The Autonomous Underwater Vehicle (AUV): A Cost-Effective Alternative to Deep-Towed Technology

THOMAS S. CHANCE, ART A. KLEINER & JAY G. NORTHCUTT, *C&C Technologies Inc., Lafayette, Louisiana, USA*

ABSTRACT

Detailed surveys are required in deep water to avoid potential hazards and to provide for the construction and development of offshore oil leases. Unfortunately, data acquired with existing technology are expensive and often questionable in accuracy. To address this problem, C & C Technologies Inc. (C&C) of Lafayette, Louisiana, USA has contracted with Kongsberg Simrad for the construction of a HUGIN 3000 deepwater Autonomous Underwater Vehicle (AUV). The HUGIN 3000's survey sensors will include multibeam bathymetry, side scan sonar and sub-bottom profiler. C & C, an international hydrographic surveying company, has been developing AUV technology for the U.S. Navy for the past five years. Manufacturing is currently underway and sea-trials begin in May of 2000. One major oil and gas company has committed for HUGIN survey work and C&C is offering discounts for other early commitments.

INTRODUCTION

As the technology applied to energy exploration and production advances to meet the deepwater challenges beyond the continental shelf, Autonomous Underwater Vehicles (AUVs) will be increasingly employed. AUV technology has just reached a milestone as the result of the first commercial purchase of an AUV by C&C Technologies, Inc. of Lafayette, Louisiana.

The deep-towed system, the conventional deepwater mapping tool, suffers from chronic waste and inefficiency. To rectify this problem, Kongsberg Simrad, in conjunction with C&C Technologies, is developing the HUGIN 3000. The HUGIN has evolved from an AUV programme amassing more than one hundred missions since 1995. The HUGIN will be integrated with an acoustic tether to monitor data acquisition and optimise system performance.

DEEP-TOWED SYSTEMS

The deep-towed system originated as a mapping tool to accommodate large-scale academic surveying projects comprising multiple traverses of lengthy, straight lines. It was later adapted to similar applications, such as pipeline routes, fibre-optic cable routes, and block hazard surveys. Provided by manufacturers such as EDO Corporation, Kongsberg Simrad, and Datasonics, Inc., the deep-towed system is the true precursor to the survey AUV and remains the standard deepwater survey tool of today. Typical deep-tow instrumentation packages include the side scan sonar and sub-bottom profiler.

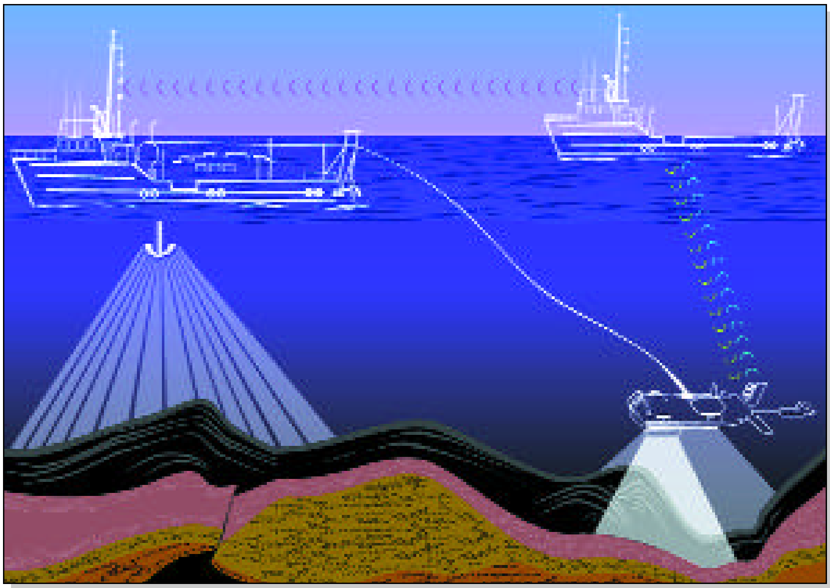
Unfortunately, due to the massive amounts of tow cable required (10,000 metres is not uncommon), deep-towed costs are extremely high. Such cable lengths demand huge handling systems and constitute a substantial surface area when towed. Survey speeds are therefore limited to 2.0 to 2.5 knots and vessel turns often require 4 to 6 hours to accomplish, which devour a painful portion of a survey budget.

