Autonomous Underwater Inspection Using a 3D Laser

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ABSTRACT

This Technology Assessment Status report contains a summary of the state-of-the-art of the proposed technology to perform autonomous underwater inspection using a 3D laser. The primary technology challenges for the AUV-based 3D Laser are 3D Laser technology, sensor packaging for AUV platforms, multi sensor optimized modeling and mobile platform accuracy. Areas for future development outside the scope of this effort include autonomous re-plan of a path to revisit these areas where change was detected for the collection of high-definition optical imagery, as well as enhancements to the stability of the stationkeeping mode of the AUV for improvements in detection accuracy.
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1.0 TECHNOLOGY OBJECTIVE

The integration of an underwater 3D Laser imaging capability with Lockheed Martin’s Autonomous Underwater Vehicle (AUV) represents a major improvement over current AUV sonar imaging capabilities. Development and integration of these capabilities further enhances the benefits associated with performing Inspection, Repair and Maintenance (IRM) activities using an AUV. AUVs outfitted with 3D laser imaging systems will provide new, high accuracy tools for subsea integrity management that are currently used extensively in terrestrial applications, including High Definition Scanning (HDS) for close-in inspection of problem areas, and underwater LIDAR (Light Detection and Ranging) for 3D mapping and inspection of flowlines, risers, and other subsea infrastructure. When integrated with autonomous change detection against an existing 3D model, the 3D laser will provide an unprecedented capability to quickly and accurately assess subsea infrastructure integrity and autonomously detect damage or degradation with centimeter resolution or better.

Under RPSEA Project 09212-3300-06, 3D at DEPTH, LLC developed an underwater 3D imaging capability, based on patent pending technology, which demonstrated the ability to generate accurate 3D models of deepwater assets. This capability provides sensor data resolution that is more accurate than 3D sonar data at considerably faster collection rates. Successful tank trials were conducted December 2011.

Under RPSEA Project 09121-3300-05, Autonomous Inspection of Subsea Facilities, Lockheed Martin (LM) developed AUV technologies that provide the capability to conduct AUV-based post-hurricane platform inspection using 3D mapping, and change detection with a 3D sonar. Successful technology validation trials for this technology were conducted with the Marlin™ AUV during the summer of 2011.

The scope of this project is to repackage 3D at Depth’s 3D laser for AUV deployment and integrate it with LM’s AUV-based inspection capability. The resulting AUV-based 3D laser inspection system achieves the capability to (1) conduct close-in, high resolution structural inspection, (2) generate 3D models of risers, flowlines and
other subsea structures, and (3) perform detection of flaws or damage against a priori structural models. In addition, the resulting data can be geo-spatially registered, enabling end users to geographically register inspection data in world-view database applications such as ARC-GIS.

This report presents a technical assessment of existing and emerging technologies to be used for long range, high resolution 3-D underwater laser sensor inspection.

The maturity of a project is measured using the Technology Readiness Levels (TRL) as documented in the American Petroleum Institute Recommended Practice (API RP) 17N. The AUV-based 3D Laser Imaging capability will be advanced from TRL 0 (unproven concept) to TRL 4 (pre-production system environment tested) under this contract. The anticipated TRL transitions will occur as the project progresses through its four phases as shown below in Figure 1.

![Figure 1 - AUV-based 3D Laser Imaging TRL Transitions](image)

### 1.1 Technology Assessment

The primary technology challenges for an AUV-based 3D Laser are 3D Laser technology, sensor packaging for AUV platforms, multi sensor optimized modeling and mobile platform accuracy.
1.1.1 3D Laser Technology

3D laser scanning has become a prominent sensor for acquiring spatial data in three dimensions with high fidelity and low processing time. 3D imaging systems are instruments that are used to rapidly measure (typically on the order of thousands of measurements per second or faster) the 3D coordinates of points on an object or within a region of interest.

3D Laser sensor technology leverages a land-based survey and measurement industry that was transformed by 3D laser scanning technologies. It is a mature, multi-billion dollar industry that quickly produces precise, high resolution 3D models of as-built facilities with a variety of Commercial Off The Shelf (COTS) post processing programs. Developing this technology to provide high definition subsea laser imaging enables the deep-water industry to use the current state of the art in 3D metrology and related best practices developed for the terrestrial market.

There are several methods and technologies being used to perform 3D laser scanning. Laser light can be projected as a single point or a laser line containing hundreds of laser points. Time-of-flight 3D laser scanner uses laser light to find the distance of a surface by timing the round-trip time of a pulse of light. Triangulation 3D laser scanners shine a laser on the subject and uses a camera to look for the location of the laser dot. Structured light laser scanning projects a narrow band of light onto a surface producing a line of illumination that appears distorted from other perspectives than that of the projector, and can be used for an exact geometric reconstruction of the surface shape.

All methods have strengths and weaknesses that make them suitable for different applications. The maximum ranges of 3D imaging systems vary from under 1 m to over a kilometer (several feet to over half a mile), and measurement errors vary from sub-millimeter level to centimeter level (thousandths of an inch to tenths of inches), with greater errors more often associated with the longer range instruments. Required
scan time, size, weight, power are all variables that need to be traded off against one another. Performance in a wide variety of water turbidities is also desired.

3D at Depth, LLC is the developer and supplier of the underwater 3D laser. The laser parameters are compatible with current AUV concept of operations. They will contribute their proprietary imaging technology and expertise in subsea imaging applications, developed in conjunction with offshore oil & gas end users and subsea survey & positioning service providers.

