric LiDAR point measurements per square meter	Analysis of LiDAR georeferenced 3D point cloud Water and atmospheric conditions	• > 900 pts/m² • > 80% of area surveyed for water depths from 0-5 m *
Detection of emplaced objects	Percent detected of all emplaced objects within the useable bathymetric area	• location of all objects surveyed with sub-meter accuracy • water and atmospheric conditions • dimension and orientation of objects • 3D point cloud for object detection	• > 90% prob. of detection (≥ 100mm) • > 50% prob. of detection (75mm ≤ x ≤ 100 mm)
Classification of detected objects	Percent of detected objects properly classified as an emplaced munition (TOI)	(Same as above)	• > 75% classification of detected objects as TOI's (≥ 100 mm) • > 50% classification of detected objects as TOI's (≤ 100 mm)
False Alarm Rate estimate	Total number of false positives (FP) ~~divided by the useable bathymetric area~~	(Same as above, plus:) • ~~Clutter and target density (emplaced objects / m²)~~ • Calibration target results for MTF analysis	• ~~< 1 false alarm / 10,000 m²~~ • Highly Dependent on sea state/turbidity/etc. • **New Data Product:** False Alarm Rate, determined as function of MTF

Performance Objectives

Performance Parameter	Metric	Data Required	Success Criteria
Quantitative Performance Parameters (continued)			
Area Coverage Rate	Number of acres of data collected per day	• Log of field work accurate to 15 minutes • Surveyed area from analysis of LiDAR point cloud	• >15 acres per day*
Location Accuracy	Planar and vertical resolution and standard deviation in northing, easting, and vertical for calibration objects	• Depth measurement from analysis of LiDAR point cloud • On-board camera - visual clarity • NTU value(s) of survey area • HI-ARL measurements	• planar resolution 50 - 150 mm point spacing • vertical resolution < 30 mm • < 30 mm standard deviation for each point
Maximum Detection Depth	Maximum depth with point density < 100 pts/m^2 and > 10 pts/m^2	• Depth measurement from analysis of LiDAR point cloud • On-board camera - visual clarity • NTU value(s) of survey area • HI-ARL measurements	• > 5 m depth • >1 Secchi depth

Performance Objectives - Qualitative

Performance Parameter	Metric	Data Required	Success Criteria
Qualitative Performance Parameters			
Ease of Use: Operability	• Procedures of sensor deployment & workflow	• Feedback from technician on site • Survey documentation	• Recommendation of system for use
Operational Cost	• Survey operations • Post processing effort • Person power requirements	• People time for survey activity and data post processing • area coverage	• Costs lie within expected ESTCP operations
Limits of Applicability	• Unusable bathymetric area	• Analysis of LiDAR georeferenced 3D point cloud	• < 20% of area surveyed not useable in 0-5 m depths

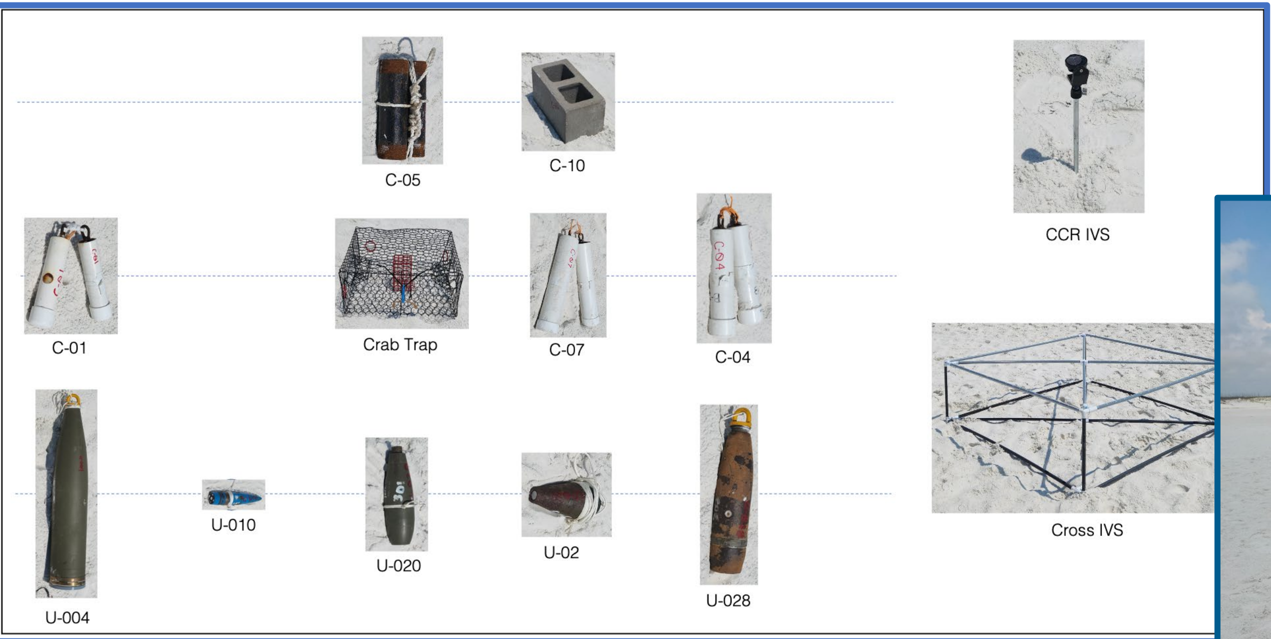
Results to Date

- IVS Zone: Detection and Classification
- Summary of Salient Panama City Engineering Test Results
    1. ***Instrument Verification Survey:* Shell Island, Days 2, 3, 4, and 5**
    2. ***Shallow Water Calibration Target Area:* Shell Island, Days 4 and 5**
    3. ***Shallow Water Control Zone:* Shell Island, Days 3, 4, and 5**
    4. **Blind Zone Test: Cancelled**
- Lessons Learned/Design Improvements for UH-ARL Test
- Current Status of Project

IVS Zone: Detection and Classification

- Unsupervised object detection performed in IVS zone by human data analyst
- Detection was performed at two confidence levels
  1. Strong detection - analyst was reasonably sure an object was present
  2. Weak detection - analyst wasn't sure if an object was present, false positives not penalized
- Detected objects were then classified as:
  1. Munitions
  2. Clutter
  3. Unknown

Panama City, FL:
Engineering Test: IVS Zone



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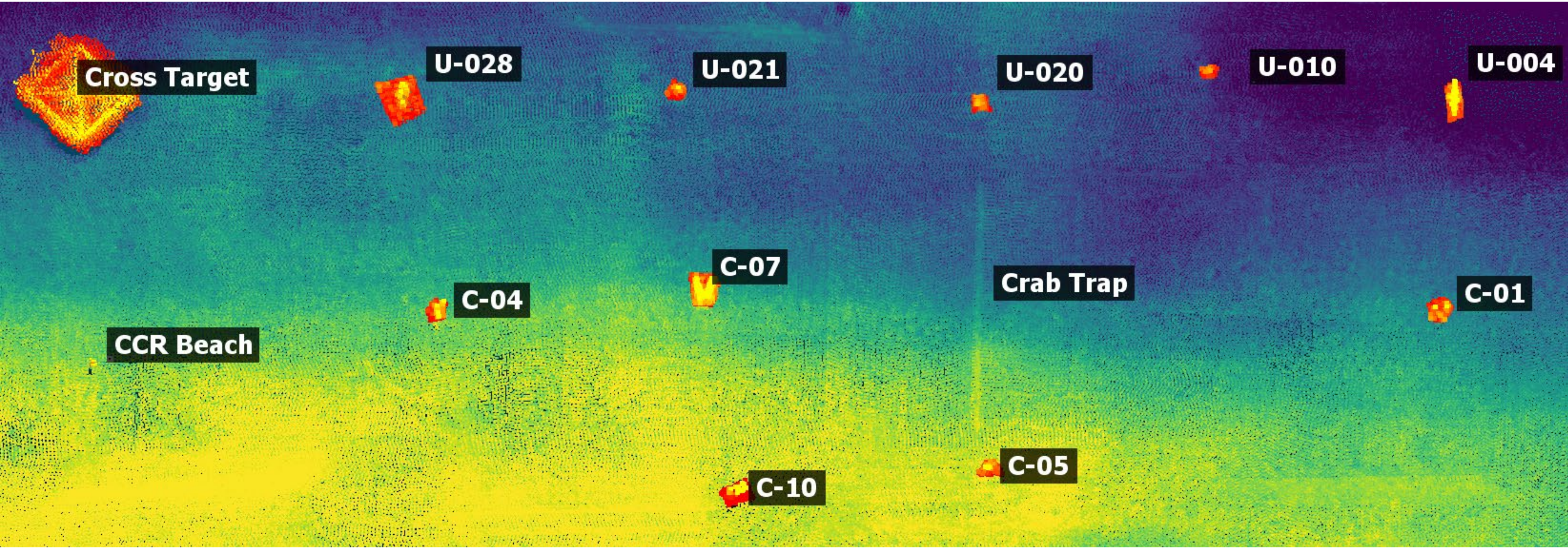
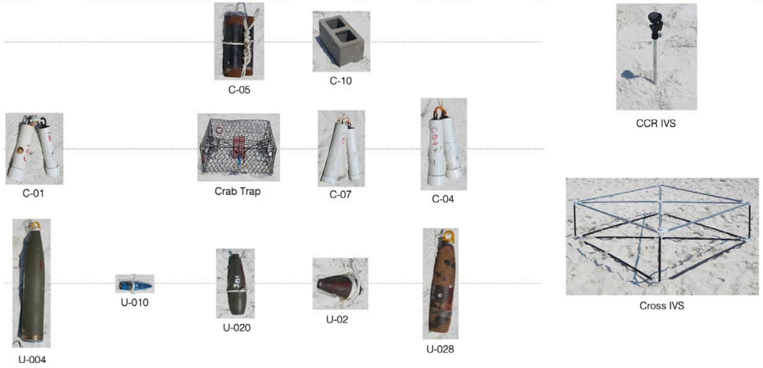
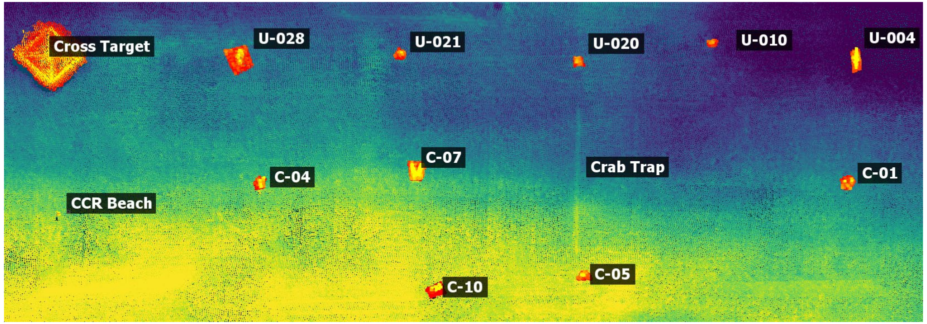
Panama City, FL: Engineering Test Instrument Verification Survey (IVS) Results



