Munitions Response: Underwater Geophysical Sensors

September 17, 2015
Welcome and Introductions

Rula Deeb, Ph.D.
Webinar Coordinator
Agenda

- **Webinar Logistics**
  Dr. Rula Deeb, Geosyntec (5 minutes)

- **Overview of SERDP and ESTCP**
  Ms. Katherine Kaye, SERDP and ESTCP Program Office (HGL) (5 minutes)

- **Development of a Real-Time Underwater Magnetometer Array**
  Dr. Mark Prouty, Geometrics (25 minutes + Q&A)

- **Underwater Electromagnetic Sensors: UXO Detection and Classification in Marine Environments**
  Dr. Thomas Bell, Leidos Corporation (25 minutes + Q&A)

- **Final Q&A Session**
How to Ask Questions

Type and send questions at any time using the Q&A panel.
In Case of Technical Difficulties

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    - International: 330-871-6014
    - Required conference ID: 13338919

- Submit a question using the chat box
SERDP and ESTCP Overview

Katherine Kaye
SERDP ESTCP Program Office, Munitions Response Program Area
SERDP

- Strategic Environmental Research and Development Program
- Established by Congress in FY 1991
  - DoD, DOE and EPA partnership
- SERDP is a requirements driven program which identifies high-priority environmental science and technology investment opportunities that address DoD requirements
  - Advanced technology development to address near term needs
  - Fundamental research to impact real world environmental management
ESTCP

- Environmental Security Technology Certification Program
- Demonstrate innovative cost-effective environmental and energy technologies
  - Capitalize on past investments
  - Transition technology out of the lab
- Promote implementation
  - Facilitate regulatory acceptance
Program Areas

1. Energy and Water
2. Environmental Restoration
3. Munitions Response
4. Resource Conservation and Climate Change
5. Weapons Systems and Platforms
Munition Response

- Munitions on land
  - Classification

- Munitions underwater
  - Wide area and detailed surveys
  - Cost-effective recovery and disposal
  - Characteristics of munitions underwater, their environment and mobility
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<td>October 1, 2015</td>
<td>Hexavalent Chrome Elimination from Hard Chrome Surface Finishing</td>
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<td>LED-ing the Way: Sophisticated and Energy Efficient Exterior Lighting Systems for DoD Installations</td>
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<td>Emerging Contaminants: DoD Overview and State of Knowledge on Fluorochemicals and 1,4-Dioxane</td>
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<td>December 17, 2015</td>
<td>Resource Conservation and Climate Change</td>
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SERDP & ESTCP Webinar Series

Development of a Real-Time Underwater Magnetometer Array

Mark Prouty, Ph.D.
Geometrics, Inc.
Outline

- Traditional method of using magnetometers
- Limitations of existing sensor technology
- Development of new sensing technologies
- Sensor development results
- Real-time array results
Sensing Objects with Magnetometers

- Ferrous material is sensed by its effect on the Earth’s magnetic field
- By making measurements over a certain region, the object can be visualized
Traditional Data Acquisition Step

- Traditional sensors are large, expensive and consume a lot of power
- Therefore, magnetometers today are typically used in two steps
- First, the data is gathered...
Data Analysis Step

- ... and then the data is plotted and analyzed
- We would like to eliminate this two-step process
MFAM Development

- Under Geometrics and SERDP funding, we have developed smaller, low power sensors
- Previous SERDP projects
  - MM1512: Basic sensor development
  - MR 1568: Exploring high performance regimes
- Ongoing SERDP project
  - MR 2104: Development of miniature electronics and real-time array
Principle of Operation

- Cesium atoms have a magnetic moment that precesses, like a top, in a magnetic field.
- The precession can be sensed by its effect on the absorption of light passing through the cell.
- The frequency of precession is proportional to the magnetic field.

