OTC 25381
AUV-Based 3D Laser Inspection for Structural Integrity Management in Deepwater Fields

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Agenda

• Background
  – Vision for AUVs in Deepwater Fields
  – Prior Work related to AUV-based 3D Imaging
  – Benefits of AUV-based 3D Laser Imaging

• Project Execution and Results
  – Project Objectives and Plans
  – Simulation Objectives & Results
  – Offshore Test Objectives and Results

• Conclusions
  – Summary of Results
  – Future Implications for Structural Integrity Management
**Vision for AUVs in Deepwater Fields**

- AUVs will offer significant improvements in safety and operating efficiencies as well as substantial reductions in cost over current methods.

- AUVs will leverage a wide range of inspection sensors and technologies, including video, photographic, sonar, laser, ultrasonic, magnetic, and others.

**AUVs Will Become an Increasingly Important Tool for IRM in Deepwater Fields**
Prior Work: RPSEA 09121-3300-05 “Autonomous Inspection of Subsea Facilities”

Project Objective:
- Develop and demonstrate 3D Modeling and Change Detection using an AUV-based 3D Sonar including:
  - Close-in, high resolution 3D sonar imaging
  - High resolution, geo-registered 3D models
  - Detection of changes against a priori models

The Marlin® AUV Builds Geo-Registered 3D Models “On the Fly” At Speeds of ~ 2 Knots
Prior Work: RPSEA 09121-3300-06
“High Resolution 3D Laser Imaging for IRM Operations”

Project Objectives:

• Develop subsea 3D laser imaging and measurement capability from TRL 2 to TRL 5:
  ✓ Pool test on tripod
  ✓ ROV Test Tank
  ✓ Offshore testing on tripod
  ✓ Offshore testing on ROV

Underwater 3D Laser Prototype Testing Has Produced Spectacular Results with Millimeter Accuracies
Benefits of AUV-based 3D Laser Inspection

- Benefits of geo-registered 3D models:
  - CAD Modeling for structural and thermal analysis
  - Precise Measurement / Metrology
- Benefits of AUVs over ROVs / Divers:
  - Smaller vessel (or no vessel)
  - Fewer people offshore
  - No umbilical management
  - Highly mobile platform for efficient IRM operations
- Benefits of AUV-based 3D Laser Inspection:
  - 3D model generated “on the fly”
  - Autonomous change detection without Operator Intervention
  - Rapid Condition Assessment

AUV-Based 3D Laser Imaging Holds the Potential to Become a Key Tool for Structural Integrity Management
Autonomous Underwater Inspection Using a 3D Laser

Project Overview

Project Objective
• Develop and demonstrate 3D Modeling and Change Detection using an AUV-based 3D Laser, including:
  – Close-in, high resolution 3D laser imaging
  – Generation of high resolution, geo-registered 3D models of subsea structures
  – Detection of changes against a priori models

4 Phase Project Plan:
• Requirements / Interface Definition
• Hardware / Software Design & Build
• Onshore Integration & Testing
  – 3D Laser FAT
  – Simulation Laboratory Integration & Testing
• Offshore Prototype Testing

Potentially Dramatic Cost Reductions and Improved Operating Efficiencies can be Achieved if High Accuracy Inspections can be Performed with an AUV
Phase 3: 3D Laser Factory Acceptance Test

- **Key Test Requirements:**
  - Sensor Packet Control Testing
  - Scanning Operations in Water
  - In-Water Range Demonstration
  - Scanning Operations in Air
  - Mechanical / Mounting Validation
  - Navigation / Serial Data Validation

- **Summary of Results:**
  - 2 Days of Sensor Testing Utilized
  - 42 Unique Tests Conducted & Passed
  - Final Delivery of:
    - DP2 Sensor Test GUI Simulator
    - DP2 Sensor Software Users Manual
    - DP2 Sensor ICD Final Version

100% of 3D Laser Sensor FAT Tests Achieved Pass Criteria
Phase 3: Laboratory Simulation

Objectives:

- Integrate the 3D laser interfaces into the system
- Maximize the use of actual hardware interfaces such as processors and sensors
- Use simulators and emulators in place of actual hardware
- Simulate AUV-based underwater 3D laser imaging
- Assess and optimize performance prior to offshore testing
Marlin Simulation Lab –
RPSEA LiDAR Configuration

Front End Investment in Laboratory Simulation
Substantially De-risks Offshore Operations
Three methods for scanning

- Continuous Line Scan Mode
- Full Scan Mode
- Bow Tie Scan Mode

All scan modes are fully programmable and reconfigurable at any time.
Simulated Vehicle Parameters & Noise Sources

Simulation Objectives:
- Simulate typical vehicle characteristics and evaluate performance on the specific test case(s)