Panama City, FL: Engineering Test Instrument Verification Survey (IVS) Results





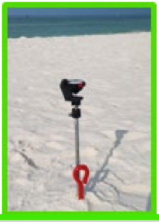
Object ID	Blind Test
U-004 north	Identified, Strong Detection
U-006 east	Strong Detection
U-020 north	Strong Detection
U-021 west	Weak Detection
U-028 north	Identified, Strong Detection
C-04 pvc pair	Identified, Strong Detection
C-07 pvc big	Identified, Strong Detection
Crab trap ivs	Missed
C-01 pvc small	Missed
C-05 metal conduit pair	Missed
C-10 concrete block	Identified, Strong Detection

- Unsupervised object detection performed by human analyst
- Detection was performed at two confidence levels
  1. Strong detection - analyst was reasonably sure an object was present
  2. Weak detection - analyst wasn't sure if an object was present, false positives not penalized

Panama City, FL:
Engineering Test: Calibration Zone

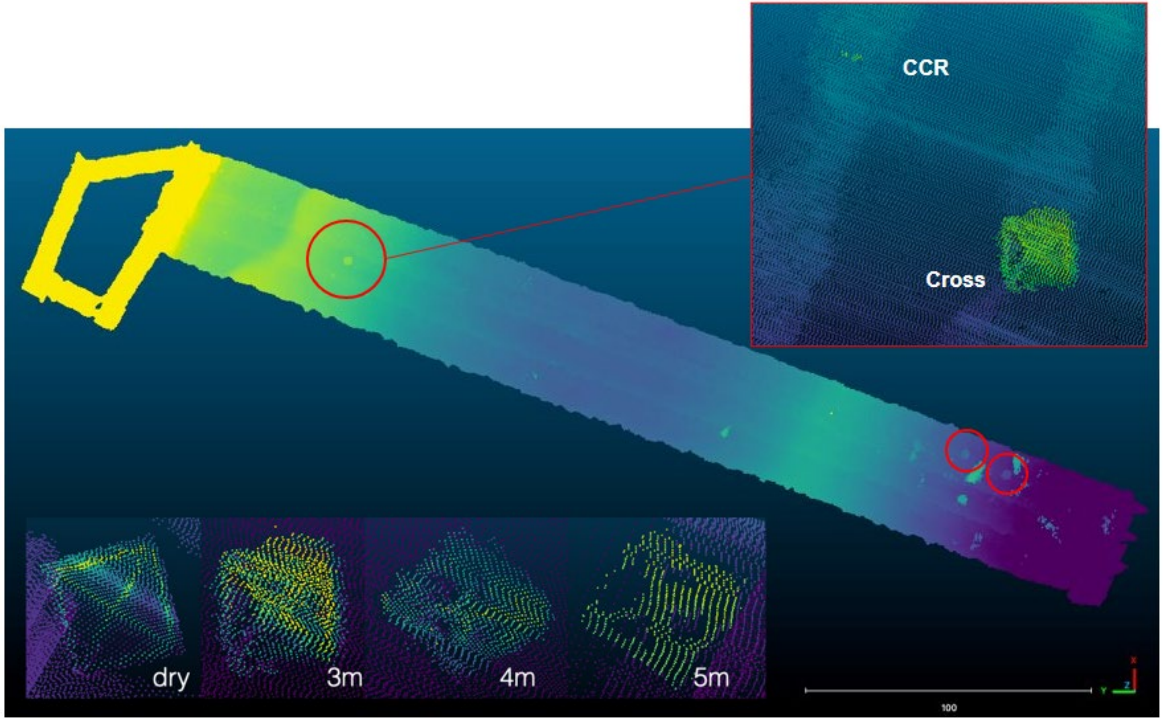
Calibration Target Analysis

- All calibration targets deployed at Panama City were detected on land and underwater
- Targets used to investigate point density distribution and resolution properties by applying **MTF Analysis**



Corner-cube retroreflector

Retroreflective tape



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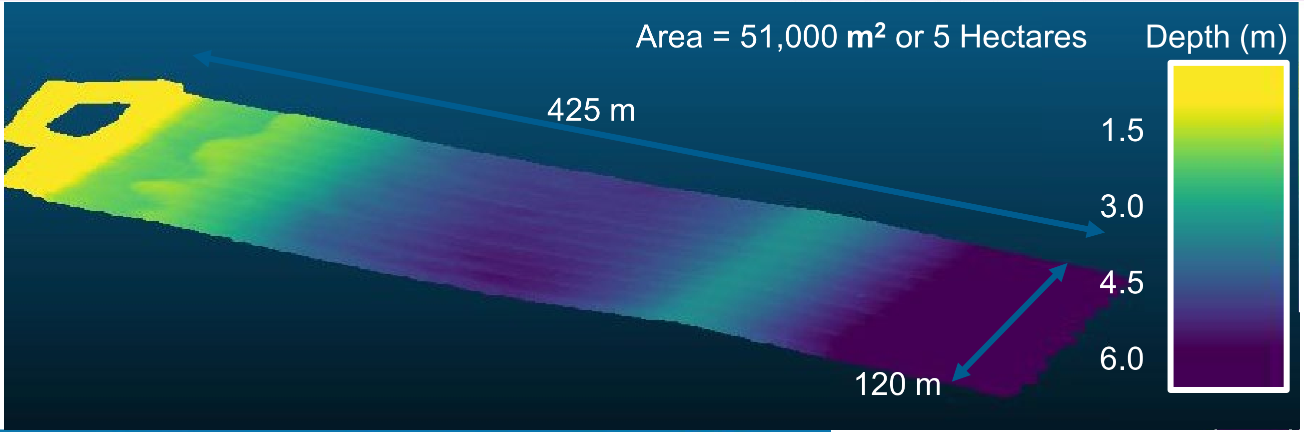
Panama City, FL:
Engineering Test: Control (Non-Blind) Zone

Classified EDGE Point Cloud:

- Land (yellow)
- Bathymetry (lt. green – blue – purple)
- Water Column
- Water 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.

