A new approach to Pipeline Inspection using Autonomous Underwater Vehicles (AUV’s).

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Abstract

AUV’s have successfully been introduced into Oil and Gas operations for Geophysical and Environmental surveys, replacing vessel based and towed systems, and development continues to advance rapidly mostly as a spin out of the defense industry. Total and Chevron have been working in a Technology Co-operation Agreement to understand, influence and adopt these advances in technology with a view to start to conduct sonar and visual pipeline inspection with AUV’s. Together, the companies have developed a new approach to pipeline inspection. AUV’s have advantages and disadvantages over more traditional towed systems and Remotely Operated Vehicle (ROV) systems, in terms of capability with regard to pipeline inspections. This necessitates a change in philosophy to take full advantage of AUV attributes and this change will require improvement in sensors, autonomy software and data processing and management. In order to meet this new level of requirement some technology gaps need to be addressed, particularly in the areas of AUV navigation, real time 3D mapping and feature recognition, and data communications with intelligent sensors.

The result of this new approach to pipeline inspection utilizing AUV’s will bring improved safety due to better data quality and potential increased frequency of inspection, resulting in better integrity of subsea assets. The deliverable for the co-operation will be new specifications for AUV pipeline inspection surveys that will guide the AUV suppliers and operators to enhancing their current capabilities to meet both companies’ requirements for pipeline inspection information. These developments will also provide a stepping stone for acceptance of AUV’s into additional inspection and light intervention programs and eventually field resident systems.

Introduction

The goals of the TOTAL/Chevron Technology Co-operation agreement for global AUV pipeline inspection were to gain alignment in our global requirements for AUV pipeline inspection and to define these requirements in an AUV pipeline specification document. This document would be written while understanding the limitations of AUV’s compared to ROV’s and towed platforms, but without compromising the key requirement to assess the integrity of our offshore pipeline assets.

The specifications would cover periodic inspection of pipelines which currently may be categorized into sonar or visual inspection or a combination of both approaches. These specifications would provide a basis to discuss a business case for introducing AUV pipeline inspection to each of our different business units in order to fully comply with existing regulatory standards and current industry best practices.
We would use the most stringent requirements from both companies to define the specification and to enable an assessment of technology gaps that need to be addressed in order to meet these requirements. We would also engage and support the AUV industry and the pipeline inspection service suppliers in order to meet our new requirements.

As always, the two companies reserve the right to modify further our approach to pipeline inspection and these specifications, in order to address continuing changes in technology capability, change in regulatory statutes, or requirements from our integrity management groups.

**Summary of Inspection Tasks**

*Pipeline Integrity Standards*

Referring to industry best practice guidelines and internal requirements for deepwater Pipeline integrity from both companies, a validation process has been done internally to confirm and verify an AUV approach to pipeline inspection.

In general, the following main threats have to be identified following to any inspection campaign regardless the used tool (ROV or AUV), these threat group is: design/fabrication/installation threats, corrosion threats, impact threats, bulking/stability/fatigue threats, natural hazard threats and finally incorrect operations threats.

*Requirements for Pipeline Inspection*

The following high level requirements for pipeline inspection were indentified:

- Subsea Navigation
- Visual Inspection
- Sonar inspection
- Damage Assessment
- Debris Identification
- Pipeline Features
- Pipetracking
- Buried Pipeline Detection
- Freespan Detection and Measurement
- Seabed Conditions
- Buckling Survey
- Detection of Pipeline Movement
- Corrosion Survey
- Reporting and Deliverables

**Technology challenges of transitioning from Towed Sonar and ROV techniques to AUV Inspection**

Of these requirements, several were identified as being challenging for AUV’s, due to sensor power and payload requirements, and also due to the fact that they would be conducted fully autonomously.

*Subsea Navigation*

Pipeline inspection is always accompanied with a high accuracy position survey to determine the absolute position and relative movement of the pipeline in the seabed.

The typical approach is to use a vessel based acoustic positioning system to communicate with transponder or responder units on the ROV or towfish to provide a reasonably accurate position. Some additional equipment may be added such as Doppler Velocity Log (DVL) or an Inertial Navigation System (INS) to enhance the quality of navigation, but the position is usually considered accurate enough when it is finally corrected, often in post processing. During an ROV based inspection, relative position from the pipeline can be achieved visually by manual intervention of the pilot. During towed sonar inspection, a pre-determined route is followed, and advances in real time sonar algorithms have
provided immediate feedback of the offset distance from the pipeline from the sensor in order to allow adjustment of the course of the towed system.

