Emerging extended-range undersea laser mapping techniques

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Overview

“This talk will mainly focus on the application of recently investigated laser systems to enhance detailed benthic site surveys”.

- **Background**
- **Problem Overview**
- **New Approaches & Results**
- **Summary & Future Challenges**

Background (requirements)

- **All marine hydrokinetic devices will have an impact on the surrounding benthic and pelagic habitats.**
- **Detailed knowledge of the impact on these habitats is critical for decision makers (site selection, future permitting for commercial-scale activities etc.).**
- **At proposed sites currents are strong and complex, making operation with tethered vehicles (e.g. ROV) difficult.**

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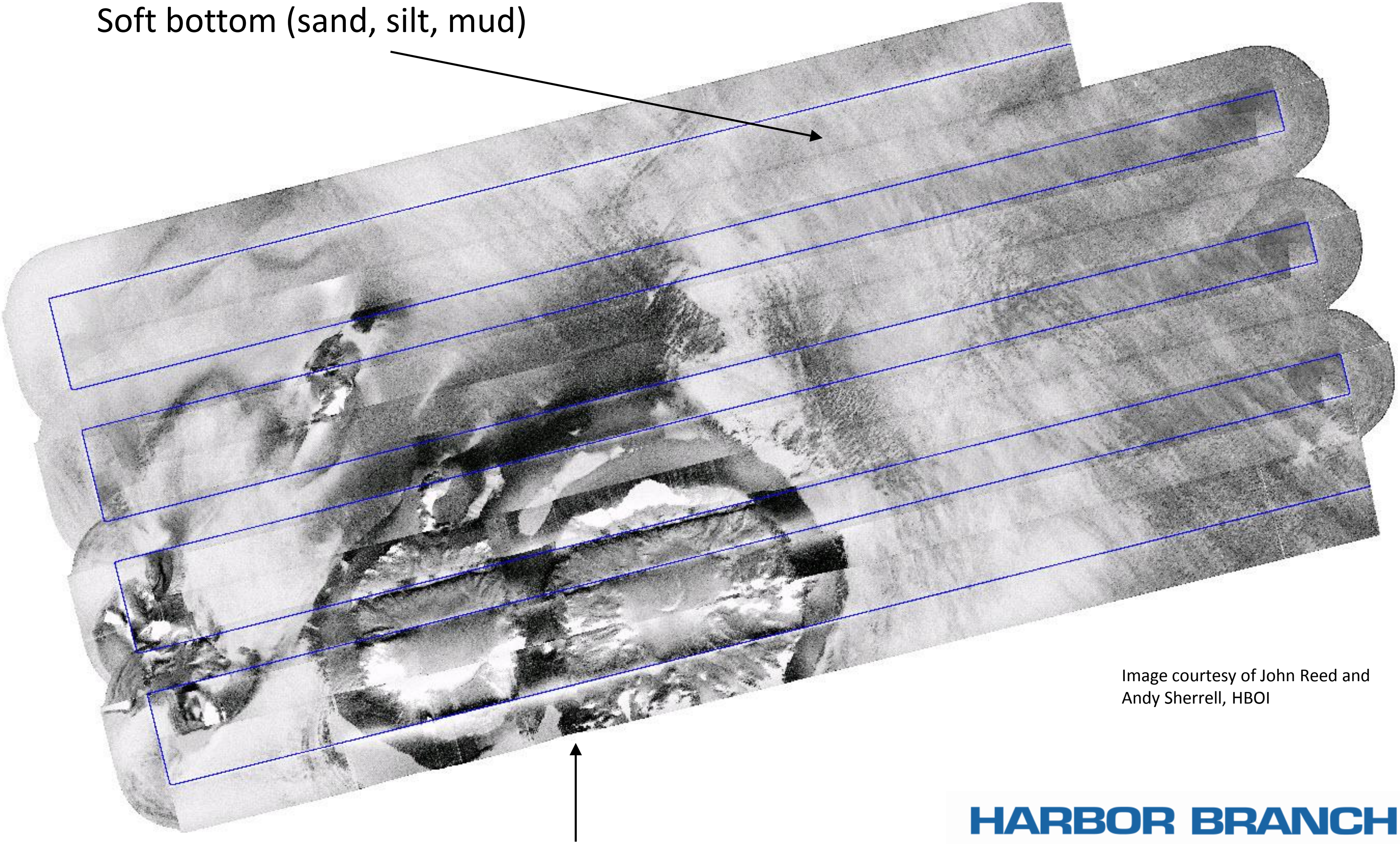
Background (methods)

- **AUVs are used to acquire both side-scan sonar and multibeam imagery of the bottom providing information on hard- vs soft-bottom habitat and low- vs high-relief. Deep Sea Coral Ecosystems are known to exist on hard bottoms.**
- **Detailed site assessment is necessary for higher resolution ground truthing of acoustic data. It is desirable that this survey be performed concurrently.**
- **AUVs are 3x faster than deep tow, with less data quality degradation due to coupling of surface motion. However it's desirable to fly AUV greater than 10m from the seafloor to avoid collisions.**

Mosaic of Side Scan Sonar Imagery



Soft bottom (sand, silt, mud)

Hard bottom (likely to be live habitat)

Image courtesy of John Reed and Andy Sherrell, HBOI

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Example Images from Optical Survey