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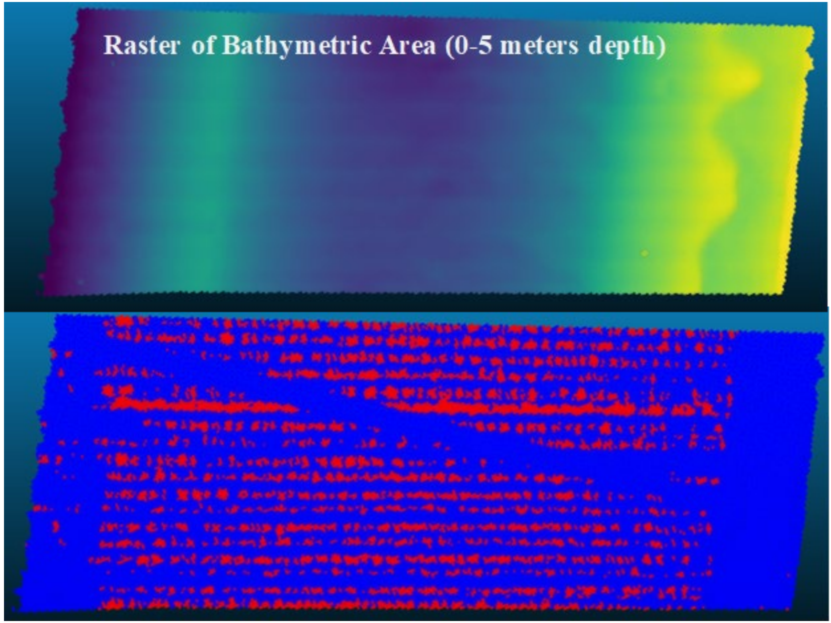
Performance Objectives: Useable Bathymetric Area and Depth

- Useable Bathymetric Area: **Success**
  - >300 points per square meter
  - 80% of area surveyed for depths from 0-5 meters
  - Results from engineering test #4: **80.3% of area >300 pts/m²**
- Maximum Detectable Depth: **Success**
  - >5 m depth or >1 Secchi depth
  - **Maximum depth >6.5 m**



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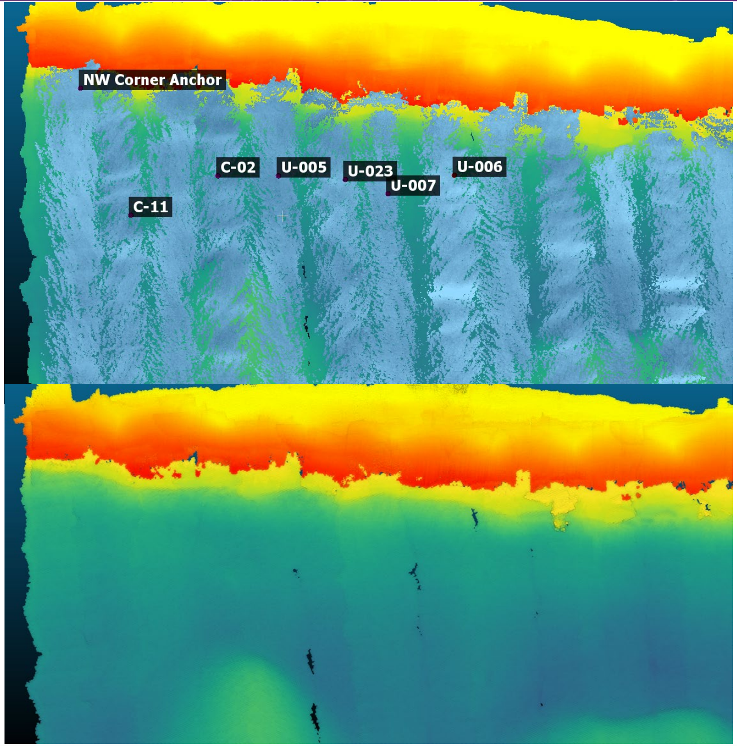
Performance Objectives:
Detection and Classification of Submerged Objects

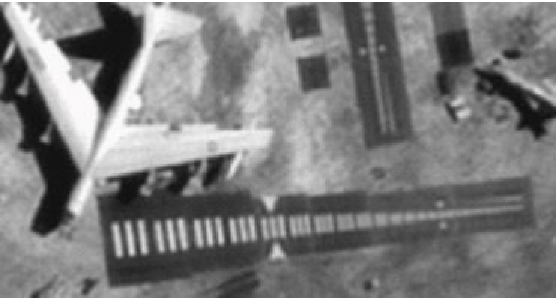
- Method used for IVS search applied to submerged objects by analyst
  - Supervised test performed using search radius of 1 m around provided locations
- **No "confident" detections**
  - Submerged objects **not resolved**
  - Detection, classification, and false alarm performance objectives ***not successful***
- ***Why not?***
  - Adjusted flight plans resulted in less point density than IVS zone
  - Lower point density due to CONOPs changes
    - **Should have seen some detections**



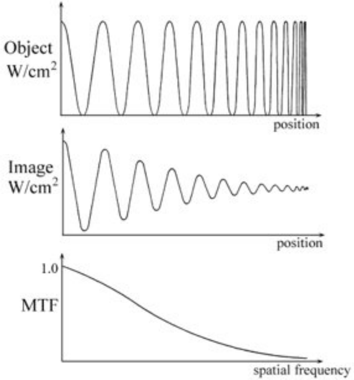
Non-Conformance Analysis: Resolution Assessment using MTFs

Modulation Transfer Function (MTF) is a resolution metric defined by **feature size** and **contrast**.

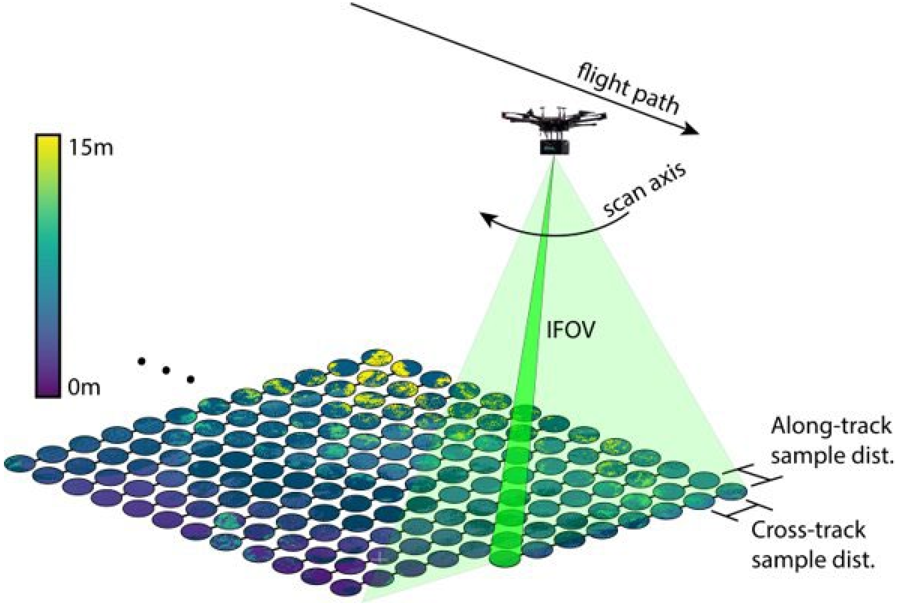
- Measured contrast decreases as frequency increases
- At high frequencies, contrast is eventually extinguished
- The cutoff frequency represents the smallest resolvable feature size



Fiete, R. (1999). Image quality and λFN/p for remote sensing systems.



Boreman, G. D. (2001). Modulation Transfer Function in Optical and Electro-Optical Systems



For LiDAR images, height is the contrasting signal for MTF analysis

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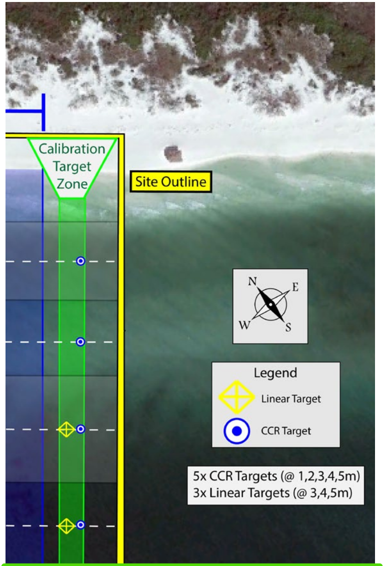
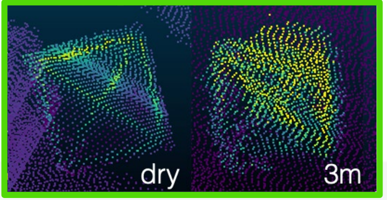
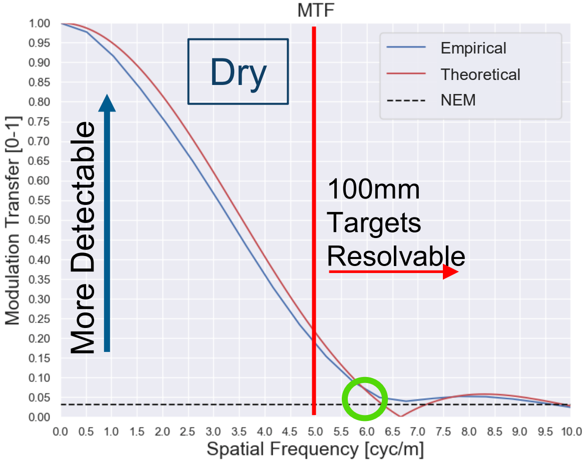
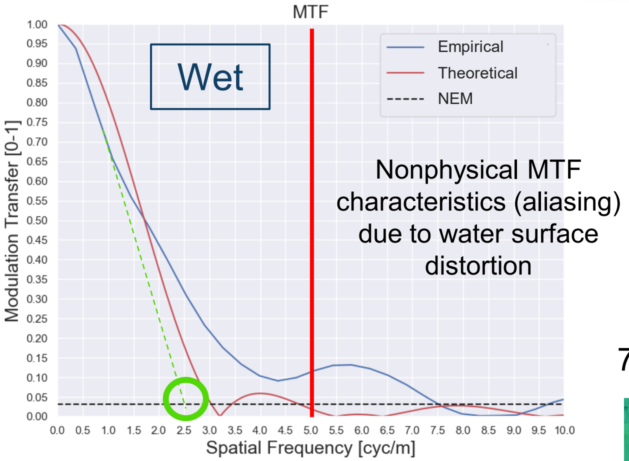
Panama City, FL Campaign MTF Analysis