These approaches also require a dedicated surface support vessel during the inspection campaign, and the absolute positional accuracy degrades with water depth.

One of the main advantages of using AUVs is the possibility of operating without a surface navigation support vessel. The key requirement for pipeline inspection is the requirement to follow the pipeline with high accuracy to enable close sensor proximity to the pipeline. This is considerably more difficult to achieve with an AUV and in order to perform this task two differing technologies are to be used:

- Pipeline recognition
- Subsea Features positioning

**Pipeline recognition**, is a technology used to lock-on to a subsea pipeline either visually or by using sonar information. The software will recognise the pipeline shape and the use of this technology will allow AUVs to follow the pipeline by recognition of pipeline shape and continue the survey inspection mission as planned.

This image recognition also will be used not only to identify the pipeline shape and give the order to AUV controls to follow it, but it will also control the altitude and the heading of the AUV in order to maintain a defined attitude with respect to the photography taken by the AUV, so that all the images taken by the AUV should have more or less the same characteristics along the whole pipeline.

With sonar recognition the offset to the pipeline will be derived in real-time enabling course changes to maintain the optimum offset-to-altitude aspect ratio for sonar inspection.

However, the down side of these methods is the lack of absolute position as it depends on the INS data which has accumulated errors of several meters every 1000 metres (3000 feet).

**Subsea Features Positioning**, is a technology under development that allows the AUV to recognize its actual and real position through comparing the current position information with the stored information for certain subsea fixed features, these features are recognized either through real-time image or sonar data processing. On recognition of a detailed feature, the INS position will be reset and the INS accumulated error will be back to zero. The accumulated INS position error will rise again until the next feature is recognized and the process repeated. The subsea features can be manifolds, x-mas trees, sleepers, valves, anodes etc, or potentially pipeline markers. So long as the features are identified at reasonable intervals and the AUV is moving at reasonable speed, high accuracy positional data will be provided without the need of a surface vessel.

The database of information for the subsea features will be provided as part of AUV pre-mission planning. This technology is not applicable when the AUV is performing inspection in areas never previously inspected, or where no subsea features are available.

In addition this data will be supplemented by real-time determination of the top of pipe from a multibeam echosounder or laser scan across the pipeline. This YZ navigation relative to the measured top of pipeline will ensure that the AUV maintains the correct relative position for visual and cross profiling survey.

**Visual Inspection**

Typically visual inspection data is coming from three cameras fitted on the ROV (Center – left – right) cameras. The left and right cameras may be located on booms to observe below the pipeline and the relationship of the pipeline to seabed. This arrangement is not easily replicated by a free flying AUV and so an alternative approach needs to be made. It is required that AUV pipeline survey will be conducted at altitudes of one to three metres (three to ten feet) directly above the pipeline, dependent on pipeline diameter.

Power consumption and power management for continuous video and video lighting are other factors for AUVs, so it is necessary to use HD digital still cameras instead of video cameras. Sufficient photographic images will be obtained to ensure significant overlap between adjacent frames to obtain full coverage of the pipeline. Strobe lighting will be used and synchronized to each photograph. This will reduce the power requirements and also the storage requirements as compared to video.
The output from the digital cameras will be mosaiced together in post processing to form a continuous image of the pipeline from above. This image will be correctly geo-referenced allowing for ease in comparison of co-ordinates, and it will also provide the advantage of allowing accurate measurements of any feature on the image.

Transferring all visual inspection data to digital format will give the opportunity to apply different processing algorithms to identify anomalies / defects which will save time during the post processing verification. These anomalies could be but not limited to coating damage, debris with survey corridor, local buckling and lateral movement drag marks on the seabed.

**Frespan Detection**

Freespans are traditionally determined by either ROV or sonar methods. Accurate determination of freespans is a major requirement of any pipeline inspection.

Typically freespans are measured through a cross section profile of the pipeline at regular intervals using mechanical profilers. These systems provide good quality data where the ROV is stable (particularly if the ROV is running on a wheeled undercarriage), but they are slow and create some distortion due to forward movement and also from any roll of the ROV during the scanning process. A similar process will be adopted by AUVs, but due to the requirement for higher speed survey, faster scanning devices such as multi-beams and laser scanners will be necessary. Since the verification of freespans visually from ROV boom cameras is no longer available with AUV’s, better resolution of the cross sectional profile will be necessary to improve the current techniques, hence laser scanning will be required in most cases.

