AUTOTRACKER
Autonomous Pipeline Inspection
Sea Trials 2005
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SYNOPSIS
During November 2005, the AUTOTRACKER Autonomous Pipeline Inspection system conducted an extensive set of trials over the last 12km of the Piper/Claymore pipeline as it approaches the Flotta oil terminal, in the Orkney Isles.
This paper presents an overview of the various technologies embedded into the AUTOTRACKER system, the commercial background to autonomous pipeline inspection and achievements of the sea trials.

INTRODUCTION

Innovation
The AUTOTRACKER system \cite{1-5} is a fully autonomous pipeline tracking & survey payload. The intelligent payload is platform independent and can be integrated in any type of underwater vehicle that carries the required sensors for the input.

It can provide high-resolution, low altitude (5-10 m), high-speed (2-4 knots) inspection of underwater pipelines. AUTOTRACKER is capable of autonomously detecting a pipeline’s location and thereafter maintaining relative station to ensure optimal sensor coverage as the vehicle navigates along the pipeline. Active tracking modules use acoustic sensors like sidescan and multi-beam to detect and follow the pipe. By communicating with the deliberative layers about the status of the overall process, the advanced onboard modules are able to re-plan the mission on-the-fly, providing the ability to cope with unexpected situations where the pipe is buried or not detected. The system also integrates an obstacle avoidance and path planner module that allows the vehicle to fly safely at low altitude and high speed, and an underwater digital video that records the status of the pipeline.

As part of the system, SeeTrack software allows a real-time monitoring of the mission and a fast data processing. Sidescan, multi-beam and video data can be geo-referenced into a single display for easy analysis of the pipeline conditions.

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**Motivation**

Oil companies’ studies suggest that improving typical large field availability by just 0.1% could improve production by 30-50k barrels ($2.25M at $45 per barrel) [6]. It is known that Inspection, Repair and Maintenance (IRM) comprise up to 90% of the related field activity. This inspection is clearly dictated by the vessels availability. Mainly in winter the problem arises when some geographic areas, like the West of Shetland, prevent easy access during hard season months.

Therefore, a year round, field based (e.g. FPSO) inspection capability could provide flexible, adaptable, readily available and cheaper inspection capabilities than current methods. One analysis of potential cost savings using an inspection AUV over traditional methods for a pipeline network system predicted savings of up to 30%.

AUTOTRACKER will fill part of this gap for pipeline inspection, and provide better quality data with cheaper resources than the current ROV-based approaches.

![Figure 1: Field based inspection capability (FPSO)](image)

The next section offers an overview of the AUTOTRACKER system. Section III details the trails and concept behind the pipe trackers. The results obtained using the system are analysed in section IV. Final sections cover the conclusion and acknowledgments.

**SYSTEM OVERVIEW**

AUTOTRACKER system is divided in three main different levels: Sensor processing and fusion; Decision Making; and Control and Analysis.

Sensor processing and fusion section deals with the processing of low level information coming from the sensors. Pipe trackers, video loggers and obstacle avoidance sensors are in this level. Initially pipeline trackers have been developed for sidescan and multi-beam sensors, though the architecture could support others like sub-bottom, magnetic or video. Each one generates independent estimates of pipeline’s current location and future predictions. Both sensors acting together provided enough information for identification of the pipe during an initial approach phase, following by close distance tracking.

Sensor fusion module fuses outputs from the trackers with legacy data in real-time to generate a best estimate of pipelines location that is reported to the Decision Making level.

This level also provides interaction with the underwater video camera to collect and log pipe real-time images when the system is tracking and the image processing to generate the level of abstraction required for the obstacle avoidance module.

Decision Making section is the intelligent core of the AUTOTRACKER system. It contains the mission re-planner, obstacle avoidance module and platform interaction. Using the information coming from the Sensor fusion, the system is capable of reassessing the tracking status in real-time and change the behaviour of the platform if necessary. There are currently five possible behaviours identified: find start of the pipe; track; search pipe; skip area; back to start. The mission planner can re-plan at any time the vehicle behaviour by sending commands to the vehicle guidance through the platform interface.
The obstacle avoidance module acts as trajectory “validator” [7]. Trajectories coming from the replanner are approved by the obstacle avoidance module before going into the vehicle guidance based on the obstacle representation coming from the sensors. This allows the vehicle to progress quickly and safely at the same time [7]. All modules at this level report their status and their knowledge of the overall system to the Control level.