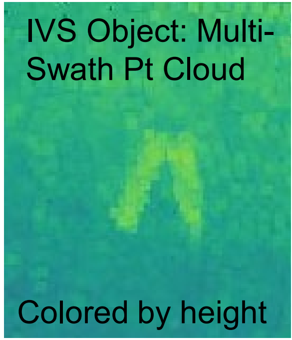








75 mm clutter object



More Resolvable/Smaller Objects

Dry cutoff resolution ≈ 80mm

Wet cutoff resolution ≈ 200mm*

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

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

*Noise-Equivalent Modulation (NEM) threshold is inherently higher for bathymetric data, but is difficult to quantify

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Lessons Learned: EDGE Limitations and Data Processing

- Instrument limitations associated with commercial system
  - **Point density** not suited for high-resolution applications
  - **Large beam divergence** for laser product safety purposes
  - **Point accuracy** not suited for high-resolution applications
- Data processing deficiencies
  - Swath alignment, boresighting errors, and water surface variability amplified total uncertainty
  - Rudimentary, manual detection/classification approach contributed to shortcomings
  - Impacts of parameters such as sea state/turbidity were less well known

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Improvements Needed for UHI-ARL Engineering Test

- Need: Improved resolving power
  - Advanced R&D lidar designed to specs quantified by Co-I's SERDP research
    - Highly collimated beam
    - Improve pointing solution (up to one order of magnitude)
    - Increase point density (3-4x per m^2)
      - Success Criteria: > 900 pts/m2
      - Anticipated: ~1300 pts/m^2

Parameter	Base	Improved
Points per scan	88	293
Mirror pointing error	0.25 deg	0.01 deg
Across-track sampling at 15m	90 mm	27 mm
Spot diameter at 15m	64 mm	15 mm
Beam divergence ($1/e^2$)	4.2 mrad	1 mrad
Point Density (points/m^2/swath)	350	1371

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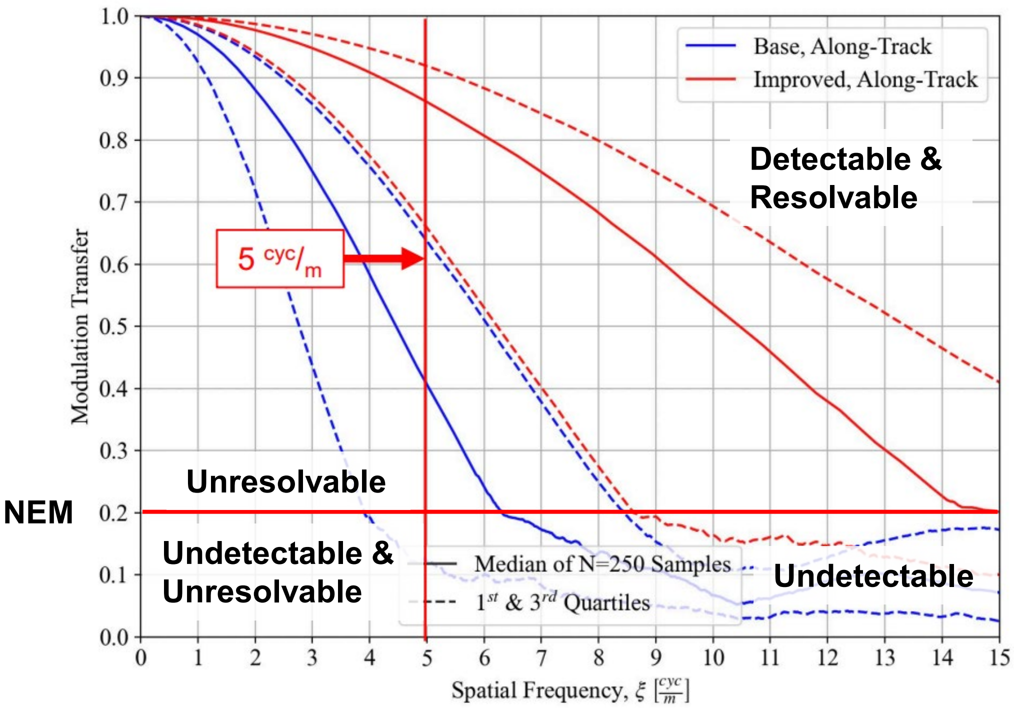

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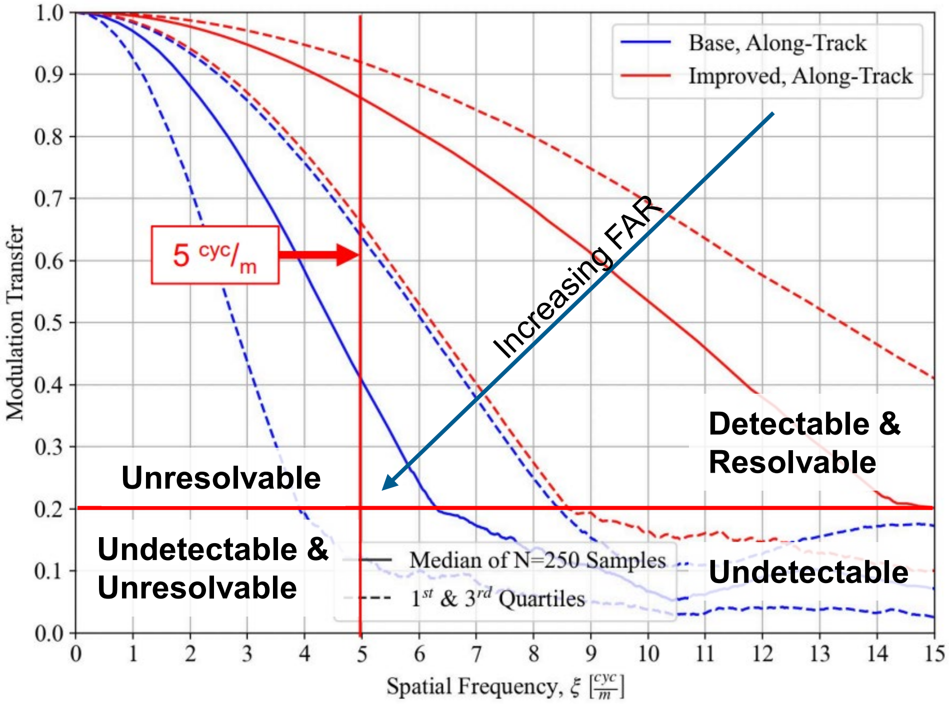
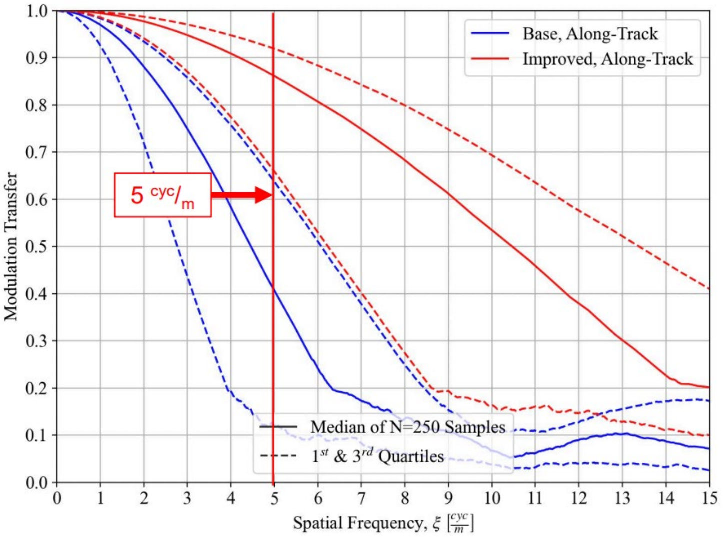
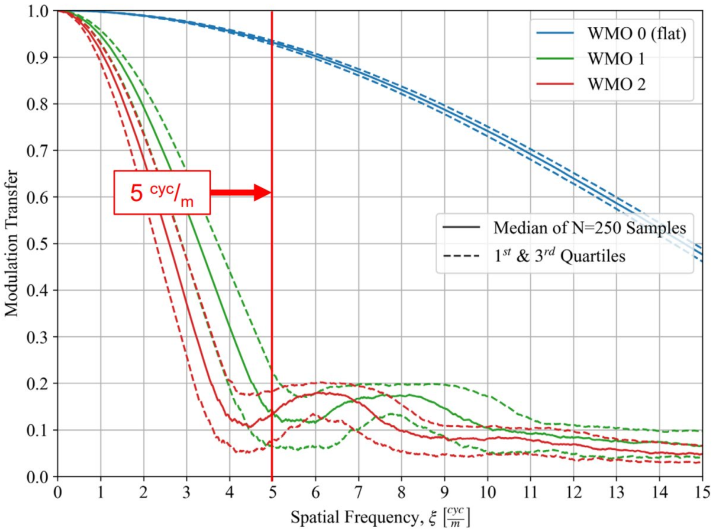
      - Success Criteria: > 900 pts/m2
      - Anticipated: ~1300 pts/m^2
  - False Alarm Rate as function of MTF
    - Working with Co-I's team to generate empirical relationship between MTF and FAR at time of measurement