<table>
<thead>
<tr>
<th>Vehicle Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical AUV Speed</td>
<td>1.0 m/s</td>
</tr>
<tr>
<td>Alternative AUV Speed</td>
<td>0.2 m/s</td>
</tr>
<tr>
<td>Cross Track Angle</td>
<td>+/- 15°</td>
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<tr>
<td>Cross Track Scan Rate</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Target Scan Range</td>
<td>3m – 15m</td>
</tr>
<tr>
<td>Scan Type</td>
<td>Bow Tie</td>
</tr>
<tr>
<td>Scan Pulses</td>
<td>504</td>
</tr>
<tr>
<td>Scan Frame Time</td>
<td>33msec</td>
</tr>
<tr>
<td>Scan Dead Time</td>
<td>9msec</td>
</tr>
</tbody>
</table>

Noise Source(s)
- Navigation Error
  - Standard
- Timing Error
  - 1.8 msec std dev
- Sensor Calibration – Offset
  - 1mm about all axes
- Sensor Calibration – Rotation
  - 0.25° about all axes
- Sensor Noise – Range
  - 1 cm std dev
- Sensor Noise – Pointing Angle
  - 0.02° std dev

Shows the vehicle pose, path, and bowtie scan for a single frame of the mooring chain scan simulation.
Jumper Metrology

- Simulation Images:

<table>
<thead>
<tr>
<th>Vehicle Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>AUV Speed</td>
<td>1 m/s</td>
</tr>
<tr>
<td>Target Scan Range</td>
<td>8m above wellhead flange</td>
</tr>
<tr>
<td></td>
<td>5.5m above manifold</td>
</tr>
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</table>

OTC 25381 - AUV-Based 3D Laser Inspection for Structural Integrity Management - Jacobson
Pipeline Bar Anode Depletion

Simulation Images:

- Uncorroded Bar Anode

- Corroded Bar Anode

<table>
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</tr>
</thead>
<tbody>
<tr>
<td>AUV Speed</td>
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</tr>
<tr>
<td>Target Scan Range</td>
<td>5 m</td>
</tr>
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</table>
**Pipeline Concrete Coating Damage**

- Simulation Images:

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</thead>
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<tr>
<td>AUV Speed</td>
<td>1 m/s</td>
</tr>
<tr>
<td>Target Scan Range</td>
<td>5m</td>
</tr>
</tbody>
</table>
**LiDAR Scans at 2 Knots Simulation**

- Other Notable Test Cases:
  - Wellhead Verticality
  - Manifold Anode Depletion
  - Pipeline Bracelet Depletion
  - Pipeline Dent / Pit Detection
  - Mooring Chain Pit / Wear Damage Detection and Measurement
  - Platform Inspection
  - Spoils Volume
Laboratory Simulation - Conclusions

• Excellent Results for Some Test Cases:
  – Wellhead Verticality:   < 0.08 degrees angular error
  – Jumper Metrology:      < 0.5% length / elevation error
  – Anode Depletion:      2% to 10% dimensional errors
  – Spoils Volume:         < 2% volumetric error

• Additional Effort to Assess / Optimize Other Test Cases:
  – Pipeline Dent / Pit / Concrete Coating Damage Detection and Measurement
  – Mooring Chain Pit / Wear Damage Detection and Measurement
Phase 4: Offshore Prototype Testing

• Test Objectives:
  – Image test targets using an AUV-based 3D laser
  – Generate geo-registered 3D models
  – Evaluate 3D model resolution and dimensional accuracy
  – Evaluate viability of AUV-based 3D inspection for use in deepwater fields

• Test Venue:
  – Local offshore waters adjacent Palm Beach, FL
  – Water depths 60 – 80 ft.
  – Currents 0.5 – 2 kt
Test Cases and Fixtures

Test Cases:

• Sandy Bottom Area:
  – Pipeline Test Fixtures
  – PRCI Pipeline Sample (6” ID, 6’ L)
  – Anode Volumes on Manifold
  – Mooring Chain
  – Jumper Metrology
  – Wellhead Verticality

• Downed Barge
  – Structural Inspection of the Barge
  – Spoils Volume
Offshore Prototype Testing
Progress To Date

• Dockside Integration Completed
• Test Fixtures Placed Offshore
• Testing in Progress
• Results Pending
Conclusions

• AUV-Based 3D Laser Imaging Offers Powerful Capabilities for Structural Integrity Management:
  – Imaging from Moving AUV is faster and more efficient than other means
  – Provides geo-registered 3D models with millimeter resolution
  – Provides autonomous change detection against a baseline model
  – Eliminates Human Fatigue and Inspection Data Overload
  – Leverages 3rd Party Software Tools from Terrestrial Survey Industry
  – More Accurate, Efficient Inspections ➞ Lower Overall Life-of-Field Costs

• Potential Applications Include:
  – Pipeline Inspection
  – Subsea Facility Inspection
  – Riser / Mooring Line Inspection
  – Jumper Metrology / Wellhead Verticality

AUV-Based 3D Laser Imaging Holds the Potential to Become a Powerful Tool for Structural Integrity Management
Acknowledgements

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Questions?