Autonomy will fail if the user is left out of the loop. It is important that the user understand at any time what the system is doing. Situation Awareness (SA) is the concept that describes “the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future”. SA is a key value in AUTOTRACKER. The Control section allows the user to monitor and interact with the system and be aware at any moment of the situation. This is achieved by using Ocean Systems Laboratory’s (OSL) OceanSHELL [9] communication architecture and Seebyte’s SeeTrack application to display the information. The system follows a user-centred design rather than a technology-centred design. The system is designed around the capabilities and needs of the operators rather than displaying information that is centred around the sensors and technologies. It does not flood the user with the information coming from all the data produced. This design improves productivity and user acceptance and satisfaction. The Analysis section uses the same tools described for Control but for the post-processing and analysis of the data collected from the inspection mission. It also keeps the user-centre design that allows the operator a fast understanding of the data processed.

**TRIALS**

During the month of November 2005 trials were performed in Scapa Flow, Orkney, UK. The aim of these trials was to demonstrate the capability of AUTOTRACKER to track the full in-shore section of the Talisman Piper/Claymore Pipeline, 12km length, which crosses the main entry channel of Scapa Flow from the Isle of Burray to the Isle of Flotta.

![Figure 2: Scapa Flow chart, Orkney Islands](image)

**Objectives**

Trials were conducted to test and tune performance of the tracking modules over real pipeline. Full system trials were aimed to help establish operational parameters, include stability and fail-safe mechanisms. They were conducted as an AUTOTRACKER enhanced, actively tracked pipeline inspection over an extended section of pipeline.
Platform

Vehicle

The vehicle used during those trials was Subsea7 GEOSUB AUV. This vehicle provides long autonomy and high endurance combined with survey-quality sensor technologies. The characteristics of GEOSUB are described in Figure 3.

<table>
<thead>
<tr>
<th>Range</th>
<th>60hrs @ 4 Kn (2m/s), Li-Ion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sonar</td>
<td>Dual-Freq EdgeTech, plus Sub-Bottom</td>
</tr>
<tr>
<td>MBE</td>
<td>EM2000, 200KHz</td>
</tr>
<tr>
<td>INS</td>
<td>Phins, DVL, DGPS, Bathymetric Suite</td>
</tr>
<tr>
<td>OAS</td>
<td>Fwd-Look Multi-Beam</td>
</tr>
<tr>
<td>Digital Video</td>
<td>(via AUTOTRACKER Payload)</td>
</tr>
</tbody>
</table>

Figure 3: GEOSUB vehicle properties

Payload

Physically, the AUTOTRACKER payload is designed to be a high-performance distributed computing platform that supports the execution of an extensive set of embedded software modules which collaborate together and with the GEOSUB AUV to perform the autonomous inspection. Its principal characteristics are shown in the Figure 4.

<table>
<thead>
<tr>
<th>Processor</th>
<th>PC-104 2xPentium 4-M 1000Mhz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PC-104 1xPentium 4-M 1400Mhz</td>
</tr>
<tr>
<td>Storage</td>
<td>3xSolid-state flash disks (512MB)</td>
</tr>
<tr>
<td></td>
<td>80GB HD logger</td>
</tr>
<tr>
<td>Communication</td>
<td>100Mbit/s Ethernet bus</td>
</tr>
<tr>
<td></td>
<td>RS232 ports for OAS Sonars</td>
</tr>
<tr>
<td>Video</td>
<td>MPEG 1 &amp; 2 Digital video card</td>
</tr>
<tr>
<td>Power</td>
<td>~100W (inc OAS sonars)</td>
</tr>
</tbody>
</table>

Figure 4: AUTOTRACKER payload properties
Pre-trials

Before going to Orkney, two weeks of workshop-based integration and tests were conducted at Subsea 7’s Aberdeen base to fit and test AUTOTRACKER II payload to the GEOSUB vehicle. New drivers for real-time sidescan data acquisition were developed for the new onboard sidescan tracker.

Before these two weeks, hundreds of simulated missions were run in the OSL Synthetic Environment (SE). The OSL SE contains simulation for vehicle dynamics, sensor processing and module communications and a 3D graphic display. Testing of “as in-water” system before deployment was essential to identify algorithmic and comms problems, systematic “exercising” of all module interactions, complete “shakedown” cruises within simulation and should lead to mission planning / evaluation tools. During these two weeks, a progressive integration with the real sensors and the real vehicle was performed. This step-by-step hardware-in-the-loop process started with the integration of the data coming from the real sensors and successfully finished with the run of a complete hardware-in-the-loop simulated mission.

Trial missions

Dive plan during trials was designed to progressively increase the overall level of autonomy of the system. Thanks to the existence of high-bandwidth wireless communication between payload and control cabin it was possible to interact with the different modules while the vehicle was on surface. Therefore, for testing, tuning and analysing each of the modules independently, a set of surface missions in shallow water were performed during the first days. This allowed developers to be fully aware of what the system was doing and in consequence it helped with the fast improvement of performance and integration.

Both trackers were tested independently. Approximately every 14 seconds, sidescan tracker data collected and stacked sets of 100 beams in a high resolution image. These composed images were Time Variable Gain (TVG) corrected in real time before being sent to the tracker algorithm. The tracker algorithm was capable of discarding false detection alarms and providing the relative position and direction of the pipe, with an associated probability. The overall flow process can be seen in Figure 5.