### 1.1.2 Sensor Packaging for AUV Platforms

The 3D laser sensor has been packaged for subsea operations and has been successfully tested while completely submerged and operational. Sensor interfaces are standard Ethernet TCP/IP protocols that have been proven to integrate with a Remote Operated Vehicle (ROV). The programmable scan area, scan rate, and flexibility of beam steering will be defined by a 3D at Depth standard application program interface (API) library.

A custom power converter board was developed to regulate ROV 26V DC power to the various voltages required by the sensor. ROV testing was performed on a Schilling Robotics Ultra Heavy-Duty (UHD) work class ROV. Neither sensor size nor weight was a constraint for the ROV selected for this prior phase, and the existing sensor packaging was successfully integrated.

The sensor has undergone successful shock and vibration testing in accordance with Defense Military Standards for Mechanical Vibrations of Shipboard Equipment MIL STD 167-1A for basic survivability and identification of any resonant vibration issues. It has also been successfully thermal tested in accordance with MIL STD 810G (soak and thermal cycle), as well as transit drop tested while packaged for transit (which resulted in identification of improvements to the transit case).

The current 3D Laser packaging will be optimized for integration into the space constraints of the Marlin™ AUV pylon.
3D laser sensor repackaging is planned under the scope of this effort. Initial evaluation shows this development to be low risk.

1.1.3 3D Modeling

This project modifies the existing Marlin™ AUV software suite to accommodate a new mission for 3D laser inspection. It involves minor modifications to the same backend technology that is being used with SONAR and other sensors on the Marlin™ vehicle. The generation of a 3D model using laser sensor point cloud data has already been demonstrated. The only challenge will come from developing the interface with the new sensor for data collection.

The extension of the existing Marlin™ software to log accurately time stamped, 3D laser data to support assessment of post processing for multi-sensor optimized model building is planned under the scope of this effort. Initial evaluation shows this development to be low risk.

The technology gap that currently exists is the generation of a multi-resolution model, where different sections of the model have different resolutions, depending on whether sonar, laser or a fused, optimized data set is available for that section of the model. Sensor fusion is the combining of sensor data such that the resulting information is more accurate, more complete, or more dependable than would be possible when these sources were used individually. Depending on the outcome of the assessment, the opportunity may be realized to provide a multi-resolution model.

1.1.4 Mobile platform accuracy

Due to absorption of water, realizable deep water systems are limited in range as compared to terrestrial-based systems. An underwater laser accuracy and range measurement of 3mm at 8m range has been demonstrated for an underwater laser sensor integrated with an ROV. The current range capabilities of the AUV-based inspection system are sufficient for demonstration of this sensor.

The primary technology challenge of the 3D sensor is the presence of image distortion due to vehicle instability during HDS. Integration of data from INS will apply...
corrections to resulting dataset and will improve the current solid model measurement discrepancies.

The extension of the existing Marlin™ software to log the 3D laser data to support assessment of post processing for change detection accuracy and precision is planned under the scope of this effort. Initial evaluation shows this development to be low risk.

Depending on the outcome of the assessment, the opportunity may be realized to provide accuracy greater than expected.

1.2 Technology Summary

The core technologies of interest have all been demonstrated for other applications and / or in other environments. However, due to additional complexity and / or the new environment, there is a need for additional development and testing for application in AUV-based 3D Laser Inspection. Table 1 summarizes the current state of the individual key technologies along with an assessment of the current TRL and the expected TRL at the completion of this effort.

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<thead>
<tr>
<th>Technology</th>
<th>Summary of Technology Assessment – As Applicable to 3D Laser Inspection</th>
<th>Pre TRL</th>
<th>Post TRL</th>
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<td>Underwater 3D Laser Sensor Packaging</td>
<td>Demonstrated on ROV platform, needs to be repackaged for AUV platform deployment</td>
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<td>TRL 4</td>
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<td>Multi-Resolution Modeling</td>
<td>Data fusion algorithms will need to be applied to multiple sensor data sets and analyzed for further development and tuning</td>
<td>TRL 2</td>
<td>TRL 4</td>
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<tr>
<td>Underwater 3D Laser Mobil Platform Accuracy</td>
<td>Demonstrated on ROV platform, AUV based platform data will be integrated with INU data to improve accuracy and analyzed for further development and tuning</td>
<td>TRL 3</td>
<td>TRL 4</td>
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Table 1 - Summary of Technologies
1.3 Future Development Opportunities

In general, the key autonomy technologies of interest have been implemented and proven effective by Lockheed Martin. Adaptive path planning and change detection capabilities have been successfully demonstrated for offshore structural inspection in the Gulf of Mexico. Lockheed Martin will heavily leverage these existing technologies in order to develop the capabilities required to enable AUV-based 3D Laser inspection. The current scope of work focuses on development of the key technologies required to support structure inspection utilizing 3D laser technology. The following identifies areas where AUVs may provide further support in the future.

Once changes have been identified from the LIDAR 3D mapping scan, it may be desirable to autonomously re-plan a path to revisit these areas at a stand-off distance appropriate for the collection of high-definition optical imagery. This capability will deliver targeted high-definition optical imagery of just those areas identified as containing anomalies and will significantly reduce the operator’s workload.

Enhancements to the stability of the stationkeeping mode of the AUV will enable even further improvements in detection accuracy, and may be considered for future development.