Field Resident AUV Systems – Chevron's Long-term goal for AUV Development

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***Abstract*— The Chevron AUV development program has been running since 2007 with considerable success with a long term goal of deploying Field Resident AUV's in our subsea operating assets.**

The paper will describe some of the successes of the program and the approach Chevron is taking to meet its end goal. The main focus will be to elaborate on technology gaps that have been identified and still require closure.

Keywords—AUV; resident; inspection; intervention

I. Introduction

Chevron's Energy Technology Company works with our operational units to deliver high quality, cost effective technology solutions and services to Chevron's operations worldwide. Chevron's long running Autonomous Underwater Vehicle (AUV) Strategic Research and Technology Development Program operates within the Deepwater Focus Area, which is committed to developing strategic research and technologies for subsea deployment. Through programs such as this, we seek to continually improve our performance and differentiate ourselves from our competitors.

AUVs have successfully been integrated into Oil and Gas operations for Geophysical and Environmental surveys, replacing vessel based and towed systems, particularly in deepwater. AUV development continues to advance rapidly beyond these "standard" services, mostly as an offshoot of the defense industry, and Chevron is working to understand, influence and adopt these advances in technology. Chevron is achieving these goals by engaging with the AUV industry and supporting research and development programs that broaden the capability of AUV technology. The AUV Program focuses on both shorter term offshore trial activities and longer term research for technology gap closure. Short term initiatives include performing technology demonstrations for our business units by utilizing new technologies in commercial operations, and longer term gaps may be accelerated through direct development of hardware or software.

Our current focus is on the inspection side of the business with recent efforts on pipeline and facility inspection techniques. Included in this year's program is a detailed evaluation of several business cases for the use of AUVs in our inspection operations. We believe that increased use of AUVs in the oilfield for different types of tasks will lead to a familiarization that will increase operator confidence and reduce psychological resistance to performing more challenging tasks. For inspection activities, development AUVs are currently able to hover, harvest data from sensors, and even touch equipment, all of which has required manufacturers to overcome positioning challenges important to future intervention activities.

Chevron believes that the deployment of Resident Intervention Systems in the form of tethered/integrated robots or more maneuverable AUVs is necessary for efficient development of deepwater fields, especially where there are long subsea tie-backs with no surface facilities. This becomes more critical where we may have under ice activities with limited vertical access. Additionally, AUVs will bring better and more frequent inspections, earlier monitoring, and reduced field maintenance and development costs. To achieve these goals, further gaps need to be closed in dynamic positioning capability, obstacle avoidance, homing, real time 3D mapping and feature recognition, through-water communications, docking, recharging, low power tooling, component reliability, and autonomy. AUVs will need to make confident, reliable decisions based on analysis of information from multiple sensors; autonomous vehicles should not rely on human interaction. This will require a significant amount of simulation in 3D subsea models and extensive field testing to achieve the software robustness necessary for success.

The Chevron AUV development program has been active since 2007 with considerable success and this paper will elaborate on some of the achievements to date. However, the main focus will be to elaborate on which technology gaps we have identified that still need to filled to enable our long term goal of field resident vehicles.

II. Chevron's Long-term AUV Vision

In the long-term, autonomous underwater vehicles will be an important, and in some cases enabling, part of the offshore oil and gas industry. Within this industry, we believe that AUV systems are developing toward three main categories: geophysical/environmental survey, installation support, and integrated field support.

Figure 1 shows different applications for AUV technology and where we believe we are in the development cycle for each application with respect to adoption into the industry.

For performing routine inspection, repair, and maintenance work, our vision is to have an autonomous underwater vehicle that is integrated with the field infrastructure. The AUV will "live" in a subsea docking station that provides, through the field subsea umbilical, power and communications for charging and data transfer. The AUV will live and work within a field for 6 months to 1 year before being recovered to the surface for maintenance and upgrade. Alternatively, the AUV could be stored on a platform or FPSO and lowered into the water as needed.