Particluate Scattering

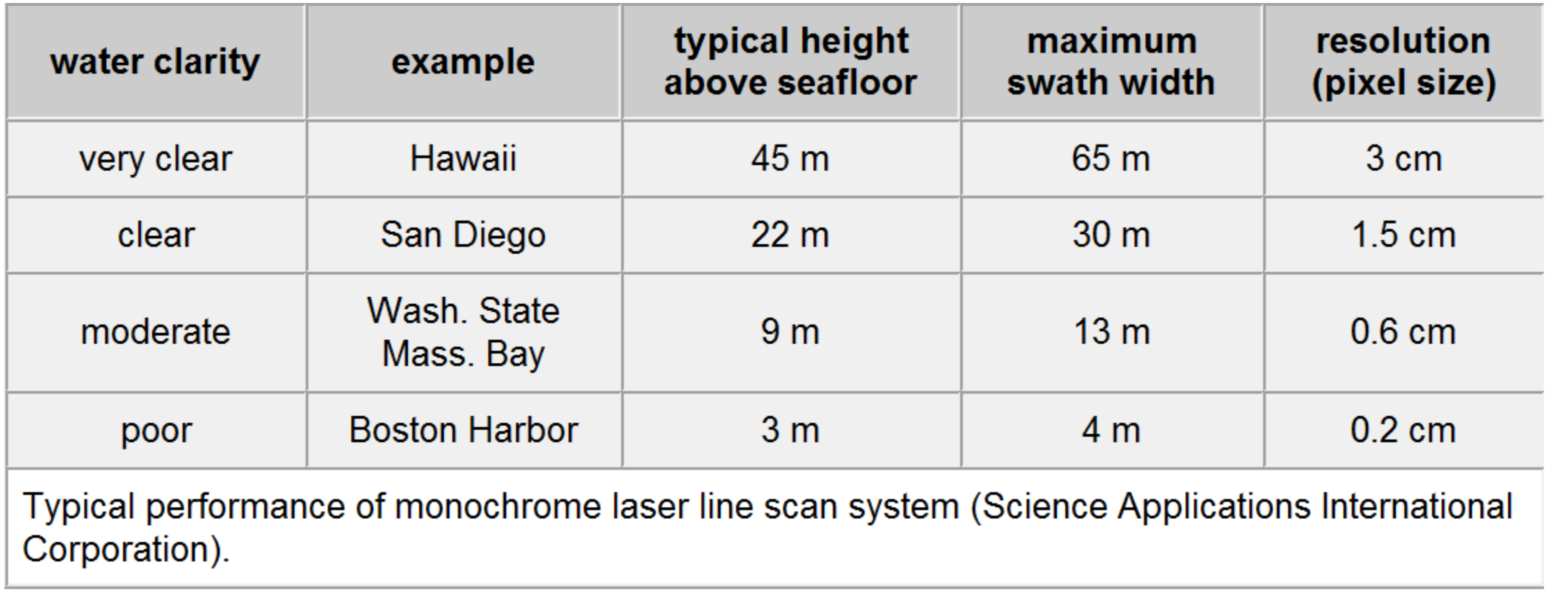
Backward: veiling luminance

Forward: Glow or blur

In both cases, the camera is about 2 meters from the subject

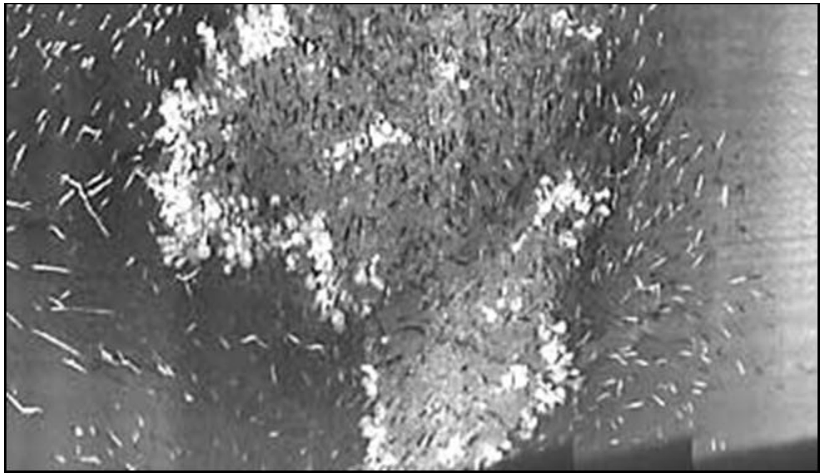
Blurring and loss of resolution due to Intra-frame motion

Existing Laser Line Scan Performance



water clarity	example	typical height above seafloor	maximum swath width	resolution (pixel size)
very clear	Hawaii	45 m	65 m	3 cm
clear	San Diego	22 m	30 m	1.5 cm
moderate	Wash. State Mass. Bay	9 m	13 m	0.6 cm
poor	Boston Harbor	3 m	4 m	0.2 cm

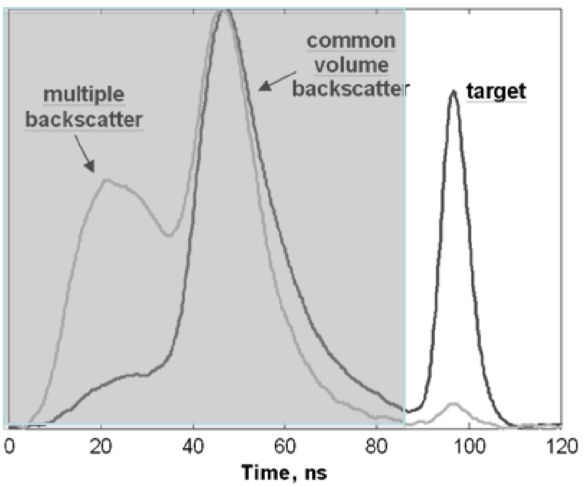
Typical performance of monochrome laser line scan system (Science Applications International Corporation).



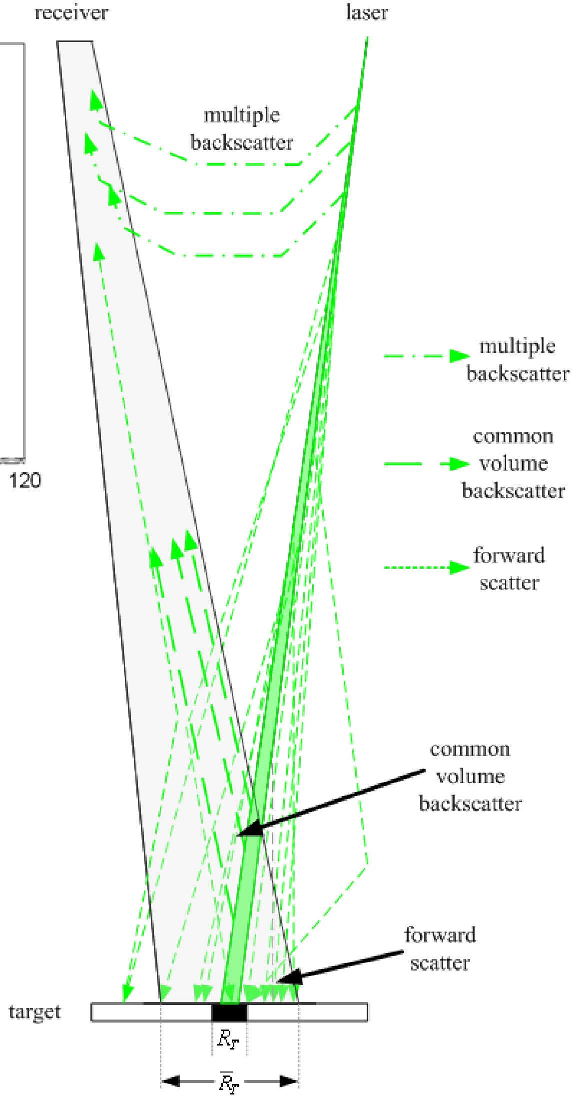
Laser line scan image of a large group of fish congregating around an isolated rock outcrop. *Courtesy: NOAA Ocean Exploration*

Near-monostatic Pulsed-Gated LLS system concept

(imager components reside on one platform; system aims to acquire only direct path irradiance)



typical irradiance at receiver for a single short pulse (i.e. at a single point in a line scan) for high (gray) and low (black) ***scattering*** coefficients. PG-LLS will gate-out the shaded portion.