\[
\frac{d\vec{A}}{dt} = \vec{T} \\
\vec{T} = \vec{M} \times \vec{H} \\
\vec{M} = \gamma \vec{A} \\
\frac{d\vec{M}}{dt} = \gamma \left[ \vec{M} \times \vec{H} \right] \\
\omega_0 = \gamma H_0
\]
Making Lower Power Magnetometers

Structure of a traditional magnetometer:
- Photo Detector
- Focusing Lens
- H1 Coil
- Cs Cell
- Split Polarizer Filter
- Collimating Lens
- RF Coil
- Cs Lamp
- Tiffany Mount

Technological Improvements:
- Low-power laser light source
- Small vapor cell
- Small, low-power light source driver
- Low-power sensor electronics
- Sensor electronics integration
- Eliminate H1 coil
- Low-power vapor cell heater

Small, low-power high-performance magnetometer
Sensor Design

- The cesium cell is mounted in the middle, surrounded by heaters
- Optical components are situated to direct the laser light through the cell and onto a photodiode

The cesium cell is ¼ inch across
Electronics Design

- Two laser beams are directed into a cesium cell.
- At the particular resonance frequency, modulation on the pump appears on the probe.
- This is used to determine the precession frequency, and, therefore the magnetic field amplitude.
Volume Production

- Our approach is to design the devices to allow for efficiency and low cost production.

Newly developed electronics module

Texas Instruments is working with Geometrics to produce large volumes of sensors.

Medium scale production will begin with the Geometrics design.
Data Comparison

- New sensors perform as well as Geometrics’ highest performance sensors

Shield can noise at low frequencies
Outdoor Demonstration

- Sensors behave robustly in uncontrolled environments
- Gradiometer measurements can differentiate near from far objects: swinging screwdriver and car
- Sensor separation 10 inches

![Graph showing individual sensor readings and signal created by moving small screwdriver and car.](image)
What Can We Do with These?

- We can now make an array of sensors that gives real-time answers
Array Measurements

- We made feasibility measurements with an earlier set of prototypes
Real-Time Processing

- Sensor data is read in and analyzed 10 times per second
- The red dot shows the position of the target
- 3D location as well as the size and orientation of the target are calculated and displayed
Real-Time Results

- Using a coil as a dipole target source at 0.5m depth
Complex Situations

- Multiple objects are not expected by the array
- How does the output behave in this situation?
- The system locks onto the nearest object

Sliding system across 2 mortar objects with different separations

$X_1 = -1, X_2 = 1, \text{2m}$

$X_1 = -0.5, X_2 = 0.5, \text{1m}$

$X_1 = -0.25, X_2 = 0.25, \text{0.5m}$
Complex Situations

- If the array is between the two objects, the amplitude measurement varies wildly, indicating the situation to the operator.
Benefits of Real-Time Analysis

- Accurately re-locate target items
  - Guide the diver to the target
  - Confirm magnetic properties of the desired object
- Ensure correct object is removed
- Determine whether other objects are nearby
  - Improved efficiency
- Skip the multi-step acquire/analyze/re-acquire process
Other Deployment Methods

- In addition to diver-held arrays, unmanned underwater vehicles, underwater arrays and deployment from drones are exciting possibilities.
Summary

- MFAM sensors are small, lightweight and low power
- Eliminates the difficulties of gathering magnetometer data
- Deployable on small platforms and in arrays for real-time information
- Makes existing applications much easier and opens up new applications
For additional information, please visit https://www.serdp-estcp.org/Program-Areas/Munitions-Response/Underwater-Environments/MR-2104

Speaker Contact Information
markp@geometrics.com; 408-954-0522
Underwater Electromagnetic Sensors: UXO Detection and Classification in Marine Environments

Thomas Bell, Ph.D.
Leidos Corporation
Collaborators

- Bruce Barrow
  Leidos

- Dan Steinhurst and Glenn Harbaugh
  Nova Research

- Carl Friedrichs and Grace Cartwright
  Virginia Institute of Marine Science
Agenda

- Project overview
- Data on underwater munitions from magnetic surveys
- Electromagnetic induction (EMI) fundamentals
- Complexities of the marine environment
- Salt water tank tests
- Field measurements
- Future work
- Transition plans
Problem Statement

- SERDP/ESTCP-developed electromagnetic sensor arrays can reliably detect and classify buried munitions on land under operational conditions.