Identifying Updated System Requirements

- Dr. Jeff Thayer’s SERDP Project Outbrief – 14:45ET (14 Aug)





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Improved MR Lidar System & ConOps

- Design-to Specification: ≥4 Points on 100mm Munition
  - at 3m depth, with calm, clear conditions
- Redesigned Optical Chain
  - Estimated 40-50% increase in Transmitted light (reduction in “wasted” photons)
  - <1 mrad divergence shown on benchtop demonstrator
  - Optics sub-assembly completed, awaiting final integration in R&D flight unit
- Enhanced Pointing Angle Measurement Precision
  - Encoder-based pointing angle measurements
  - Encoder subassembly mechanically integrated (benchtop)
  - Firmware development complete

Improved MR Lidar System & ConOps

- Enhanced Data Processing (in development)
  - Improvements enable higher resolution geolocation of lidar returns using improved algorithm
  - Higher fidelity boresighting correction/calibration
- ConOps Lessons Learned Integrated in Planning for UHI-ARL Test
  - Coordinating with the UHI-ARL team to ensure improved ConOps/flight planning over Panama City Test
    - Improved knowledge of zone boundaries and non-“blind” target locations
    - Flight altitudes and speeds optimized to hit point density objectives
  - Coordinating Logistics with Martine Bissonnette, UHI-ARL Team
    - Anticipate submitting demonstration plan by end of month

Remaining To-Do's

- Finalize data analysis code, subsystem tests to reflect HW upgrades
- Integrate subsystem components into flight unit
- Perform preliminary functional testing, calibration and validation
  - Validate optical performance meets point density and divergence requirements
  - Validate encoder resolution meets theoretically required resolution
- Perform full system test at Coconut Island (Moku o Lo'e), Hawaii
  - Littoral environment
  - Presence of ocean waves
  - Varied bottom surface types
- Apply Co-I's SERDP research methods to assess go/no-go for live site with upgraded unit

Upcoming Activities/Deliverables

- Demonstration Plan UH-ARL Test: < 31 Aug 2025
- Backyard Testing/Validation Campaign: ~Nov 2025
- Perform Test at Control Site: 9-13 Feb 2026
- Analyze Data from Control Site
  and Document Performance: 27 Mar 2026*
- Update Demonstration Plan (Go/No-Go): 27 Mar 2026*
- Final Report: 30 April 2026*

(*Proposed Date)

Technology Transfer

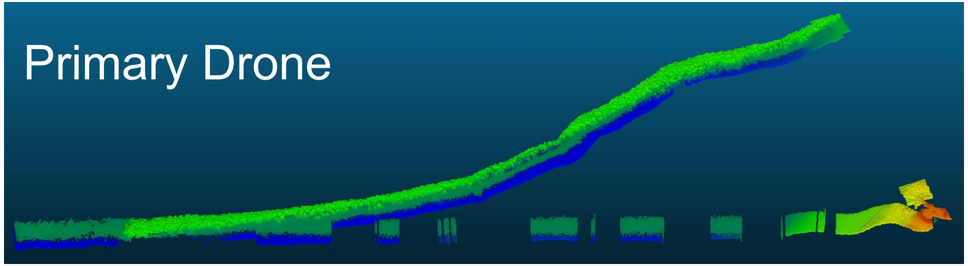
- Transition research to operations (CU SERDP)
  - Utilize remaining funds to build MR R&D unit to improve UQ analysis, optimize ConOps, and minimize point localization errors
  - UQ analysis for autonomous boresighting and swath overlay corrections
  - Calibration targets for empirical assessment of performance and improve post processing
  - System modeling for optimizing performance in MR applications
- Presentations at SERDP/ESTCP Symposium and Related Conferences
- Develop user manual for operational purposes

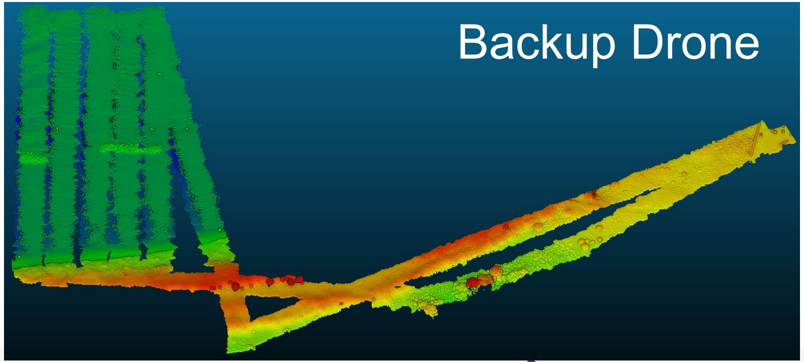
BACKUP MATERIAL

These charts are required and will be used by the Program Office but may not be presented.

Lessons Learned: ConOps

- Enhanced ConOps with experience gained from Panama City demo
  - Higher point density required without overlap
  - Overlap should include different viewing angles
- Deviation from operational test plan
  - Local logistics & provided information on test site
  - Drone Issues -> Adjusted flight plan for control zone -> Lowered point density





Test Design

- Flight ConOps
  - Altitude: 15-25 m
  - Speed: 3-5 m/s
  - Sidelap: 40-65%
  - Duration: 15-90 min
  - Scan Orientation: North at 0 degrees
- Instrument Verification Survey (IVS)
  - Deploy a subset of targets, clutter, and calibration objects on dry beach area (record easting, northing, and orientation)

Test Design

- Test object descriptions
  - Primary TOI will consist of either inert or surrogate munitions (30 total) with diameters ranging from **60 mm, 81 mm, 105 mm, and 155 mm.**
  - Secondary TOI (8 total) with **~40 mm** diameter as a stretch goal.
  - Clutter objects (20 total) (Scuba tank, crab pots, anchors, soda cans, or similar)
  - Calibration objects (7 corner cube reflectors, 4 reflective crosses)
- Underwater location capability
  - Determine orientation to within a few degrees
  - Provide position information within a 0.5 meter radius

Test Design – Environmental Data

- Base station settings (Ground truth)
  - Locate at USGS monument
  - Collect 1 hr before survey and for 15 min after
  - Rinex file data output
- Turbidity measurements
  - With nephelometer in NTUs (two significant digits)
- Other:
  - Water surface
  - Ocean current
  - Meteorological
  - Bottom Surface

Panama City, FL: Engineering Test Performance Objectives: IVS Zone

- Detection of emplaced objects: **Success**
  - > 90% prob. of detection (> 60mm)
  - > 50% prob. of detection (≤ 60 mm)
- Classification of detected objects: **Not successful**
  - > 75% classification of detected objects as TOI's (> 60 mm)
  - > 50% classification of detected objects as TOI's (≤ 60 mm)
- False Alarm Rate estimate: **Not successful**
  - < 1 false alarm / 10,000 m2

Reality

Classification	Munitions	Clutter
Munitions	40% (2/5)	0%
Clutter	0%	50% (3/6)
Unknown	60% (3/5)	0%
Missed	0%	50% (3/6)

Total IVS Zone Objects	**11**
Total Munitions	**5**
Strong Detections	18
Correct Strong Detections	7
Correct Strong Munition Detections	**4**
Total Detections (Strong + Weak)	37
Correct Total Detections	8
Correct Total Munition Detections	**5**
Missed Objects (all clutter)	3

Detection Results

Revised Test Plan

- Engineering test 1
  - Drone issues
  - 2 days of tests
- IVS zone
  - Performed late day 2
  - Also day 3
- Searching/orientation flights
  - Day 3 and 4
- Calibration zone
  - Located on day 4
- Control zone
  - Revised plan performed day 5: 15m AGL with 50% side-lap @ 3m/s

Reasons for Test Plan Revision

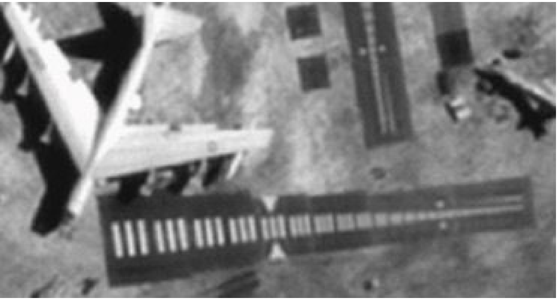
- Extenuating factors
  - Local logistics
  - Unforeseen change of UAS platform
  - Antiquated flight planning software (associated with backup drone)
  - Poor communication on location and orientation of Calibration and Control zones
- Impact on test plan
  - Fewer flights were possible
  - Shorter flights were necessary
  - Orientation flights required
  - Blind tests skipped (timing)

Resolution Assessment using MTFs

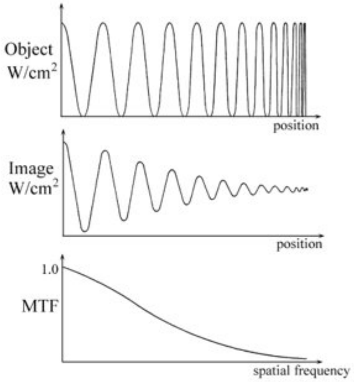
MR22-3257: Quantitative Assessment of LiDAR Technology for Detecting, Localizing, and Characterizing Underwater Munitions in Shallow Waters

Modulation Transfer Function (MTF) is a resolution metric defined by **feature size** and **contrast**.