Where sonar inspection is specified, the AUV will be able to perform this with improved data quality, due to it’s stability, real-time pipetracking capability and hence a stable offset-to-altitude aspect ratio.

In areas where freespans are still known to be changing length and reaching critical levels, a two pass AUV pipeline inspection will be specified. The first pass will be akin to the towed techniques, using high frequency sonar, followed by a pass directly over the pipeline using the cross sectional profile laser scanning technique.

**Corrosion Survey**

Currently a typical Corrosion Protection(CP) survey with an ROV requires carrying a remote cell sensor to provide continuous CP potential reading along the pipeline, and also a CP probe which is carried in the ROV manipulator to enable a stab of the anodes to provide a referenced value. The remote cell indicates relative changes in potential along the pipeline between these stabs. Alternatively over shorter pipeline some training wire techniques may be used.

In case of AUVs, it is not practical to attempt to use either technique, so CP measurements has been identified as technology gap facing AUV’s and their ability to carry out a full pipeline inspection survey list of tasks. However both TOTAL and Chevron having internal research and development efforts to overcome this obstacle and both companies expect to have passive solutions for CP survey suitable for AUV deployment operational by early 2015.

One possible approach is to use intelligent sensors in anodes and to use Data Harvesting techniques to transfer the data to the AUV. Here, a sensor on the anode measures the pipeline potential at regular intervals and stores the value until the next AUV survey. The sensor also includes a radio, optical or acoustic device, which can allow the data to be transferred wirelessly to the AUV using radio frequency or electro magnetic (RF or EM), free space optical (FSO) or acoustic waves.

This option would more likey be pre-designed for use in green field applications, or may be retro-fitted where CP is a crital factor in extension of pipeline life beyond initial design parameters or where continuous monitoring may be required. These smart resident systems are not limited to CP measurements, but could be extended to whatever measurements are required from subsea facilities such as pressure, temperature, flowrate, hydrate levels, wall thickness, etc.
Outline Specification

Visual Inspection
Visual inspection of the pipeline shall include HD still photographs of the full length of the pipeline, taken from directly above the pipeline. The images shall be obtained using either a HD stills camera or a stereo camera, in conjunction with a flash light strobe. The camera(s) aperture shall be set such that the pipeline field of view covers between between 40% and 70% of the screen size considering the area of interest. At least 50 per cent overlap between images is required. The AUV shall be capable of capturing images from one to three metres above the pipeline at speeds from 1 to 2 knots.

Sonar Inspection
AUV inspection by sonar will require a high frequency sonar system (400 to 1000 kHz). The AUV will maintain an offset of 10 to 20 metres from the pipeline with an aspect angle of between 5 and 30 degrees referenced from the seabed.

Damage Assessment
The AUV shall be capable of detecting damage and anomalies of dimensions 5cm x 5cm by visual or sonar imagery.

Debris Identification
The AUV shall be capable of identifying a minimum debris size of 25cm x 25cm x 25cm within a ten meter corridor width on each size of the pipeline. Debris type should be identified visually where in the camera field of view, or interpreted with sonar or multibeam backscatter imagery.

Pipeline Features
Mattresses, crossings, sleepers, stabilization structures, support structure shall be detected and identified through post processing of imagery and multibeam.

Pipeline crossings shall require an additional 250m survey along the crossing pipeline on each side.

Pipe Tracking
No buried pipeline tracking or depth of burial information is necessary other than what is determined from the visual, multibeam or sonar sensors.

Buried Pipeline Detection
Detection of buried pipelines shall be optional but may be required in shallow water pipelines. Refer to individual scope of work. Sub-bottom profiler of magnetometer devices may be specified to conduct pipeline crossings at regular intervals.

Free Span Detection and Measurement
Free span shall be detected using a scanning laser or Multi-Beam Echo-Sounder (MBES) to calculate the height of the top of the pipe (best fit with pipe diameter) and by applying the diameter of the pipe to determine bottom of pipe. Comparison should be made with the mean observed seabed levels either side of the pipeline. The position of the free span shall be given relative to KP during post processing of data.

Side scan sonar shall also be used to provide complimentary information to the MBES data, where a second pass sonar survey is specified. Freespan should be calculated based on the acoustic shadow of the pipeline on the sonar image.