![Figure 5](image1.png)

Figure 5: (a) Original image, (b) onboard time variable gain correction (c) and tracker output from a real-time sidescan.

In the same way but at higher frequency (approximately twice a second), the multi-beam sensor was tuned during different missions and was able to provide its own estimation of the position of the pipeline. Details of the original multi-beam profile and the pipe estimation are shown in Figure 6.

![Figure 6](image2.png)

Figure 6: Original multi-beam profile and tracker best estimation of the position of the pipeline

Information coming from both trackers combined with the existing legacy (e.g. “as laid”) information of the pipeline was fused in the Sensor Fusion module to provide the best estimation of the position of the pipeline and the tracking status.
The Decision making system was already in a mature status coming from the trials performed in Peterhead harbour and Orkney Islands in 2004. However, different modifications were developed to be able to cope with the new specifications mainly coming from the integration of the sidescan tracker and fusion. Figure 7 shows an example of a mission where both trackers were working together. It can be seen how different sections of the search pattern are optimised for the characteristics of detection of the different sensors.

Despite the never generous weather conditions, various full missions were successfully performed on surface and dived at different altitudes above the pipeline – down to 5 to 6 metres. They allowed collecting data from the different sections of the pipeline with different offsets and to improve the robustness of the overall system. An example of mission is shown in Figure 8.
RESULTS

Sidescan and multi-beam trackers have been shown to be very robust. They are capable of discarding seabed false alarms and provide an estimation of the location of the pipeline that fully corresponds with the raw data. This is important and a successful achievement. Intelligent systems require a good interpretation of the incoming data to be able to provide behaviours coherent with the environment. Trackers are capable of providing this accurate interpretation of the environment, and all sub-systems operate stably.

The trials demonstrated that advanced pipeline inspection using a fully autonomous AUV is technical feasible and has many advantages. The AUTOTRACKER core has ably demonstrated that it can cope with the data uncertainty and unexpected situations that can be found in a real environment. It has also demonstrated how it is possible to improve currently available techniques and collect better data at higher speed. An example of the video data collected from the trials is shown in the next Figure 9.
CONCLUSIONS AND THE FUTURE

We believe the AUTOTRACKER autonomous pipeline inspection technology is ready for commercial exploitation. The trials clearly demonstrated the stability and performance of the system.

The trackers for sidescan and multi-beam sensors have been shown to be very robust. The sidescan tracker localises the pipe at long distances (up to 100m) and assists in the vehicle’s approach. The task planning module then re-positions the vehicle in the optimum relative position for the desired inspection. The multi-beam tracker can then help to keep the pipeline under the vehicle for video data collection (and perhaps in future, other measurements such as CP).

The embedded decision making processes for mission re-planning based on real-time sensor data processing provides a very high-level of autonomy to the vehicle, and allows it to cope with unexpected situations and uncertainty of the environment, like buried sections or obstacles without operator intervention.

Although the trials demonstrated the robustness of the existing sidescan and multi-beam trackers, it would be possible to add more sensors (for example, sub-bottom or magnetic tracking) to the tracking that would potentially provide more information and certainty about the status and position of the pipeline – particularly when buried.

There is still development work to be done related to the tracking of multiple pipelines. This could provide added value to the system in case that working in a more complicated area of inspection will be required.

Synthetic Environments have provided a suitable and realistic platform, previous to trials, to test the different modules of the system. They allow the identification of algorithmic and communication problems and assist in the evaluation of module interactions. By simulating the vehicle dynamics, sensors and communications, a systematic “exercising” of the system and a complete “shakedown” is possible. An easier to use interface to this test environment might provide a very useful pre-mission checking tool.

Human-Computer Interaction (HCI) of the system is still developer oriented. To provide access to the system of a non-expert technical user it will be necessary to design a more user friendly interface for commercialisation. It is also recommended to provide communication with the payload while submerged. Acoustic sonar communication for monitoring is under investigation. This would be integrated inside the SeeTrack application umbrella.

With these trials, the AUTOTRACKER system working together within the S7 GEOSUB AUV has clearly demonstrated its commercial capability, and we believe is mature enough to progress to the next stage and perform a commercial inspection task over at least 50km of underwater pipeline.

ACKNOWLEDGEMENTS

The development of AUTOTRACKER Autonomous Inspection Payload has taken many years, and has involved a large group of people and professionals. Special thanks go to all the members of Seebyte Ltd and Subsea 7 for their constant motivation during the hard and stressful times. Useful collaboration has been provided from the previous EU project partners at the University of Balearic Islands and the National Technical University of Athens. The authors would like to also thank the BP for funding this work, and especially Lee Billingham for his continuing support.
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