- There is a significant munitions contamination problem in U.S. coastal and inland waters.

- The marine environment introduces complexities in the response of these sensor systems which could adversely affect their performance.
  - There is little actual data on the effects of the marine environment on relevant electromagnetic signals and noise.
Project Overview

- Empirical investigation of the effects of marine environments on munitions detection and classification using advanced electromagnetic induction (EMI) sensor arrays
  
  • Controlled tests and experiments to address the fundamental physics of the EMI response in a conducting medium
  
  • Field measurements of the EMI response to the water column and underlying sediments in various marine environments
Underwater Munitions
Survey Data from Underwater Sites

- Marine Towed Array (MTA)
  - Active depth control, 1-2 m above bottom
  - 8 magnetometers, 4.2 m array width
  - 5 sites, 819 km survey lines, 244 ha full coverage survey

- Transverse Gradiometer
  - Passive tow 2-4 m above bottom
  - 2 magnetometers, 1.2-2 m spacing
  - 2 sites: 64 km survey lines
Underwater Munitions Distributions

- Analysis of data from the various magnetic surveys in project MR-200703 indicate that
  - Anomaly distributions can be similar to moderate density (102-103/ha) land sites
  - Most targets (~80%) are buried in the sediment
  - Larger targets are more common than on land

- Intrusive investigations find relatively large number of intact munitions*

*Biased by analysts’ choices for intrusive investigation
EMI Sensors (Metal Detectors)

A  Abrupt change in primary field excites eddy currents in buried object
B  Eddy currents diffuse throughout the object and decay

Details depend on the size, shape and orientation of the object
NRL TEMTADS Sensors

- TEMTADS: 4-element square array of transient electromagnetic (TEM) sensors developed by G&G Sciences for ESTCP project MR-200909
  - 35 cm square by 8 cm high transmit coils paired with 8 cm three-axis receive cubes
  - Programmable electronics measure secondary (induced) field decay out to 25 ms
Classification

- Classification exploits eddy current decays observed from a complete range of excitation directions
  - Excite and measure target from many directions using an EMI sensor array

- Determine the target’s “EM fingerprint” by inverting the data using a standard EM response model
  - Three principal axis polarizabilities corresponding to intrinsic EM response along target’s three principal axis directions
Classification: Fingerprint Matching

- Classification compares an unknown target’s principal axis responses with a library of polarizabilities for known targets.
Underwater EMI

- There are additional electromagnetic effects in an electrically conducting medium like sea water that could affect classification performance
  - Attenuation and distortion of EMI signals
  - New signal components from electric field interactions with the target (current channeling)
  - Electromagnetic response from the sea water itself, bottom sediments and the sea surface
  - Target corrosion and biofouling

- Effects observed at high frequencies (>1kHz) in field tests undertaken in SERDP project MR-1321
  - Modeling studies (MR-1632) have concluded that the effects are minimal for the time domain sensors typically used for munitions detection and classification on land
SERDP Project MR-2409

An empirical investigation of the factors influencing marine applications of EMI

• Objectives
  ○ Validate the models for EMI performance in the marine environment and the assumptions that are made to simplify the calculations
  ○ Inform the models regarding parameter values appropriate to different sedimentary environments and the level of complexity that must be retained to support reliable EMI data inversion and target classification

• Approach
  ○ Salt water tank tests of electromagnetic induction in a conducting environment
  ○ Field measurements of relevant properties of marine environments
  ○ Analysis and modeling support
Salt Water Tank Tests

- 6000 gal tank (10’ diam): Salinity 0-35 ‰
- TEMTADS sensors in waterproof cases
Salt Water Response