The Laser, MBES and side scan sonar sensors shall be able to detect a minimum height of 5-10 cm and a minimum length of 1m.

Seabed Conditions
Trench condition, rock dump condition shall be detected through post processed multibeam cross sectional profiles
**Buckling Survey**

The AUV shall be capable of detecting local and global buckling. Local buckling shall be detected through visual means, and global buckling shall be detected through post processing of AUV navigation. The photographic mosaic shall be used to determine local changes in pipeline direction. In order to evaluate global buckling, the pipeline position shall be derived from application of the laser or MBES offset of the pipeline from the post processed position of the AUV following integration of the Inertial Navigation and DVL data with the subsea feature baseline datasets.

**Detection of Pipeline Movement**

The AUV shall similarly be capable of detecting pipeline movement through post processing of imagery, multibeam and navigation. Particular attention shall be made to look at any spoil build up on either side of the pipeline. Multiple year on year comparison of position shall be processed with regard to the pipeline co-ordinate database.

**CP Survey**

The techniques for conducting CP Survey if required will be specified separately for each pipeline. New techniques will be specified by either company at a later stage. Coating damage and the general conditions of galvanic anodes should be reported along with the potential values as specified. In addition to anode current output, these nominally will include electrical field gradient measurements and current densities in the vicinity of the pipeline, in order to confirm the pipeline protection against corrosion.

**Reporting and Data Deliverables**

A comprehensive inspection report shall be required.

Standard ROV or sonar inspection type deliverables are to be delivered in order to assist in transition to acceptance of AUV Survey as a replacement for other surveys by our business units and the legislative authorities. This will also facilitate ease of comparison with previous inspections. This should include anomaly, damage, debris and freespans listings, and a standard four box chart format including plan with anomaly annotation, longitudinal profile, cross sectional profile and engineering data. A separate CP survey report will be required.

Additional non standard products will include:

- Photographic mosaic geo-referenced to the project datum. Degradation of video resolution should be minimal if compression techniques are to be used. The image formats should be in JPG, TIF, geoTIF, BMP, or MrSID.
- A sonar mosaic geo-referenced to the project datum.

Future additional requirements:

**Leak detection**

Leak detection will be an increasing requirement during pipeline inspection, and new techniques will be used to determine smaller amounts of loss. Today we can detect gas bubbles visually and by sonar. Small liquid to liquid leaks can also be found with these techniques, however more research is required in sonar and contact sensors to further refine the scale of detectibility of smaller liquid to liquid leaks.

**Conclusions**

Chevron and TOTAL have succeeded in promoting a new approach to pipeline inspection using AUV’s, without comprise of the overall needs for integrity management. This new approach is not without challenges, however the sensors and technology exists to overcome these challenges and this will lead to changes in pipeline inspection standards and regulation.

The introduction of pipeline inspection using AUV’s will be the beginning of a full range of IMR sensor development suitable for AUV deployment. These new tools will contribute positively to the development of AUVs, leading to wider scopes of work and further acceptance in the industry. Ultimately, with the deployment of field resident AUV systems, we will see increasing frequency of inspection of our subsea assets, leading to earlier detection of problems. This will lead to a reduction in downtime for field maintenance, and of course better stewardship of our environment.

**References**
• Integrity management of submarine pipeline systems, DNV –RP-F116
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A New Approach to Pipeline Inspection Using AUVs

Agenda

• Project Overview
• Requirements for Pipeline Inspection
• Technology Challenges
• Outline Specification
• Conclusions
A New Approach to Pipeline Inspection Using AUVs

Project Overview

Objective

• Development of a new approach to subsea pipeline inspection using AUVs, in order to:
  
  i. Create a specification for AUV pipeline inspection
  
  ii. Identify and close gaps in sensors, software and AUV technology
  
  iii. Provide direction to the AUV and equipment suppliers
  
  iv. Engage and work with service suppliers to meet pipeline inspection specification

Goal

• Utilize AUVs for pipeline inspection as a standard integrity management approach as soon as the technology matures.
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Pipeline Inspection Requirements

Integrity inspection requirements for offshore pipeline assets:

- Subsea Navigation
- Visual Inspection
- Sonar Inspection
- Damage Assessment
- Debris Identification
- Pipeline Features
- Pipe tracking
- Buried Pipeline Detection
- Free Span Detection & Measurement
- Seabed Conditions
- Buckling Survey
- Detection of Pipeline Movement
- Corrosion Survey
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AUV Advantages

• AUV advantages:
  • Improved data quality
  • Faster inspection speed
  • Improved weather window for inspections
  • Elimination or reduction in size of support vessel

• In order to benefit from these efficiencies:
  • Technology challenges will need to be closed
  • Changes in current pipeline inspection philosophy will be adopted
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Technology Challenges

• The current challenges exist in sensor power and payload requirements, control, maneuverability, and complexity of operating fully autonomously.

