Demonstration of Abyss Solutions Mooring Chain Inspection Technology

ExxonMobil Test Tank Chain Pilot – Final report

For

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Table of Contents

1 Document Details

Document History

Date	Version	Description
10.11.2018	1.0	Client Submission

2 Introduction

Abyss Solutions has developed a state of the art, inspection approach and hardware system for sub-millimeter accuracy measurements of oscillating mooring chains underwater. The approach utilizes a stereo-vision system combined with strobe illumination. High-fidelity still imagery is captured and stitched together to produce a 3D model of the chains. This is used to obtain accurate measurements of the chain links. The approach is uniquely placed in the market as the results are invariant to chain motion and the hardware used can be readily integrated on a wide range of underwater remotely operated vehicles (ROV).

3 Inspection Overview

Abyss Solutions inspected a 3-link replica of a mooring chain on October 29-30, 2018 using its imaging system mounted on a third party ROV within a large test tank. The inspection involved:

1. **Hardware Integration:**

   Abyss Solutions integrated its high-fidelity optical imaging system on a third party ROV within 50 minutes. The process was relatively simple and required a single member of staff only. The system that was integrated consisted of a stereo imaging set as well as specialized strobe lighting. The system was capable of capturing high detail and accurate color imagery as well as precise 3D measurements.

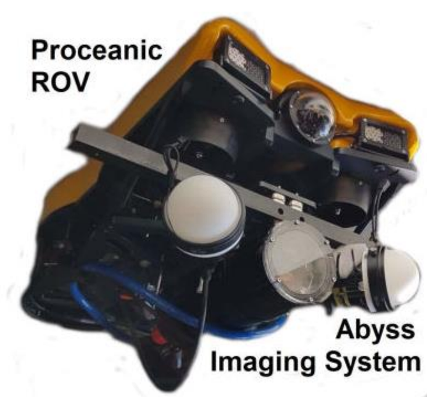


Figure 1: Image of Abyss Solutions' imaging system integrated on the third party ROV.

2. **ROV Inspection:**

   The ROV was navigated along the length of the chain to capture imagery from multiple perspectives. Following calibration and testing, 3 chain links were inspected within 30 minutes, excluding setup time and interruptions. Streamlining of this process is envisaged to reduce this to 10 minutes.

3. Chain Oscillation

Following onsite calibration with the chain held stationary, the chain was oscillated vertically with a maximum velocity of 1m/s (to mimic extreme offshore conditions). The vehicle was navigated through a series of angles along its length to achieve maximum coverage.

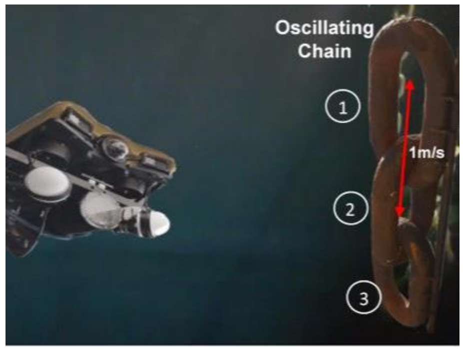


Figure 2 Image of the oscillating chain setup used during the inspection.

4. Onsite Analysis

A subset of the imagery was used to generate preliminary 3D models of the chains onsite. Preliminary chain measurements were provided to onsite personnel within 20 minutes of data capture. The provision of measurements was interactive with personnel able to nominate the precise measurements required.

4 Analysis Approach

The analysis approach adopted during the pilot involved the following:

1. Image Enhancement

Imagery collected was subject to image enhancement to improve the appearance of the fine details of the chain links and the representation of chain geometry.

Figure 3 Example of a raw underwater image subject to algorithmic enhancement.

2. Photorealistic 3D Models

The enhanced imagery was used to re-construct an enhanced color and high-detail virtual replica of the chain links. The models were produced to scale for the purpose of 3D measurement.

Figure 4 Image of photorealistic 3D model of a chain link.

3. Dimensional Measurement

The 3D models were used to estimate bar diameters in the plane (a) and orthogonal (b) to the face of each link. Additionally, grip lengths (c) were determined for each end of the center link.

