MEMORANDUM

Subject: Progress Report 015–

This document provides a progress report on the project “Chaotic LIDAR for Naval Applications” covering the period of 4/1/2014–6/30/2014.
FY14 Q3 Progress Report: Chaotic LIDAR for Naval Applications

This document contains a Progress Summary for FY14 Q3.

Progress Summary for FY14 Q3

The use of chaotic lidar for underwater system experiments progressed in this quarter. Experiments were set up for ranging using the chaotic system. Channel identification experiments continued, using a high speed receiver and adaptive signal processing.

The chaotic lidar project was presented at the Defense, Sensing, and Security conference in Baltimore, MD on 07 May, with a talk entitled “Chaotic Lidar for Underwater Channel Identification”. The slides from this presentation are attached.
Chaotic Lidar for Underwater Channel Identification

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SPIE DSS 2014
Ocean Sensing and Monitoring
07 May 14
Outline

- Introduction
- Channel Identification
- Chaotic Lidar
- Preliminary Results
- Status and Future Work
- Conclusion
Goal: Channel Identification

- Context
  - Intensity-modulated optical system operating in water (sensor, communications, ranging, imaging, mapping)

- Problem statement
  - Measure variation in system response as a function of frequency of intensity modulation
  - i.e., transfer function $H(f)$ of the water
Motivation: Hybrid Lidar-Radar

- Modulate optical carrier with radar signals
- Modulation discrimination against scattered light
  - Scattered light decorrelates as phase randomized
  - Decorrelation increases exponentially with frequency
  - Electrical discrimination improves performance
- Continuous monitoring of modulation response
  - Decorrelation effect changes with water conditions
  - Would like to explore frequency spectrum to 1 GHz
Challenges: High Frequency, High Power Lidar Systems

- Technology challenge for channel ID: GHz modulation with W power
- Systems to date
  - Bulk CW lasers with external modulators
  - Diodes with direct current modulation
  - Mode-locked pulsed lasers
  - Fiber lasers with high speed modulator
- Proposed: Internally modulated fiber laser
  - No modulator subsystem
  - Fiber laser allows high frequency
  - Fiber amplifiers allow high power
  - Frequency doubler for NIR $\rightarrow$ green
Internally Modulated Fiber Laser

- Chaotic ytterbium-doped fiber laser
- Uses ultralong cavity (>100 m) to encourage simultaneous, incoherent lasing of many chaotically competing resonant modes

Ytterbium-doped fiber
85 cm 6/125 μm

WDM
ISO
Circulator
OC
50:50
ISO
Output

WDM: Wavelength-division multiplexer; ISO: Isolator; OC: Output coupler; FBG: Fiber Bragg's grating

b) Time Series

Frequency (Hz)
Time (us)
Amplitude (mV)

~5 GHz peak at 1064 nm (per 10 dB BW)

D) Chaotic Attractor

$\text{l}(t)$ $\text{l}(t-\tau)$ $\text{l}(t-2\tau)$
Fiber Amplifier Simulations

Mathworks.com: “Fiber Lasers and Amplifiers Design Toolbox”

- Numerical modeling of fiber amplifiers using custom tools to solve rate equations
- Both steady state and dynamic simulations

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**Preamplifier Performance**

- Experiment: 45 mW
- Simulation: 43 mW

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**Gain Amplifier Performance**

- Experiment: 6.3 W
- Simulation: 6.0 W

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Design Goal: 40 mW

Fiber Length: 20 cm

Fiber Length (cm) vs. Pump/Signal Power (mW) vs. Excitation Ratio (N/N_{tot})

Amplitude (mV) vs. Time (µs)
Chaotic Lidar Transmitter

- Chaotic Fiber Laser
  - High Frequency

- Fiber Amplifiers
  - High Power

- Frequency Doubler
  - Green

- Underwater Channel
  - Channel Identification

Fiber Laser and Amplifier

- Gain amplifier on board
- Fiber output to free space
- Fiber laser and pre-amplifier in enclosure

Frequency Doubler

- Focusing optics
- Nonlinear crystal
- Output optics
- Receiver optics

Gain amplifier on board
Fiber output to free space
Fiber laser and pre-amplifier in enclosure
Correlation-based ranging:
- Wideband $\rightarrow$ high resolution
- Processing gain $\rightarrow$ sensitivity
- Unambiguous thumbtack peak

**Chaotic Lidar in Turbid Water (c=5.5)**
- Avg. Error = 0.48 cm
- Sub-cm accuracy at 5 attenuation lengths

**Cross-correlation of Reference and Return Channels**
- Thumbtack peak at target location
- 8 cm FWHM peak

**Translation Stage**
- 20 cm $\rightarrow$ 80 cm
Channel Identification

- Approach used in communications channel identification
- Leverages wideband chaotic signal as probe

\[ y(t) = x_1(t) * h_{tx}(t) * h_{water}(t) \]
\[ z(t) = x_2(t) * h_{eq}(t) * h_{filt}(t) \]
\[ e(t) = z(t) - y(t) \]
\[ e(t) \to 0 \]

Underwater Channel Frequency Response
\[ H(f) = M(f) < \theta(f) \]
- Digitized chaotic signal used for channel identification on known digital filter

- Free space channel identification using known digital filter as DUT
Channel Identification
Experimental Setup

**Experimental Setup**

- **Fiber-Coupled Chaotic Lidar Transmitter**
- **Reference Signal**
- **Reflected Signal**
- **High Speed Digitizer**
- **Channel Identification Signal Processing Chain**
- **Backscatter Frequency Response**

**Signal Processing Chain**

- **Equalization Filter**
- **Time Alignment**
- **Frequency Domain Filter**
- **Gain Setting**
- **Gain**
- **Adaptive Filter**

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FC: Fiber coupler; L: Lens; PD: Photodiode; M: Mirror; LNA: Low-noise amplifier; PMT: Photomultiplier tube; RF: Radio frequency; DC: Direct current; DMM: Digital multimeter; DUT: Device under test
Channel Identification

**WIDEBAND PROBE**

- PMT: 1 GHz bandwidth
- Electrical LPF: 39 MHz passband

**WATER SIMULATION PREDICTIONS**

- Backscatter: Rolls off with frequency
- Target: Visible at high frequency
Design high frequency, scalable power transmitter
Adaptive receiver to model channel
Characterize electro-optic components
Water measurements: Show frequency response of scatter, impact on performance
Conclusion

- New tool for water measurements
  - Motivation for channel identification
  - Internally modulated fiber laser addresses technology challenges for transmitter
  - Adaptive receiver provides usable model of channel