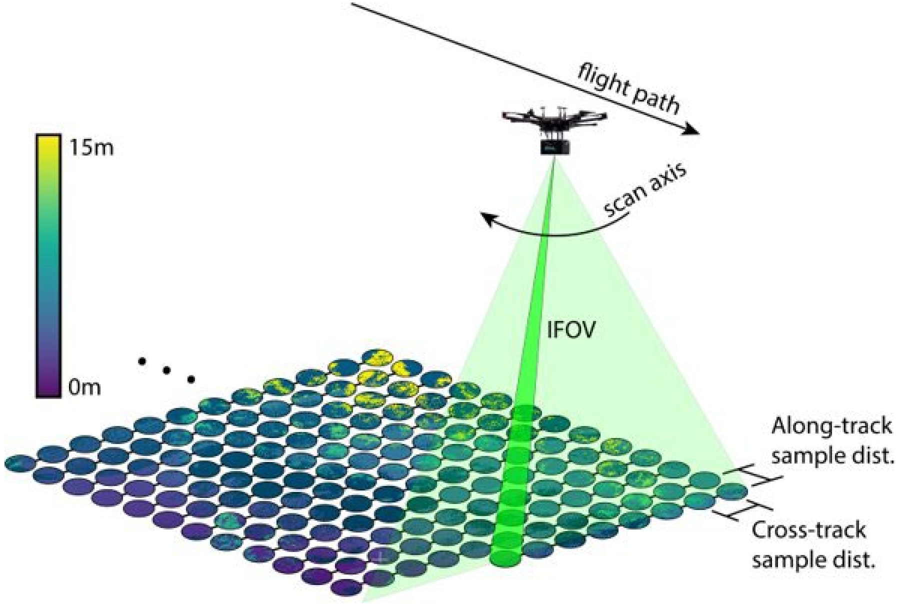
- Measured contrast decreases as frequency increases
- At high frequencies, contrast is eventually extinguished
- The cutoff frequency represents the smallest resolvable feature size



Fiete, R. (1999). Image quality and λFN/p for remote sensing systems.



Boreman, G. D. (2001). Modulation Transfer Function in Optical and Electro-Optical Systems



For LiDAR images, height is the contrasting signal for MTF analysis

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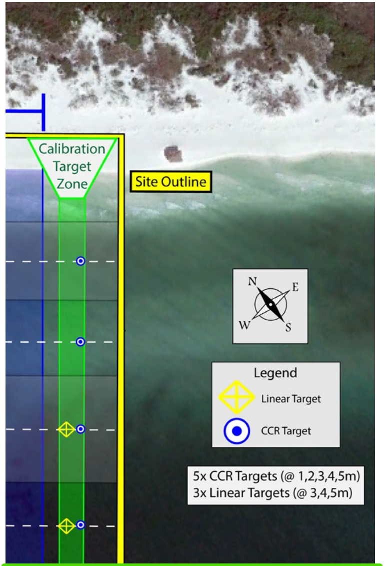
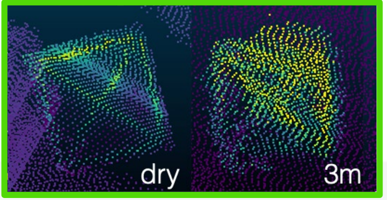
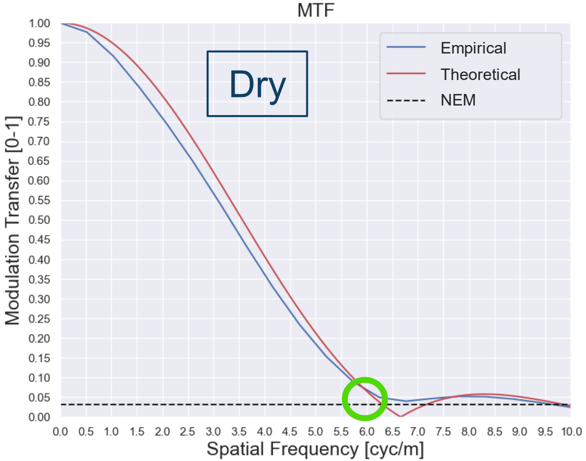
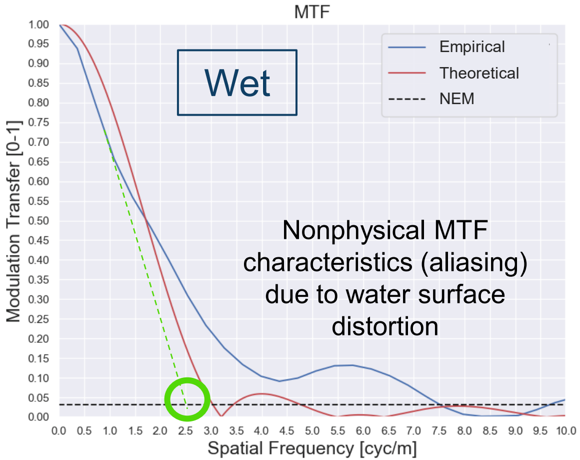
Panama City, FL Campaign MTF Analysis

MR22-3257: Quantitative Assessment of LiDAR Technology for Detecting, Localizing, and Characterizing Underwater Munitions in Shallow Waters









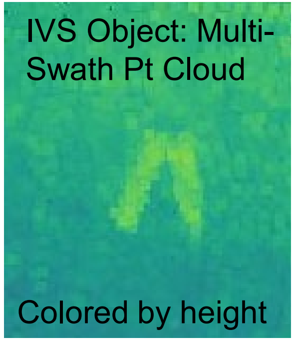
Dry cutoff resolution ≈ 80mm

Wet cutoff resolution ≈ 200mm*

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

75 mm clutter object

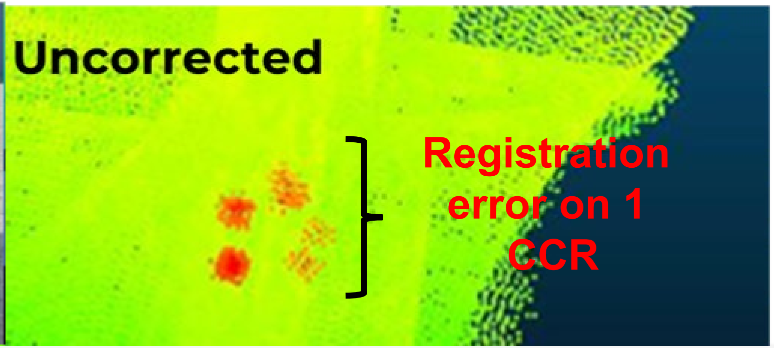


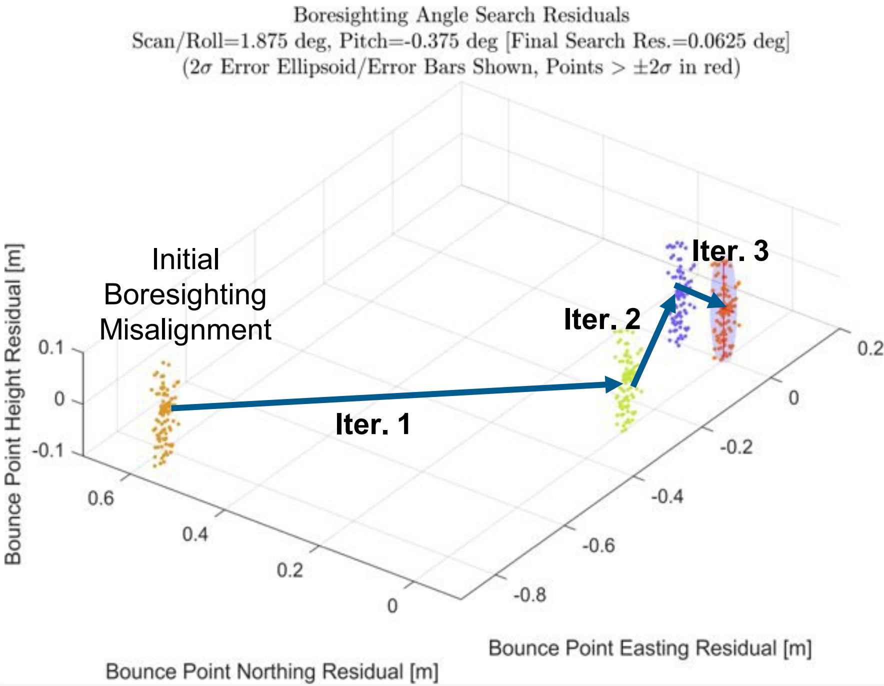
*Noise-Equivalent Modulation (NEM) threshold is inherently higher for bathymetric data, but is difficult to quantify