	Overall Program Lifecycle TDS Level								
Technology	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Geophysical Survey	9	9	9	9	9	9	9	9	9
Environmental Survey	9	9	9	9	9	9	9	9	9
Pipeline Inspection AUV (sonar)	6	7	8	8	9	9	9	9	9
Structural facility survey GVI	5	6	7	8	8	8	9	9	9
Pipeline Inspection (full)	3	3	4	5	6	7	8	9	9
Advanced Facility inspection	2	3	3	4	5	6	7	8	9
Field resident inspection	2	3	3	3	4	5	6	7	8
Light intervention	2	2	3	3	4	4	5	6	7
Field resident light intervention	2	2	2	3	3	3	4	5	6
Under ice resident	1	2	2	2	3	3	4	5	6

Figure 1: AUV Program Lifecycle TDS development. (Note: scale 1 - 9).

A. Geophysical/Environmental Survey

AUVs have already become an integral part of the geophysical survey community, and will likely see increased use as operator comfort increases and unit costs fall. These vehicles collect excellent data, and the increasing independence of AUVs from large, or in fact any, surface vessels will increase the feasibility of operating several vehicles simultaneously. As AUV use increases for traditional geophysical tasks such as sidescan and multibeam sonar data collection, options for more advanced sensors will emerge. Examples include sensors for detecting hydrocarbons within the water column and magnetic anomalies on or below the seafloor.

B. Installation Support

The increasing complexity of subsea installations is driving a need for better subsea monitoring of these installation tasks. AUV technology is well-suited for the monitoring of continuous activities, such as pipe lay. Additionally, an AUV could be commanded to follow an ROV while maintaining a certain separation distance and attitude, essentially acting as a cameraman to give the ROV operator another viewpoint of his work.

C. Integrated Field Support

Many oil and gas developments are increasingly remote, whether due to deep water, arctic under-ice conditions, or distance from population centers. In such locations, the ability to perform routine inspections and even light intervention tasks using an autonomous underwater vehicle has attractive benefits.

Starting in the docking station, the AUV will work through a queue of routine inspection and maintenance work, autonomously prioritizing activities based on task importance and battery life. Upon returning to the dock after completing a full duty cycle, that AUV will upload all of the inspection data (photographs, 3D models, CP readings, etc.) to the operations center where they can be automatically distributed to the most relevant recipients. If an operator wishes to perform an unscheduled task, that task can easily be inserted into the work queue to happen immediately or at any specified time. Depending on the particular project, the AUV could be optimized for long-distance pipeline inspection, riser inspection, torque tool operation, etc.

For more complex work that is beyond the autonomous capability of the vehicle, high-rate communication equipment could be installed within the field to allow a remote operator to wirelessly provide real-time command and control to the vehicle, essentially flying it like a traditional tethered ROV. With this capability, a hybrid AUV/ROV system would be able to perform most light in-field tasks.

III. History of Chevron's AUV Program

Chevron's AUV program began in 2007 to take advantage of developments in autonomous technologies and drive them toward a future of field-integrated operations. By steering the industry, understanding the technology gaps, and strategically working to close said gaps, the AUV Program seeks to accelerate the rate of development and adoption of these promising technologies into the oil and gas industry. The following is a brief summary of the major projects that have been completed over the last 5-6 years.

A. 2007-2009

From 2007 to 2009, Chevron was involved in a JIP with BP to develop a hovering AUV that could navigate in three dimensions and provide full-coverage video inspection of equipment and risers. This AUV was called the Prototype Autonomous Inspection Vehicle (PAIV), and the goal of the project was to prove the feasibility of safe and reliable autonomous operations in a complex environment. The project culminated in a tank test of the untethered, free-swimming vehicle demonstrating the following tasks: precise navigation within a cluttered environment, hull inspection, prolonged observation of a single area, riser inspection, and structure inspection.

The PAIV project successfully proved the feasibility of using autonomous underwater vehicles in and around complex subsea infrastructure. Based on the lessons learned from the PAIV collaboration, a commercially available vehicle has been developed from the ground up to specifically satisfy GVI requirements for subsea infrastructure.

Also during this period, Chevron's AUV program was involved in a technology trial of advanced software for ROV dynamic positioning and control. The ROV DP software had many similarities with the hovering AUV control software, and enabled station keeping and precise heading, speed, and displacement control functions on the ROV. During a Chevron sponsored offshore trial, the software was proven to provide far better station keeping stability than a human pilot.