- Pulse-gated LLS (PG-LLS) has been test tank demonstrated to offer performance improvement over currently used CW-LLS*
- PG-LLS offers the potential for substantial reduction in system size
- PG-LLS removes ambient light problems
- 3D – More robust object identification and characterization
- Requires packaged high rep rate pulsed laser (2-5W average power) <2% energy instability and fast gated detector – both have become available in 2010
- Significant beam spread between laser and target results in forward-scatter limitation at 5-7 one-way beam attenuation lengths (optical thicknesses)
- However range images are possible beyond 8 attenuation lengths

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* Dalgleish et al. 2009, "Improved LLS imaging performance in scattering-dominant waters," Proc. of SPIE, Vol. 7317, (2009).

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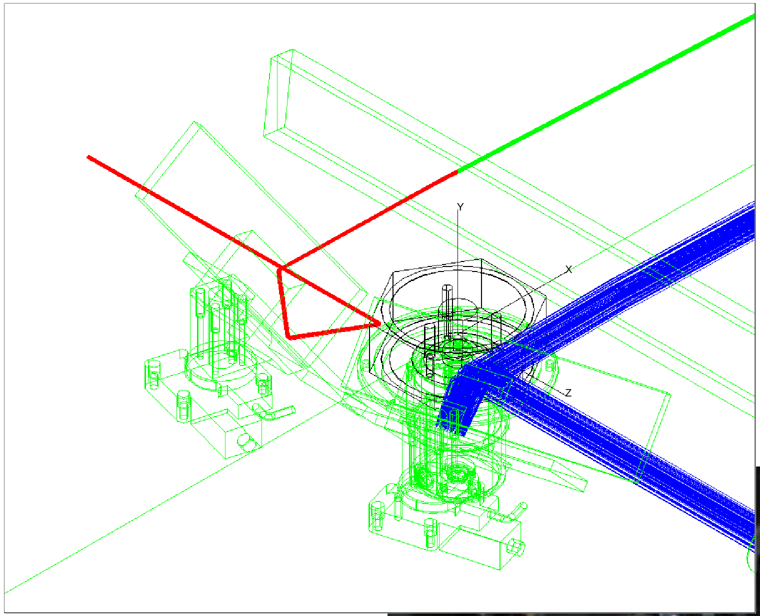
Near-monostatic pulse-gated LLS system concept

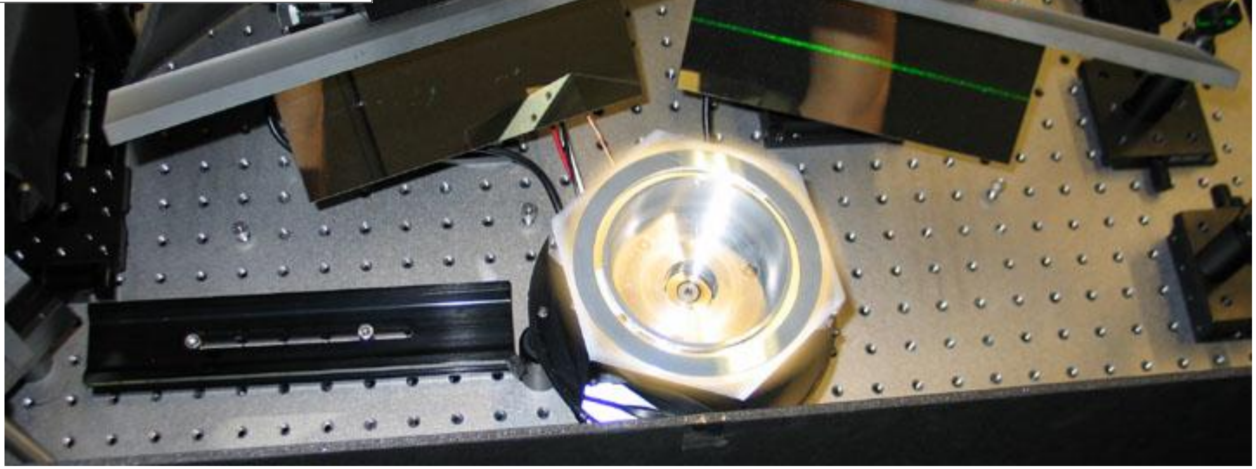
Animation showing pulsed serial imaging concept

Benchtop LLS system

Uses laser-receiver separation of 23.4cm. Allows for comparison between PG-LLS and CW-LLS.

Designed for 70 degree scan, the 10mrad – 30mrad receiver angular aperture precisely tracks the laser as it sweeps across the target. For the described tests, effective swath was < 20 degrees, limited by drum width