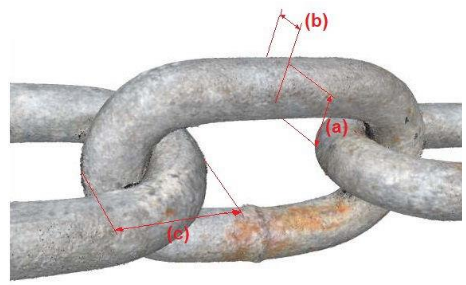


Figure 5 Image of a photorealistic 3D model of a chain link showing the measurement of bar diameters (a) and (b), and grip length (c).

4. Visual Database of Results

A visual database with both 3D models and <1mm accuracy measurements was produced within 8 hours of data capture. The database is fully interactive allowing the user to efficiently navigate the large volume of data. All processing was conducted on a standalone workstation.

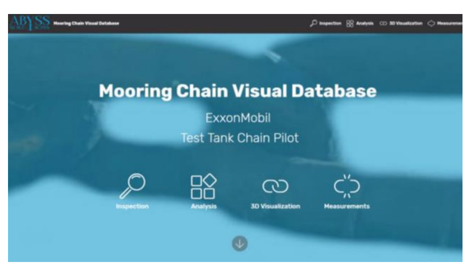


Figure 6 Screenshot of the mooring chain visual database home screen.

5. Results Refinement

3D models and measurements were subject to further processing over a period of 2 man-days with the computing infrastructure described in item 4. This enabled further refinement of the results.

5 Results

This section presents the results of the mooring chain inspection and analysis using Abyss Solutions unique technology. Samples of high-fidelity imagery captured of the chain are presented in Section 5.1 with 3D visualizations of the mooring chain presented in Section 5.2. Measurements of the chain links are presented in Section 5.3.

5.1 High-fidelity Imagery

Samples of high-fidelity imagery of the chain captured during the inspections conducted on October 29-30, 2018 are shown in Figure 7. Images captured during daylight and in complete darkness presented accurate color representation, high clarity of fine detail and no observable motion blur. The quality of the imagery following enhancement was relatively invariant to the ambient lighting conditions and consistent across the 2 inspection days.