Boresighting Alignment: gPCE UQ

MR22-3257: Quantitative Assessment of LiDAR Technology for Detecting, Localizing, and Characterizing Underwater Munitions in Shallow Waters

- Boresighting correction for measurement co-registration remains difficult & manual
- Measurements of ground control points of known position can assist
- gPCE allows direct modeling of boresight angle bias and can be used to automate modeling and calculation of boresighting angles





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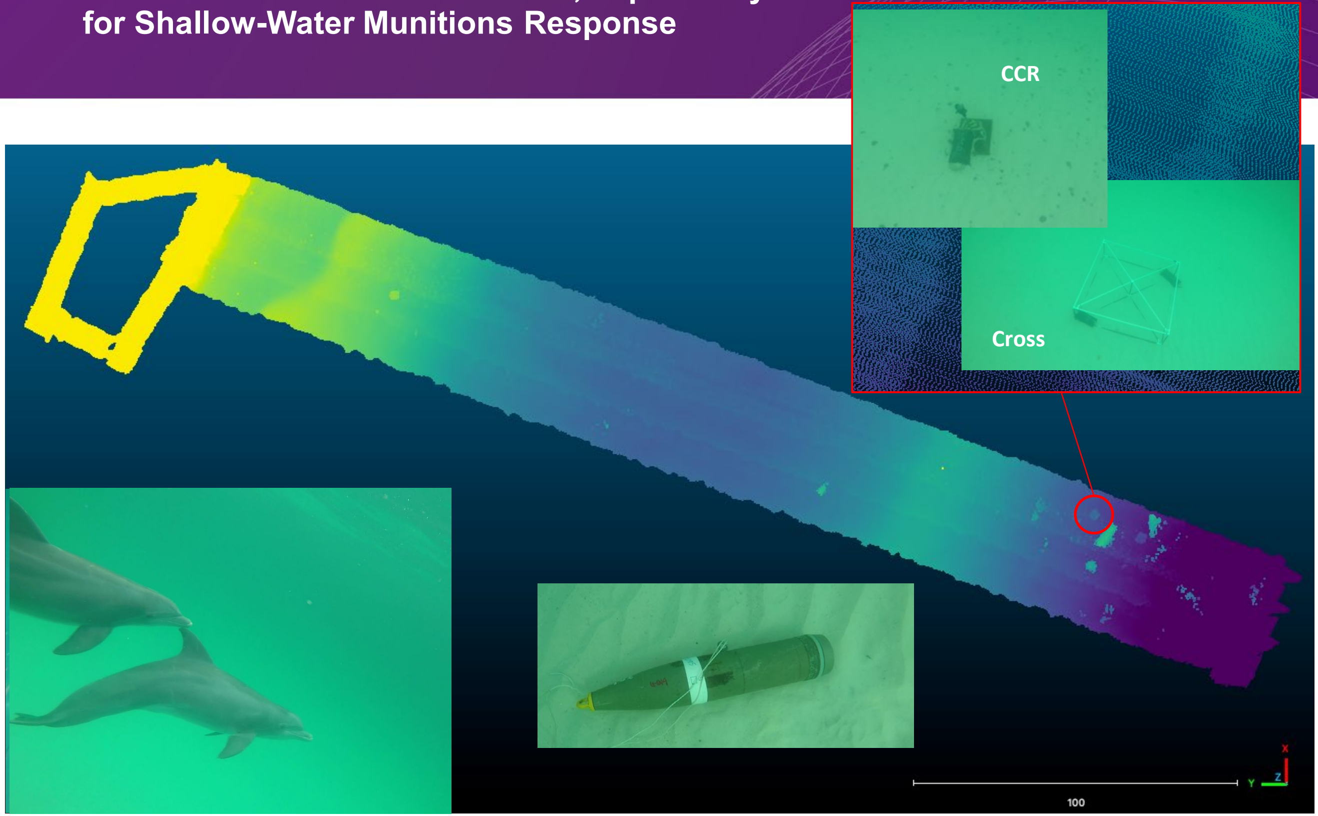
Detection: Bathy Point Cloud Processing

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

Submerged Object Analysis

- Diver deployment, orientation, and localization of calibration targets, clutter objects, and surrogates
- Analyze LiDAR points classified as submerged
    - All calibration targets identified
    - Clutter in water column detected
    - Proud objects detected



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Research to Operations to Research (R2O2R)

- Post Operational Assessment indicates research iteration required
- CU SERDP research elucidates next steps
  - Limitations of commercial EDGE design must be addressed with new design
    - Reduced beam divergence
    - Increased point density
    - Improved point accuracy
  - Improved data processing required
    - Automatic boresight alignment
    - Replace data analyst with statistical approach and ML
  - ConOps and survey methodology advancements
    - Improve point distribution and # of viewing angles on scene/targets

REQUIRED BACKUP MATERIAL

These charts are required and will be used by the Program Office but may not be presented.

MR22-EO-7964
Demonstration of UAS-Based Topobathymetric Lidar for Shallow-Water Munitions Response

Performers: Orion Space Solutions (formerly LiTeWave Technologies, Inc.) / University of Colorado

Technology Focus - *Demonstrate the EDGE LiDAR for Munitions Response (MR): first in controlled environments (Panama City Beach, FL & Coconut Island [Moku o Lo‘e], Hawaii); then in a live site.*

Demonstration Site - *Shallow nearshore areas along the southern part of Shell Island near Panama City Beach, Florida and nearshore areas along Coconut Island (Moku o Lo‘e), Hawaii*

Demonstration Objectives

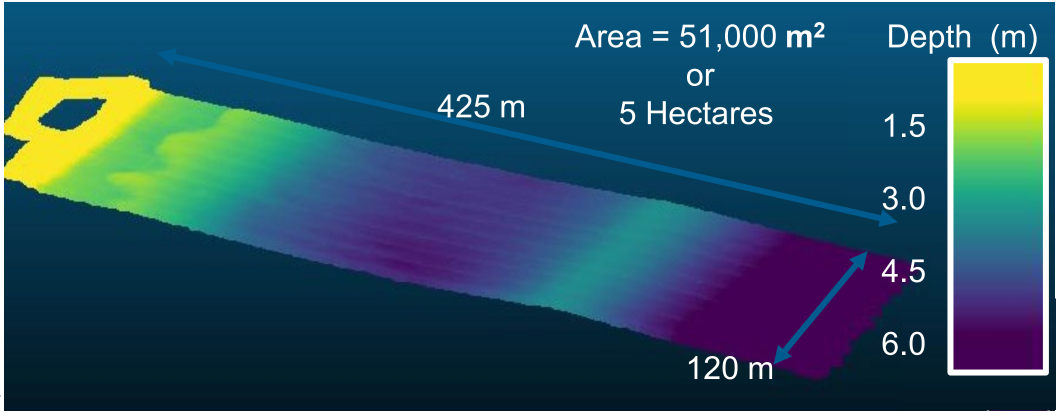
- *Perform demo at an ESTCP test site using a UAS-mounted topographic-bathymetric LiDAR capable of both wide-area and detailed bathymetric surveys with munition surrogates.*
- *Perform a demo at a live munitions site if criteria met.*
- *Determine Operational parameters required.*

Project Progress and Results

- *Demonstrated wide-area survey capability of EDGE LiDAR system: >300pts/m^2 , >80% usable area 0-5m*
- > Maximum depth >6.5 m
- *Established the current limits of resolvability of EDGE LiDAR*
- *Designed hardware modifications to improve MR performance*
- *Implementing and validating upgraded MR LiDAR unit*

Technology Transition

- *Enhance ESTCP field outcomes: rapid survey, improved safety*
- *Foster new LiDAR capabilities for DoD/ DOE applications*



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Plain Language Summary

- What problem are you addressing?
  - Detection, classification, and localization of proud unexploded ordnance (UXOs) in shallow waters of 0-5 meters depth.
- What are you trying to achieve and how are you doing it?
  - Demonstrate the detailed survey capabilities of the EDGE LiDAR for Munitions Response (MR): first in controlled environments (Panama City Beach, FL & Coconut Island [Moku o Lo‘e], Hawaii); then in a live one (Vieques – or similar); and define CONOPS parameters.
- What are the expected outcomes and how is it advancing existing knowledge?
  - Develop a UAS-based LiDAR system for active sites to detect proud UXOs in shallow waters with high confidence and low false alarms.
  - This novel LiDAR technology can safely and rapidly access and map difficult to navigate aquatic areas

Impact to DoD Mission

- What's the most impactful thing that's happened since the last time you presented your work to us?
  - Determination of design parameters required for improving resolution of commercial EDGE LiDAR for MR applications in shallow waters (0-5m) and build-up of improved LiDAR to new design requirements.
- Why is this important?
  - While object detection in the water column has been previously demonstrated, the ability to locate, characterize and identify smaller objects on bottom bathymetric surface has direct DoD relevance.
- How is your project advancing DoD capabilities?
  - Other DoD applications include MCM applications, obtaining geospatial information of littoral zones (especially in areas that are inaccessible to boats or large aircraft), ingress and egress for operations, and collision avoidance for maritime navigation.