Prototype components were fabricated by Lincoln Laser, Arizona

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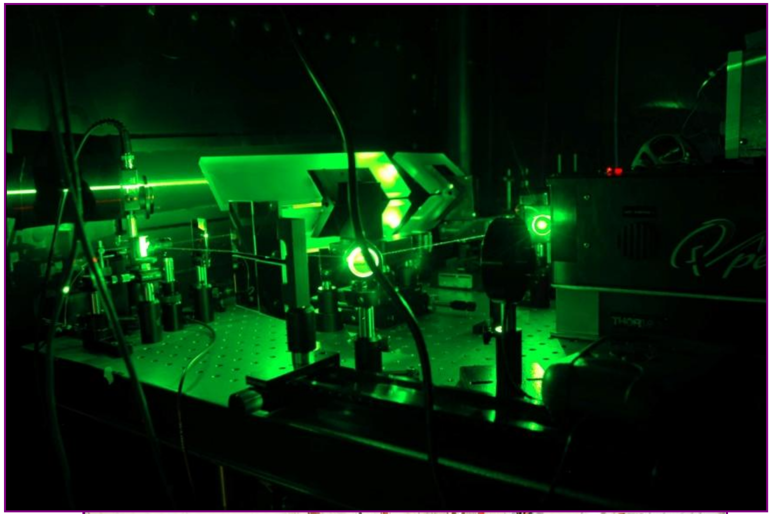
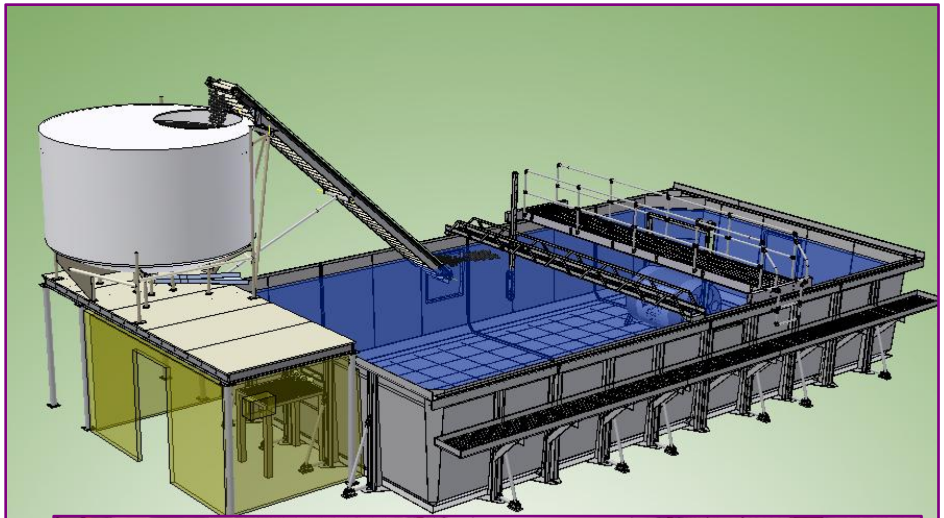
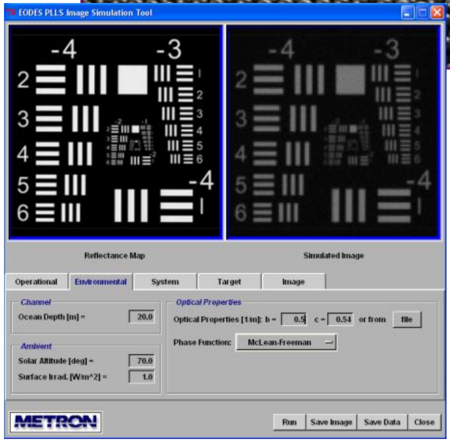
PG-LLS Prototype



Electro-optics test facility




EODES PLLS Image Simulation Tool

Reflectance Map

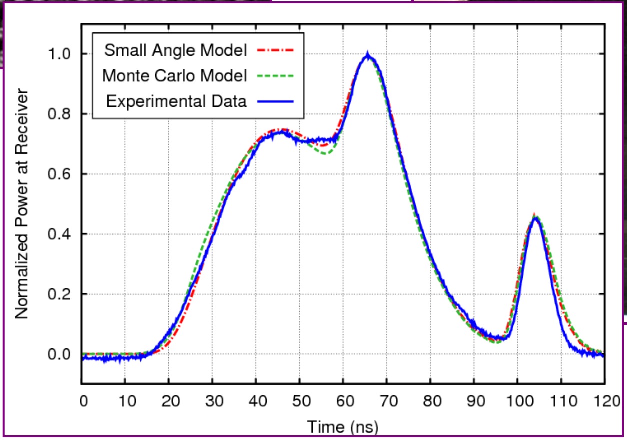
Simulated Image

Operational | Environmental | System | Target | Image

Channel
Ocean Depth [m] = 20.0

Ambient
Solar Altitude [deg] = 70.0
Surface Irrad. [W/m^2] = 1.0

Optical Properties
Optical Properties [1/m]: b = 0.5 c = 0.54 or from file
Phase Function: McLean-Freeman



Development of Performance prediction/design tool

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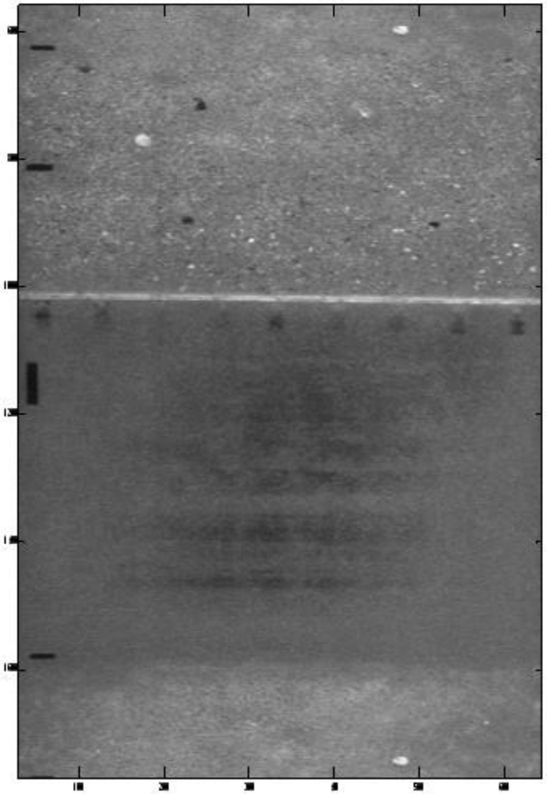
‘Seabed’ target



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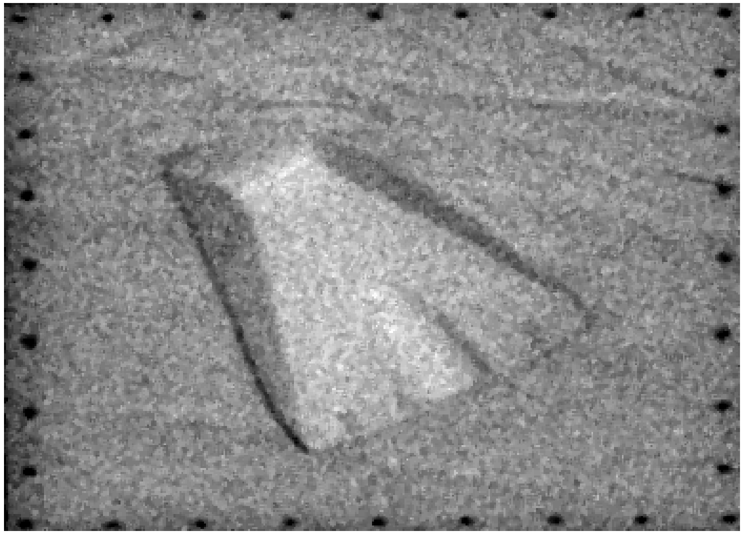
Test tank PG-LLS reflectance imaging results at 4.57 attenuation lengths (AL)