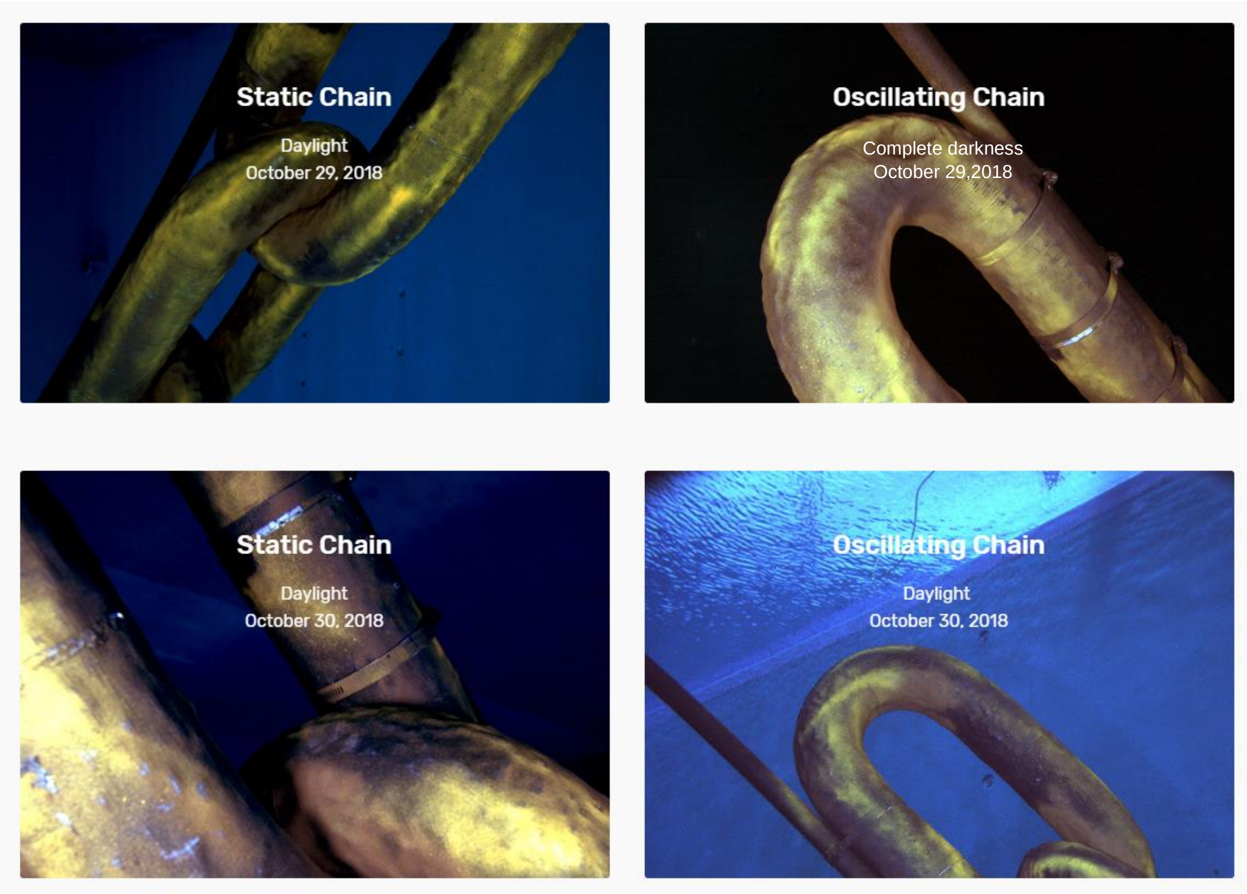


Figure 7 Samples of high-fidelity imagery of the mooring chain captured on October 29-30, 2018.

Over 600 stereo image pairs were captured of the accessible surfaces of the chain in a single inspection run. Comprehensive coverage of the chain was achieved within approximately 30 minutes for each inspection iteration, excluding interruptions. Streamlining the inspection process is envisaged to reduce this to 10 minutes.

Greatest coverage and overlap of imagery were achieved during the inspection of the oscillating chain with the ROV maintaining an independent course rather than following the oscillations of the chain. Minimal adjustment of the imaging system was required to achieve high quality image capture. This included initial adjustment of the strobe positioning for the ROV platform setup and camera exposure time to minimize motion blur during the inspection process on the first day of the inspection.

It is anticipated that this level of image quality can be replicated in field conditions given (1) similar water clarity is expected in the open ocean, (2) the chain setup mimics the geometry of an in-service chain and (3) the motion of the chain at 1m/s represents an extreme case of offshore chain oscillation.

5.2 3D Visualization

3D models of the static and oscillating chains generated using data collected on October 29-30, 2018 are shown in Figures 8-9. Click on the figures below to launch and interact with the 3D models. The 3D model of the oscillating chain has been used to generate engineering drawings of the bar sections for each link as shown in Figure 10.

Figure 8 Interactive 3D model of the static mooring chain. Click on the figure above to launch the model.

Figure 9 Interactive 3D model of the oscillating mooring chain. Click on the figure above to launch the model.