B. 2010

In 2010, the Chevron AUV Program organized an offshore trial of an AUV with commercial pipe-following software. The software package, which can be interfaced with many different types of vehicle, allowed the AUV to automatically detect and track an exposed pipeline using onboard sonar. These trials successfully de-risked AUV technology for sidescan sonar pipeline inspection in the Gulf of Mexico, and the Chevron AUV program continues to actively seek opportunities to utilize autonomous vehicles in this capacity.

C. 2011

The 2011 AUV Program focused predominately on 3D sonar modeling of standing and toppled structures using ROV and AUV. For this task, an AUV equipped with a high quality 3D sonar array was chosen. Two different sonar systems: a mechanical scanning sonar and a multibeam echosounder, were also tested on board an ROV equipped with a survey-quality navigation package.

In addition to 3D modeling of several standing and toppled structures, the trial also proved the ability of the AUV to identify changes against a priori data in real time. In shallow water, low visibility conditions, the two ROV mounted systems produced 3D point clouds showing the structures. All of this data could be viewed, rotated, and measured in various software packages to learn more about the structures.

D. 2012

In 2012, Chevron is continuing to push the capabilities of AUVs within the oil and gas industry. Before the end of the year, we will prove the concept of wirelessly harvesting data from, and recharging the batteries of, a subsea sensor using an AUV. In addition to this test, the program will continue to support research into high-rate wireless underwater communication technologies, with the goal of enabling real-time streaming of video through water. 2012 has also seen research into subsea hydrocarbon detection using AUVs. All of these efforts seek to close gaps between current AUV capability and our long-term vision of AUV application in the oil and gas industry.

IV. From Trials to Reality – A Fundamental Aim of the Program

In addition to involvement in industry steering and research efforts, the Chevron AUV program also conducts open water trials of various technologies, generally spending 1-3 weeks offshore every year. Our offshore efforts can be categorized as either technology trials or de-risking demonstrations. Technology trials focus on testing and identifying improvements for prototype-level systems with the strategic goal of closing technology gaps that are preventing AUVs from achieving the vision described above. On the other hand, de-risking demonstrations are focused on proving that a particular AUV capability is sufficiently developed for commercial work.

We believe that the proving of commercial-ready AUV technology is vital to the long-term success of AUVs because commercial use of these vehicles allows operators to build an operational history and to become more comfortable with the idea of autonomous operations, especially around expensive oil and gas production infrastructure. Additionally, the commercial success of early AUVs will help support the market as the next generation of vehicles is built.

In an effort to provide AUV manufacturers with more concrete guidelines, we are currently working collaboratively with TOTAL on a new approach to AUV pipeline inspection, which will lead to new specifications being issued in the future. The specifications will provide clarity to the AUV suppliers as to our precise requirements for their vehicles and sensor packages and we hope that the new specifications will be beneficial to them in the development of vehicles capable of pipeline inspection.

V. Technology Gaps

One of the key aims of the program is to provide assistance in closing technology gaps. There are a number of challenges to be addressed to enable field resident AUV systems, some of which are explored as follows:

A. Subsea positioning, homing, and dynamic positioning

Many advances have taken place in this area for general subsea survey and positioning requirements, in particular to achieve accurate measurement for metrology etc. Integration of acoustic positioning systems (USBL and LBL) with doppler velocity logs and inertial navigation systems is commonplace, with positional errors reduced to below the decimeter level. Operation in DP mode has been demonstrated at this level of positional accuracy. Fiducial targets or sonar buoys have also been effective in some subsea positioning applications.

However Chevron believes that field resident AUV systems, operating many different types of missions, will require some feature based navigation capability as well. Here the vehicle will have to navigate relative to the subsea infrastructure, such as a pipeline or a control panel, to enable a successful mission.

B. Real time 3D mapping, feature recognition and obstacle avoidance

Obstacle avoidance systems are improving in 2D and 3D modes based on multibeam sonar. These obstacle avoidance sonars have achieved improved resolution and viewing envelope along with reduced size and power consumption. In addition to sonar, visual imagery with stereo or 3D viewing is also being adapted for obstacle recognition and avoidance.