(12cm maximum Δrange from background)

2D Reflectance Image



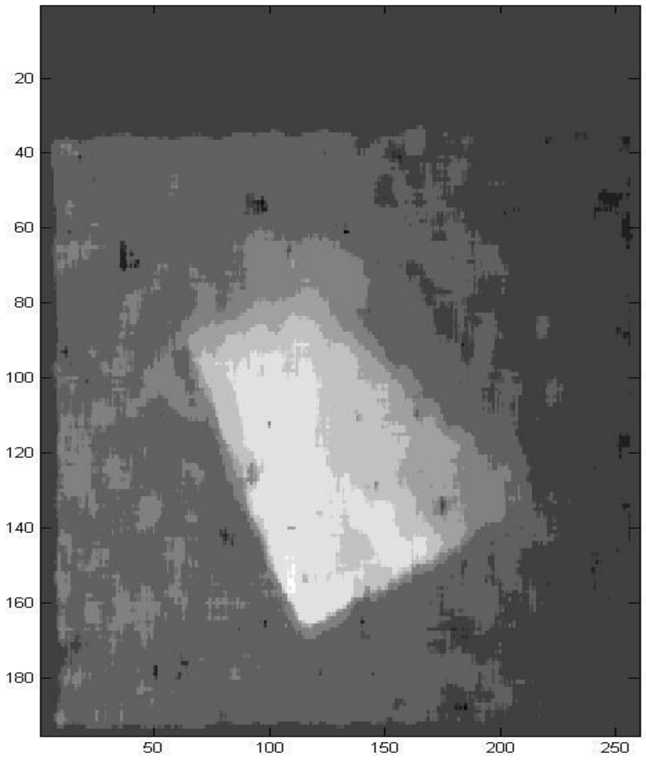
shading details are visual cues for ID

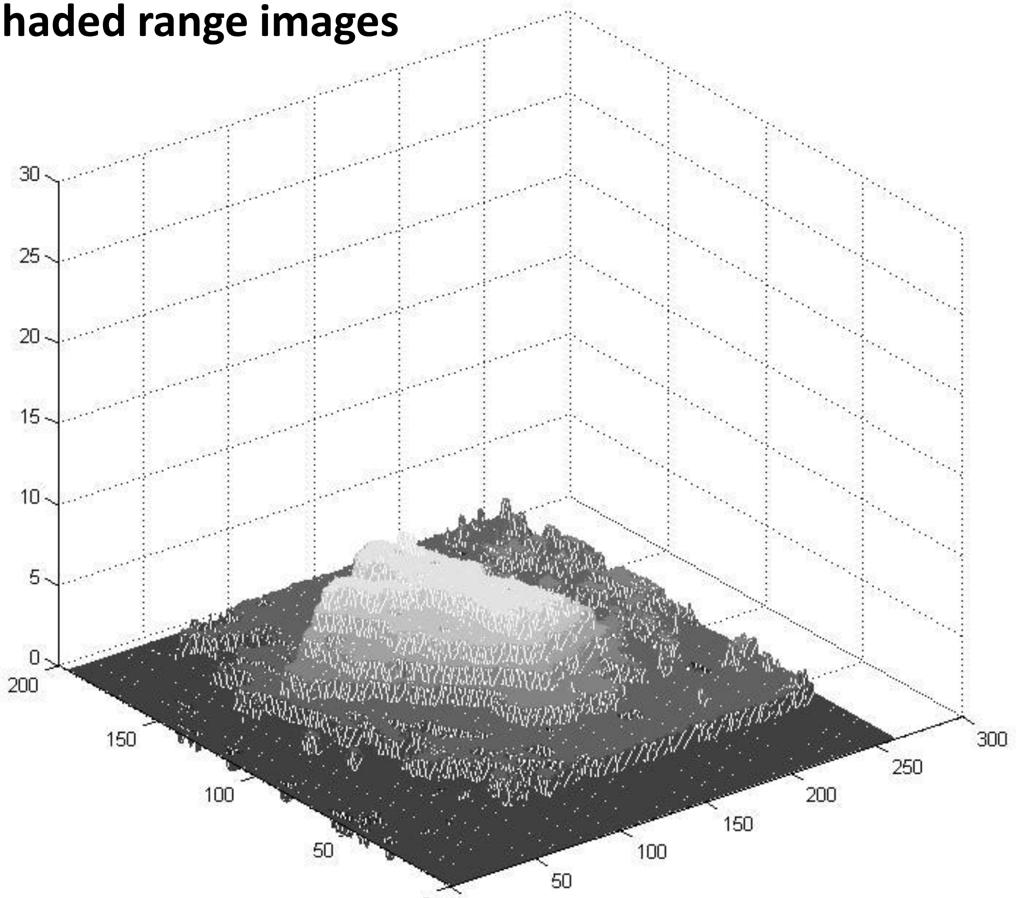
n.b. camera and light imaging configuration reaches a contrast limit at 4 AL

model of partially-proud Rockan mine moulded around rotating imaging drum

PG-LLS preliminary range imaging at 6.8 AL

2D and 3D shaded range images





n.b. range at each pixel is derived from time difference between measured rising edge of outgoing pulse to that of pulse returning from target. Digital timing resolution = 156ps (~3cm in water)

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Use of EODES simulation tool – near-monostatic PG-LLS for man-portable AUV

- Main advantage: reduce overall form factor to a size compatible with man-portable AUV

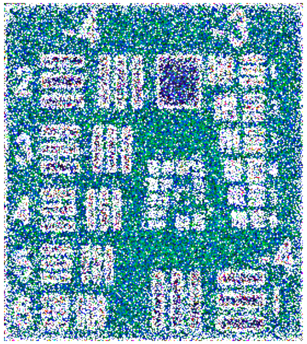
Requires packaged high rep rate pulsed laser (2-5W average power) <2% energy instability and fast gated detector – both have become available in 2010

simulated images

PG-LLS

Laser-receiver separation 5cm

5 attenuation lengths



CW-LLS

Laser-receiver separation 5cm

5 attenuation lengths

Caimi. F. M. and Dalgleish, F. R. “Performance considerations for continuous-wave and pulsed laser line scan (LLS) imaging systems,” Journal of the European Optical Society – Rapid Publications 5, 10020S, 2010.