- Salinity 35 \%, temp 27°C
- Characteristic $t^{-5/2}$ signal from water at early times
  - $\sim$20\% of expected response for unbounded medium
    - Boundary effects (40\% loss on reflection from plane boundary)
    - Residual response above surface (“in air” response)
- Weak compared to 40 mm signals at 45 cm range
Noise Levels

- RMS shot-shot signal variability
  - ~1000 shots, no stacking
- In water noise comparable to in air
  - No systematic variation with salinity
- X, Y and Z receiver axis noise levels comparable
Target Signals

- Targets to side of coils (~45 cm from center)
  - Salinity 35 ‰
- No significant differences from response in air have been observed
Field Measurements

- York River Estuary
  - Well characterized
  - Muddy and sandy areas
  - Salinity 0-25 \%
  - Depth 0-20 m

- VIMS research vessels and instrumentation
  - Conductivity-temperature-depth profiles
  - Sediment cores
    - Electrical conductivity
    - Magnetic susceptibility
Water Properties

- Conductivity, temperature depth (CTD) profiles at station locations coincident with bottom sediment collection
  - Blue: near mouth of estuary 2.7 S/m
  - Red: mid-reaches 2.4-2.6 S/m
  - Green: Pamunkey River tributary of York River Estuary 1.2-1.6 S/m
Sediment EM Properties

- Sediment cores from sites along the York River Estuary
  - Magnetic susceptibility
  - Electrical conductivity

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<td>S5410</td>
<td>10.3</td>
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<tr>
<td>S5411</td>
<td>33.4</td>
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<tr>
<td>S5415</td>
<td>69.4</td>
<td>35.2</td>
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Effect on EMI Response

- Calculations of sediment response using measured York River properties
  - $\sigma_{\text{water}} = 2.5 \text{ S/m}$
  - $\Sigma_{\text{sediment}} = 1.75 \text{ S/m}$
  - $\chi_{\text{sediment}} = 1.0 \times 10^{-4} \text{ SI}$

- Sediments have ~20% effect on background response
  - Variation with range at early times may cause problems with background subtraction
  - Need to examine small scale spatial variation
Target Corrosion and Biofouling

- Magnetite or maghemite corrosion products can alter target’s EMI response
  - Significant buildups (> several mm) required
- Biofouling not likely to influence EMI response
  - No magnetic contrast

Studies of corrosion and fouling effects on EMI (and acoustic) target responses underway in collaboration with SERDP project MR-2500
Future Work

- Continued tank testing
  - Target measurements at greater ranges
    - Current channeling effects
  - Bistatic response measurements
  - Replace sensor cases with new pressure housings

- York River Estuary field tests
  - TEM profiles and target measurements
  - ADCP current profiles
  - Niskin water samples for suspended sediments
  - Conductivity-temperature-depth (CTD) profiles
  - Sediment mechanical and EM properties
Transition Plans

- Re-fitted MR-200324 Marine Towed Array
  - Large (1x4½ m) transmit loop
  - 7 TEMTADS receive cubes
  - ~1½ m above bottom

*Calculated TEM signals for targets detected during towed magnetic survey of Potomac River Estuary off Blossom Point, MD*
Summary

- Underwater munitions sites
  - Anomaly densities can be similar to moderate density (102-10^3/ha) land sites
  - Munitions/clutter mix likely different than on land
  - Most targets (~80%) likely buried in sediment

- EMI systems can detect and distinguish between buried munitions and clutter items on land
  - Multi-axis EMI responses contain target size and shape information used for classification

- Underwater munitions detection and characterization may be possible with surface towed arrays
  - Seawater effects on EMI signals appear manageable
  - Large loop transmitter systems allow for reasonable tow heights above bottom
For additional information, please visit https://www.serdp-estcp.org/Program-Areas/Munitions-Response/Underwater-Environments/MR-2409

Speaker Contact Information
bellth@leidos.com; 301-712-7021
Q&A Session 2
The next webinar is on October 1, 2015

Hexavalent Chrome Elimination from Hard Chrome Surface Finishing
Survey Reminder

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