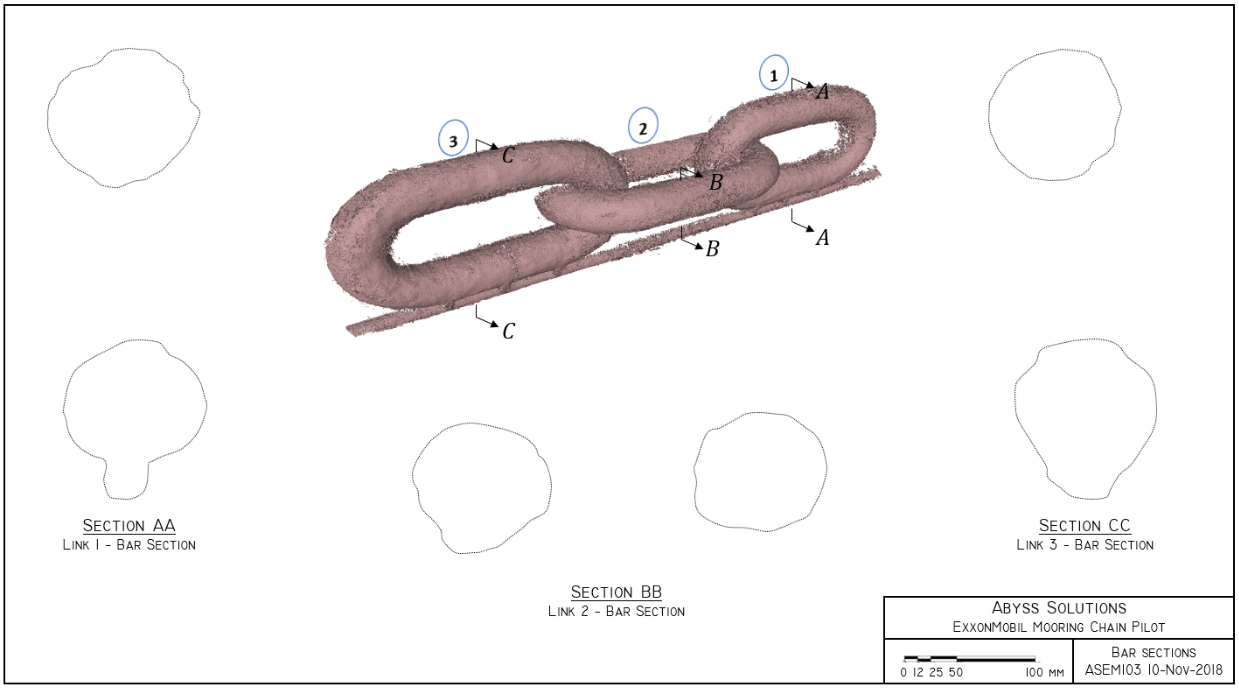
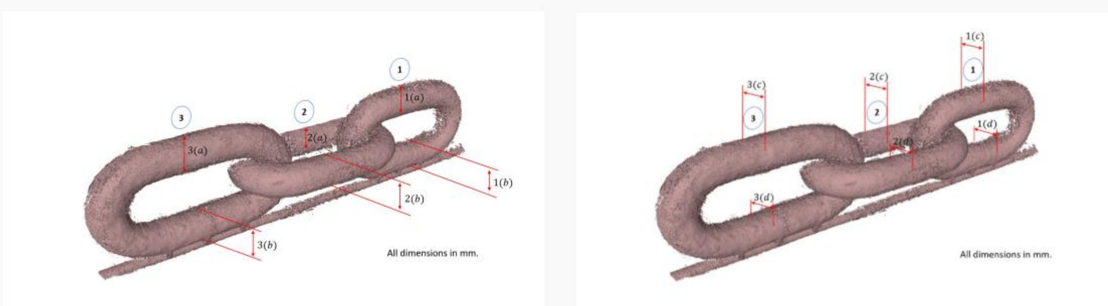


Figure 10 Engineering drawing showing bar sections for each link obtained from the oscillating chain 3D model.

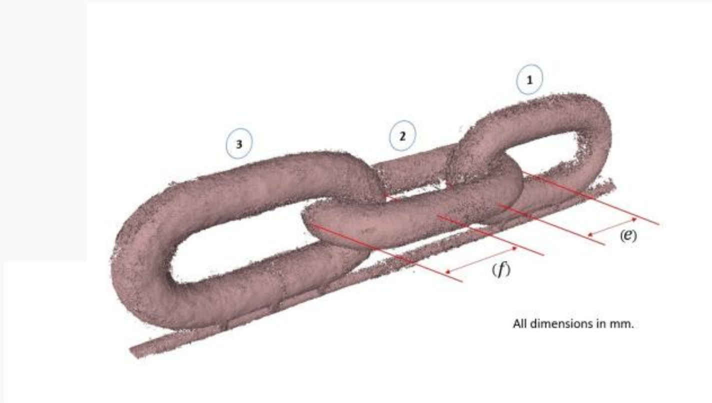
5.3 Measurements

A complete set of measurements of the chain links was obtained using the 3D models. Measurements of bar diameter and grip length are presented in Figures 11 and 12, respectively.



Link	(a)	(b)	(c)	(d)
1	106.3mm	108.9mm	107.3mm	109.5mm
2	109.2mm	109.5mm	110.9mm	109.1mm
3	109.9mm	110.9mm	109.6mm	113.7mm

Figure 11 Measurements of bar diameters for each chain link obtained from the 3D models.



Links	Grip length
1 to 2 (e)	218.8mm
2 to 3 (f)	219.1mm

Figure 12 Measurements of grip length for each chain link obtained from the 3D models.

6 Conclusion

Abyss Solutions seamlessly integrated its imaging system on a third party ROV. The operations were successful in capturing detailed data of both a static and oscillating mooring chain (moving at 1m/s).

The first day of operations focused on obtaining small-scale accurate measurements comparable to those of traditional caliper methods. The second day of operations targeted more comprehensive coverage of the chain links to deliver a comprehensive 3D model of the chain.