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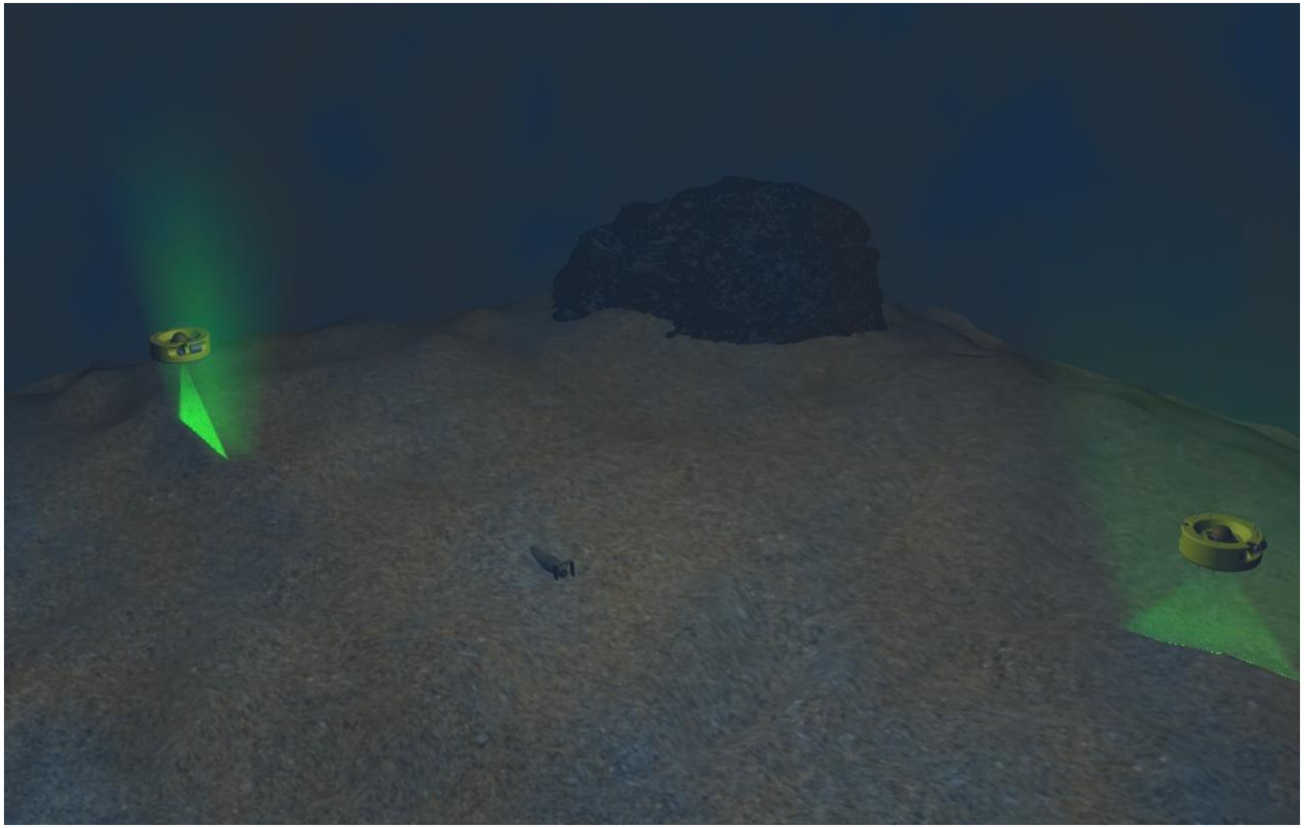
Multistatic or Distributed LLS

The Distributed Laser Line Scan (DLLS) system concept can offer greater flexibility in surveying underwater environment and offers high bandwidth communications capability



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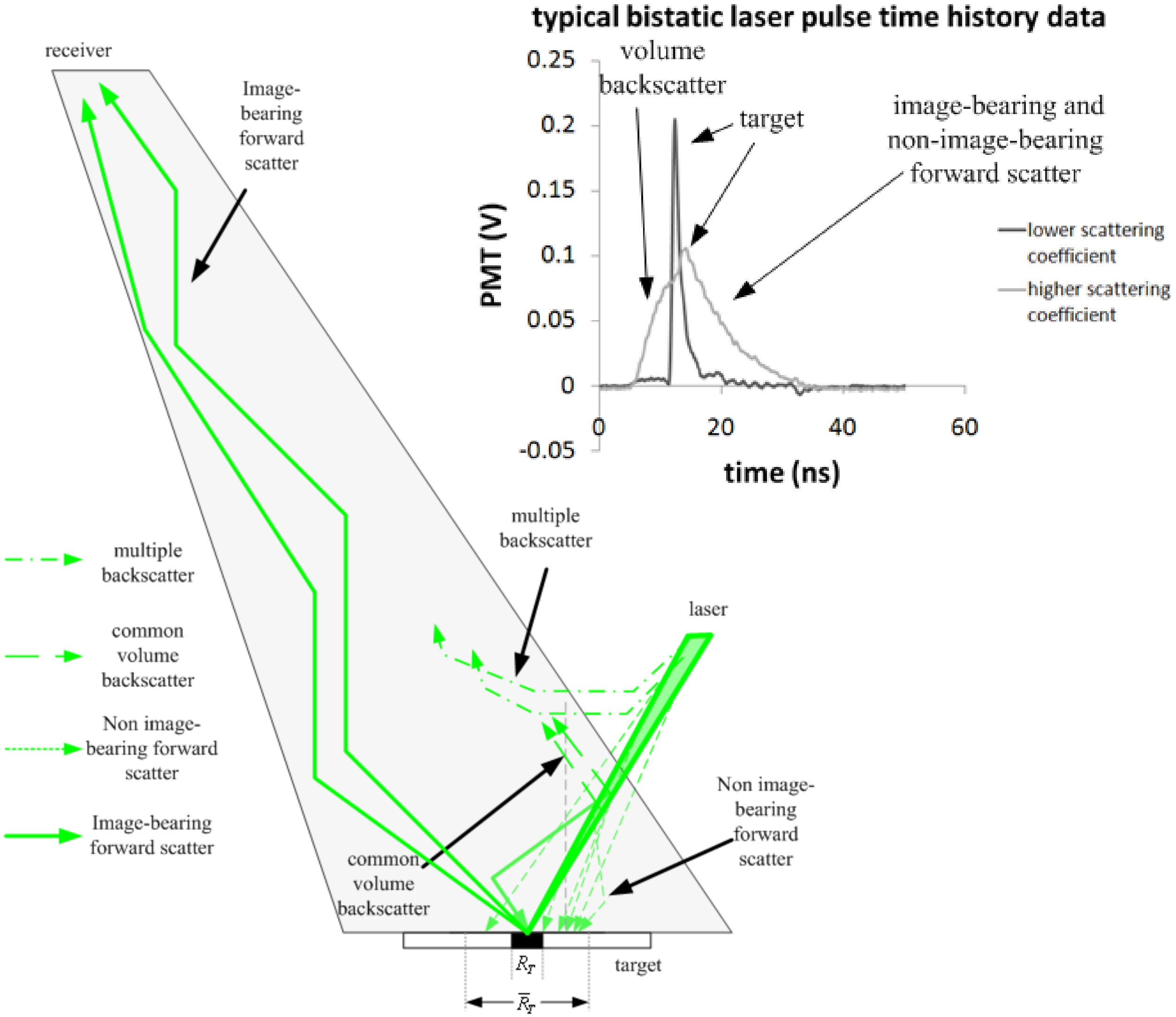
Distributed LLS system concept