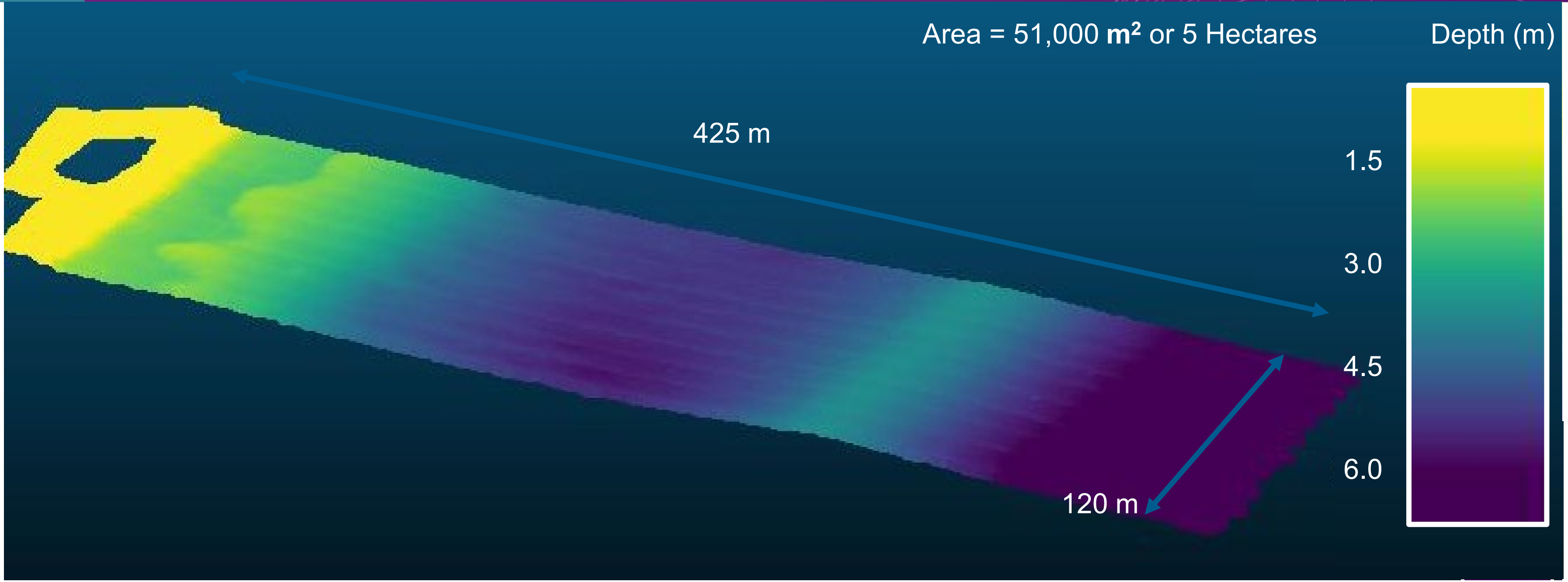
Publications

- Thayer, J.P., Sacca, K.W., Wise, A. K., and Thompson, G. 2022. Quantitative assessment of LiDAR technology for detecting, localizing, and characterizing, underwater munitions in shallow waters, SERDP/ESTCP Symposium, Nov 29 – Dec 2, 2022.
- Thayer, J.P., Sacca, K.W., and Thompson, G. 2022. Topo-Bathy Lidar Sensor for Characterization of Shallow Freshwater Environments from a UAS Platform, American Geophysical Union Fall Meeting, Dec. 2022.

Publications

- Thayer, J. P., K. W. Sacca, A. K. Wise, and G. Thompson, Quantitative assessment of LiDAR technology for detection, localization, and classification of underwater munitions in shallow waters, DoD Energy & Environment Innovation Symposium, Washington DC, Nov 28 – Dec 1, 2023, poster presentation.
- Sacca, K. W., J. P. Thayer, G. Thompson, B. Garby, M. S. Greenstein, and A. K. Wise, Water column compensation using submersible calibration targets for 3D LiDAR bathymetry, AGU Fall 2023 conference, San Francisco, Dec 11-15, 2023, poster presentation B31F-2169.
- Greenstein, M. (2024), A Comprehensive Analysis of Polygon Mirror Scanning for a UAV Based Bathymetric LiDAR, Master of Science Thesis, Ann and H.J. Smead Aerospace Engineering Sciences Department, University of Colorado at Boulder.

Additional Slide(s) for High-Quality Photos



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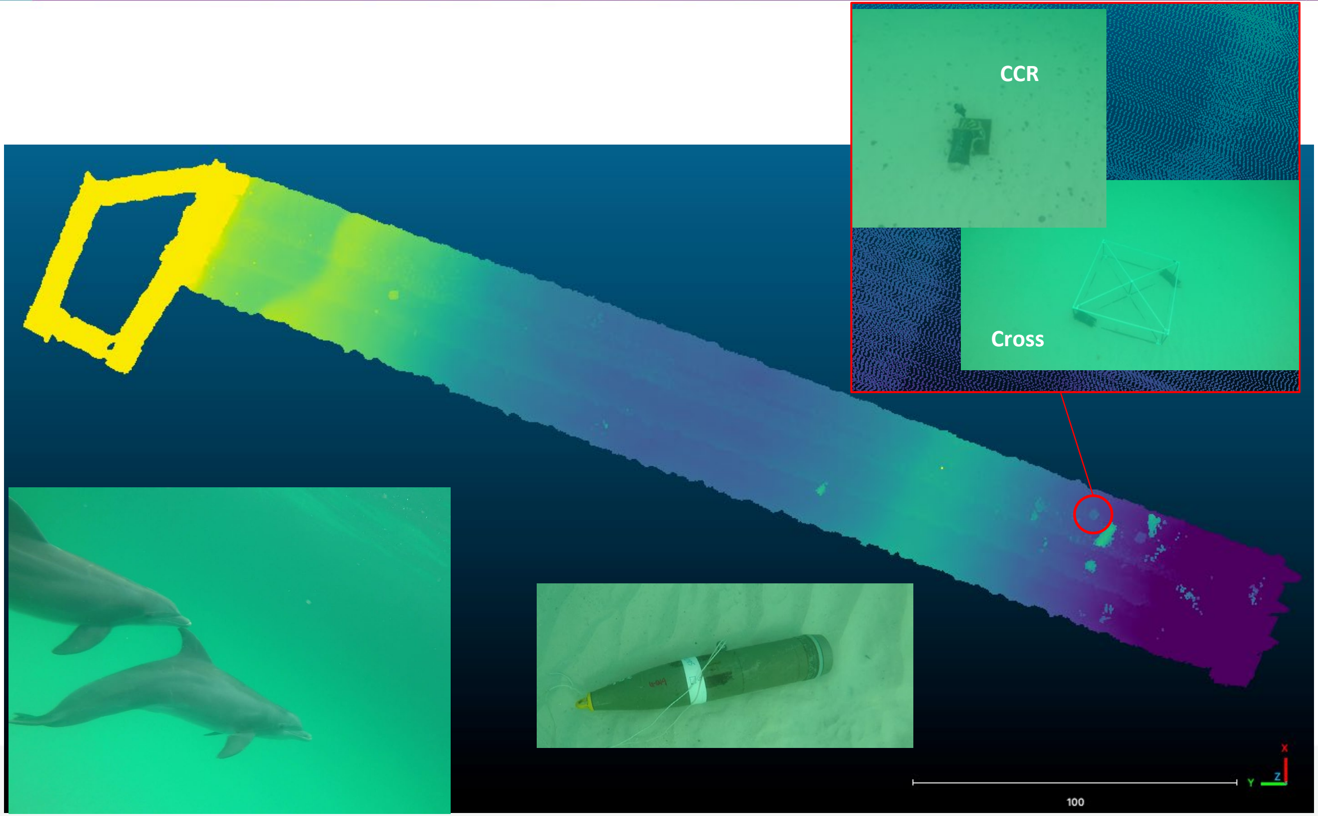

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Acronym List

CCR – Corner Cube Reflector
CONOPS – Concept of Operations
CU – University of Colorado
DoD – Department of Defense
gPCE – generalized Polynomial Chaos Expansion
GPS – Global Positioning System
IMU – Inertial Measurement Unit
LiDAR – Light Detection and Ranging
MTF – Modulation Transfer Function
MR – Munitions Response
PSF – Point Spread Function
SERDP – Strategic Environmental Research and Development Program
TOI – Targets of Interest
UAS – Unmanned Aerial System
UQ – Uncertainty Quantification
UXO – Underwater Unexploded Ordnance