• Technology challenges include:
  • Subsea Navigation
  • Visual Inspection
  • Free Span Detection
  • Corrosion Survey
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Technology Challenge – Subsea Navigation

**Traditional Approach:**
- Vessel based acoustic positioning
- Pre-determined route
- ROV visual piloting

**Challenge:**
- Real-time positioning relative to pipeline features
- Operations with no surface vessel

**AUV Approach:**
- Pipeline Recognition
- Subsea Features Positioning

*Source: TOTAL*
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Technology Challenge – Visual Inspection

Traditional Approach:
- Video Streams
- Three Video Cameras
  - two located on booms to show pipeline to seabed interface

AUV Approach:
- HD digital stills camera
- Strobe lighting synchronized to each photograph
- Photo mosaiced for continuous image of the pipeline
- Images geo-referenced

Challenge:
- Power consumption for continuous footage
- Lighting
- Proximity to pipeline

Pipeline Digital Image 2
Source: TOTAL
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**Technology Challenge – Free Span Detection**

### Traditional Approach:
- Mechanical profilers (or dual multibeam echosounders)
- Sonar processing

### AUV Approach:
- Laser scanner
- 3D rendering of pipeline and seabed relationship

### Sonar approach:
- High frequency sonar (multibeam) offset from pipe
- Bathymetry and sonar backscatter processing

### Challenge:
- Requirement for higher speed survey – faster scanning devices like lasers
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Technology Challenge – Corrosion Survey

Traditional Approach:
- Remote cell
- Direct stab of the anode

AUV Approach:
- Data harvesting
- Contactless CP

Challenge:
- Ability to identify anode autonomously
- Capability to stab CP probe onto anode
- Location of reference cell

CP Survey - Anode
Source: Chevron
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Outline Specification

- Visual Inspection
  - HD stills full length of P/L
  - HD stills or stereo camera in conjunction with flash light strobe
  - Overlap between images
  - Close altitude above P/L

- Sonar Inspection
  - HF multibeam sonar system
  - AUV to maintain fixed offset
  - Consistent aspect angle reference from the seabed
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Outline Specification

- Damage Assessment
  - Damage and anomalies by visual or sonar imagery

- Debris Identification
  - Identify with visual or sonar imagery

- Pipeline Features
  - Identified through post processing of imagery and laser/multibeam
  - Crossings survey
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Outline Specification

• Pipe Tracking
  • Visual and laser/multibeam data in real-time. No tracking required when buried.

• Buried Pipeline Detection
  • Depth of buried pipeline (Optional)

• Free Span Detection & Measurement
  • Identified using laser scanner or multibeam echosounder
  • Free span position given relative to KP during post processing
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Outline Specification

- Buckling
  - Local buckling detection
  - Global buckling detection

- Detection of Pipeline Movement
  - Post processing of imagery, AUV navigation, and laser / multibeam cross sectional profiles

- CP Survey
  - Coating damage and condition of anodes
  - Potential readings as specified
  - Anode current output
A New Approach to Pipeline Inspection Using AUVs

Outline Specification

• Seabed Conditions
  • Post processed laser or multibeam cross sectional profiles

• Reporting & Data Deliverables
  • Comprehensive inspection report
  • Standard ROV and sonar inspection type deliverables
  • Non-standard deliverables:
    • Photographic mosaic geo-referenced to the project datum
    • Sonar mosaic geo-referenced to the project datum
    • 3D rendering of laser or multibeam echosounder cross sectional data
    • GIS format delivery
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Conclusions

• Development of new approach to pipeline inspection using AUVs without compromising the overall needs for integrity management.

• Sensors & technology are available but the challenges are to accommodate them to meet AUV pipeline inspection needs.

• Developed specification to provide guidance to the AUV industry.

• Modification of the specification may be necessary to address improvements in sensor capability, changing integrity management requirements from business units or regulators.

• Future additions may include:
  • Riser inspection
  • Leak detection
  • Field resident systems
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