(imager components distributed between at least two platforms; acquires both direct and diffuse path irradiance)



typical bistatic laser pulse time history data

- Offers multistatic configuration and more flexibility in deploying
- Combines imaging and communications techniques
- Can be implemented with low power (<100mW) CW lasers and other low cost commercial electronics subsystems
- Suited to complex geometries (non-line of sight imaging) and greater operational envelope
- Potential to increase area coverage and possibly signal reception by using several illuminator units and/or multiple receiver/transceiver units
- To fully realize potential, requires co-operative UUV swarms which presents significant additional challenges

[1] Dalgleish, F. R., Caimi, F. M., Vuorenkoski, A. K., Britton, W. B. and Ramos, B. "Experiments In Bistatic Laser Line Scan (LLS) Underwater Imaging," Proc. Marine Technol. Soc./IEEE Oceans Conf., 2009. Paper 090710-001.

[2] Dalgleish F. R., Caimi F. M., Vuorenkoski, A. K., Ramos B., Britton W. B., Giddings T. E., Shirron J. J. and Mazel C. H. "Efficient laser pulse dispersion codes for turbid undersea imaging and communications applications." Proc. SPIE, Vol. 7678, 2010.

[3] Dalgleish F. R., Ramos, B, Britton, W. B., and Caimi F. M., 2010, "Multistatic distributed laser line scan underwater imaging architecture," Proc. ONR/NASA Ocean Optics XX. Sept 27th-Oct 1st 2010. Anchorage, AK.

Futuristic Multistatic LLS Imaging and Networking

Animation showing distributed networking and imaging behaviors under development. Eventual implementation may be expendable due to low cost.

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Summary of imaging results: high spatial frequency target (dime)

Laser pulse time history showing target timing

Target to receiver distance = 10.87m

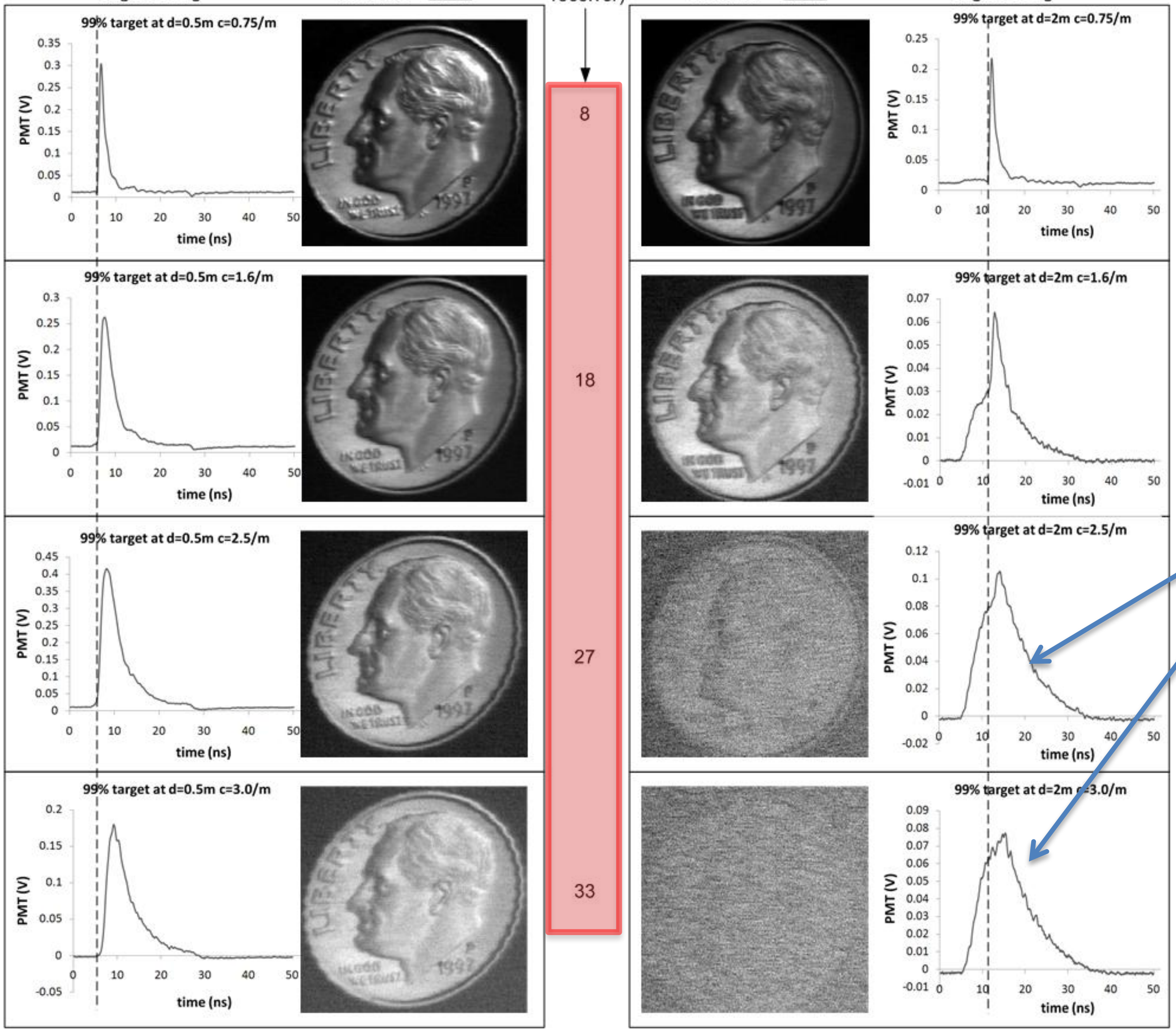
Laser to target distance = 0.5m

Beam attenuation lengths (target to receiver)