Preliminary onsite measurements were turned around within a 20-minute timeframe on both days. Comprehensive data processing was conducted within 8 hours on each day to return key measurements and a 3D model of the chain links. Results were refined, and a final report delivered within 2 man-days. All key measurements were made and reported.

6.1 Project Summary

Both static and oscillating chain links were imaged in a test tank using the Abyss Solutions imaging system integrated onto a third party ROV platform. Data collection was rapid and thorough. Streamlining of the process is anticipated to reduce the data acquisition time for an equivalent set of chain links to under 10 minutes on the field.

Data was collected with sufficient point density to enable the accurate estimation of 14 key measurements. Comprehensive 3D models were generated, which allow for measurement-based analysis to take place beyond the scope of the 14 pre-specified measurements.

Preliminary measurement results were generated within 20 minutes of the operations, which validated the integrity of the data and which may enable real time asset management decision making on the field.

Detailed results were produced within 8-hours which will ultimately aid field analysis and job planning. Results were refined, and a final report delivered with 2 man-days of work. This allows a client to quickly assess the general health of a chain while on the field.

6.2 Limitations

Limited coverage was achieved when collecting imagery wrapping around the chain, from one side to the other. This was due to the mounting cables of the chain rig obstructing the path of the ROV around the chain. This is unlikely to be an issue for inspections on the field as chains will have clear access around their exterior.

This was further complicated by the limited ability to vary the pitch of the imaging system (< 30 degrees) and capture imagery of the interior of the chain which relies on imaging from a varied range of angles. This may be overcome through the use of a tilt-table on the ROV to independently vary the angle of the imaging system relative to the ROV (by up to 90 degrees).

Limited coverage has introduced uncertainty into the measurements of bar diameter out of the plane of chain links 1 and 3 (measurements 1(c), 1(d), 3(c) and 3(d) in the diagram above). Further processing was required to reduce this uncertainty and produce accurate results in this report. Refinements in the data collection techniques will reduce data processing time while and avoid uncertainty in these measurements. This would result in a complete report within 8hrs.

6.3 Lessons Learned and Future Work

The pilot study described here entailed the integration of high-fidelity imaging hardware onto an existing ROV platform, simulated mooring chain inspection operations, visual data processing and rapid results delivery. Standardization of the high-quality imaging hardware led to trivial integration onto a new platform. Data gathering operations proceeded swiftly with the aid of an Abyss Solutions engineer, complemented by rapid data validation and processing. This enabled the survey approach to be fine-tuned quickly.

The first day of operations focused on capturing accurate measurement data while day 2 looked more towards generating a comprehensive 3D model of the chain. The work on day 1 involved the collection of close-range (0.5-1m) imagery of the chain to construct small-scale 3D models for accurate measurements comparable to those of traditional calipers or go-no-go gages. On day 2 the ROV was navigated at a further distance (1.5-2m) from the chain to increase the contextual information within the imagery for large-scale 3D modelling. Comprehensive 3D models generated in this way allow for measurement-based analysis to take place beyond the scope of the 14 pre-specified measurements as well as for corrosion and pitting analysis.

Key insights were gained in both data collection and data processing. The results from day 1 have shown that the collection of small-scale 3D models is a highly effective means of delivering the measurements required for traditional mooring chain inspections. Fine-tuning these procedures will allow for data gathering at a similar scale to take place within 10 minutes and measurement results within a further 20 minutes.

The results from day 2 have highlighted Abyss Solutions' capacity to generate full 3D models of chain links within 8 hours. Comprehensive 3D reconstruction was prioritized over accurate measurement given the limited time. Refinement of the results over an equivalent period of 2 days enabled accurate measurement from these models. Further improvements in how the data is captured can streamline the process of large-scale model generation.

This pilot represents a pathway to conducting mooring chain inspections in field conditions. Operating offshore, greater water turbidity, larger scale inspections and tighter time constraints, and varying chain dynamics can be expected. Abyss Solutions has already commercially demonstrated the ability of its imaging technology to operate robustly in turbid conditions. With streamlined operations and data processing, results can be produced rapidly in the field. Refinements in the survey approach will allow for adaptation to different chain dynamics. Some additional trivial developments in imaging hardware can also help relax the operational constraints and duration even further. A field deployment of the inspection technology is therefore recommended as the next step.