Furthermore, the oil and gas AUV industry is starting to adopt some 3D mapping and modeling techniques from other industries. Chevron recently supported a RPSEA program developing an underwater 3D laser scanning tool to create 3D models of subsea objects in minutes with millimeter-level local accuracy. These types of sensors are the building blocks for subsea field navigation, inspection and intervention.

C. Through-water communications

Improvements in underwater data communications are enabling longer range and greater bandwidth. There have been some significant developments in acoustic, radio and optical sensors, all of which are useful in certain applications and environments. Chevron has supported several DeepStar initiatives, particularly focusing on video transmission through water. Underwater docking of AUVs is one area where advances in underwater data transmission are vital. Field resident systems will collect large volumes of data for transmission to the surface, and a high speed wireless link would be an elegant solution.

D. Power management, recharging, low power tooling,

The electric vehicle industry is making considerable improvement in battery technology, which will permeate into AUV power systems. Lithium ion batteries are already improving energy budgets and fuel cell technologies have enabled AUVs to run missions of over 48 hours. In addition to the challenge of carrying sufficient battery capacity, docking and recharging will be a major challenge for resident vehicles. We believe that induction charging techniques will be more robust for long-term use than a cabled connection due to the potential for degradation and failure of underwater connectors after many cycles. Tooling will need to be all electric rather than hydraulic, and tool changes need to be robust and reliable, as any dropped equipment could lead to a critical situation.

E. Reliability and maintenance

Component reliability will be a central concern in the development of resident AUV systems. This relates not only to the vehicle itself, which may be recovered at regular intervals for maintenance, upgrade, or repair, but also to all permanently deployed hardware including docking stations, AUV-friendly intervention panels, subsea sensors, and communication devices. Cleaning of these components will likely be necessary, and individual component reliability is a critical issue for any 'Life of Field' operations, so rigorous testing remains to be completed before any long-term deployment. To date, there has been little effort to prove the ability of AUVs to survive underwater for long periods of time. Furthermore, standard interfaces and protocols need to be agreed upon to enable upgrade paths for future improvements in capability. A new DeepStar Project is working to address some of these interface issues.

F. Autonomy

Chevron believes that improvements in robotics and remote sensing in other industries are moving rapidly and will eventually be applied to the AUV industry. For example, the defense industry has made much progress in multiple AUV operations, with many of the lessons transferrable to the oil and gas subsea environment. We believe that the decision logic for fully autonomous operation is achievable and that it can be robustly implemented allowing fully autonomous capability.

G. Simulation

Simulation will play a part in several areas for long term field resident systems. Initially, 3D subsea models will provide accurate environments for reviewing vehicle access and designing AUV-friendly infrastructure. Most simulations include physics-based modeling for stress calculations and other design verifications. Simulated Systems Integrated Testing (SIT) and repeated simulations will also provide engineering information on the limitations and the durability of vehicles and components, resulting in improved design cycles and better first generation reliability. In addition, the 4D simulation environment will allow planning and examination of many different types of missions, resulting in improved operational procedures and feed back to hardware and software design improvements.

VI. SUMMARY

We believe that the Oil and Gas Industry is making strides toward the adoption of AUVs for several applications. However, AUV suppliers cannot develop this technology without an understanding of operator needs. This is particularly the case for the challenge of Field Resident Systems capable of a variety of inspection and intervention tasks.

By continued support of our AUV Program to allow testing and trialing of new equipment, either directly or via other initiatives (RPSEA, Deepstar, JV's), we believe that we are moving toward our final goal of field resident autonomous systems.

It is collectively, through discussion of the technical capabilities and limitations of robotic vehicles, that the oil and gas industry will recognize how to adapt our current approach to subsea inspection and intervention, and modify the design of our subsea infrastructure for a future enabled by AUVs. Much has still to be learned and defined, but we believe that these changes will provide increased inspection frequency, faster response to changing environmental conditions, reduction in operator errors, and efficiencies in intervention tasks, resulting in an improvement in the safety and the efficiency of operations in deepwater subsea fields.