Target to receiver distance = 10.62m

Laser to target distance = 2.0m

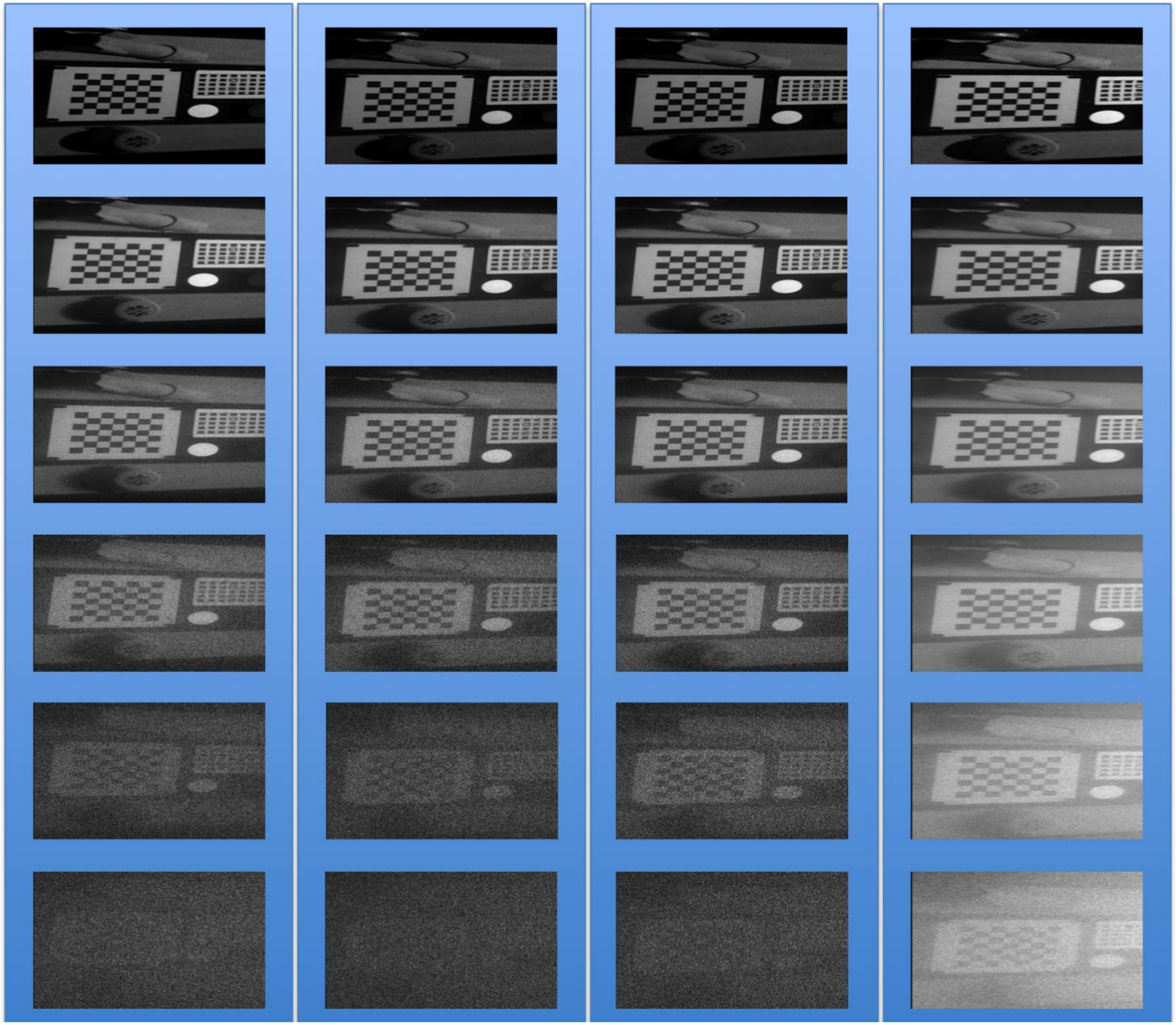
Laser pulse time history showing target timing



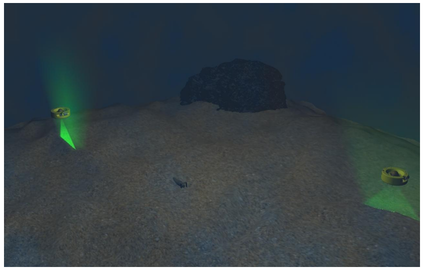
cropped sections of larger 1m x 1m target panel

Major loss of contrast and resolution due to both volumetric scatter and forward scatter/blur/glow

Summary of imaging results: Multistatic Architecture



two simultaneous images at same wavelength using FDMA communications approach



Dalgleish F. R., Ramos, B, Britton, W. B., and Caimi F. M., 2010, “Multistatic distributed laser line scan underwater imaging architecture,” Proc. ONR/NASA Ocean Optics XX. Sept 27th-Oct 1st 2010. Anchorage, AK.

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Summary

Active optical systems are available today that can provide identification quality images for detailed benthic site surveys through 4-5 attenuation lengths, but they require relatively high power and cost.

The next generation extended range systems must be smaller, require less power, less expensive and be compatible with deployment on small unmanned systems.

Autonomous networks offer greater flexibility in how systems and system components are fielded, but also present significant challenges

Other possible applications of laser techniques to MHK device monitoring

- Long range detection of marine animals

- Tracking of targets to study avoidance behavior

- Use of laser light as a deterrent

- DLLS capability could allow for laser-based control and telemetry of robotic inspection and maintenance platforms

- other ideas?

Questions?

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