Positioning of deep-towed systems embodies the age-old axiom: accuracy *versus* cost. Ranked according to cost (highest first), the three primary underwater acoustic positioning alternatives are:

- Long Base Line (LBL).
- Two-Vessel Ultra Short Base Line (USBL).
- Single-Vessel USBL (for less than 1,000 metres of water depth).

LBL, the most accurate, is also the most costly, time-consuming, and dangerous. It involves the placement of an encompassing grid of acoustic-positioning

Figure 1
A Two-Vessel USBL deep-towed positioning scenario with chase-boat transmitting towfish positions to the tow-vessel



transponder beacons, upon the seafloor. An initial, often tedious, calibration procedure is required and each LBL operation concludes with a transponder retrieval procedure, guaranteed to make any Health, Safety and Environmental (HSE) auditor shudder.

Two-Vessel Ultra Short Base Line (USBL) positioning requires the addition of a second survey vessel, or chase-boat (Figure 1). The duty of a chase-boat is to follow above the towfish, within the acoustic ranging capability of the USBL, and track the towfish position. Acoustically derived towfish positions are simultaneously transmitted via radio to the tow-vessel's navigation computer.

Single-Vessel USBL is, in effect, when the tow vessel also provides positioning for the deep-towed fish. Deep-towed systems require cable lengths of at least 2.5 times the water depth during survey operations and the acoustic ranging capability of the USBL system is generally less than 2,500 metres. Consequently, this limits the utility of Single-Vessel USBL positioning to about 1,000 metres of water for deep-towed operations.

HUGIN 3000 AUV

Recognising the need for a more efficient approach to deepwater surveying, C&C invested one year evaluating the available vendors of AUV technology. Research included meeting with designers and manufacturers and witnessing AUV demonstrations in the US, Canada and Norway.

The majority of the alternatives were academic in nature, providing limited depth capabilities and electrical power sources inadequate for the requisite survey sensors. Kongsberg Simrad's HUGIN was the only AUV that had functioned at appreciable depths, performing numerous commercial surveys in hundreds of metres of water.

The HUGIN was the only AUV integrated with a Launch-and-Recovery system. Housed (along with the AUV vehicle) in an air-transportable cargo container, the HUGIN's Launch and Recovery system has proven safe and effective in weather conditions up to sea state 5.

The HUGIN's survey instrumentation is powered by a unique aluminium oxygen fuel cell developed in conjunction with the Norwegian Defence Establishment (FFI). The HUGIN vehicle is currently in routine use by the Norwegian Underwater Intervention (NUI) providing high-precision mapping to water depths of 600 metres.[1]

HUGIN 3000 SPECIFICATIONS

Depth Rating	**= 3,000 metres**
Survey Speed	**= 4 knots**
Line Turn Duration	**= ~5 minutes**
Mission Endurance	**= >40 hours depending upon payload power load and vehicle speed**
Length	**= 5.3 metres**
Diameter	**= 1.0 metres**

Figure 2 (top)
A HUGIN vehicle begins a routine dive for the Norwegian Underwater Intervention (NUI)

Figure 3 (left)
The HUGIN launch and retrieval system, which is housed in a 20 foot cargo container and can be air freighted throughout the world

HUGIN 3000 INTEGRATED SURVEY SENSORS

Simrad EM2000 Multibeam Bathymetry and Imagery System

Edgetech Chirp Side Scan Sonar

Edgetech Chirp Sub-bottom Profiler

Seabird CTD

Magnetometer (optional)

Underwater positioning and vehicle attitude are being provided by a Kalman filter Aided Inertial Navigation System (INS) integrating data from Inertial Measurement Unit (IMU), doppler speed log, fibre optic gyro, depth sensor, altitude/forward looking sensor, USBL (or optional LBL) and DGPS. Telemetry for vehicle command and control and for the reading of sensor data is being provided by two underwater acoustic telemetry systems. Surface operations employ UHF radio communications.

COST SAVINGS

Efforts to curb deepwater survey costs have spawned the recent interest in AUV technology. Cost savings result from the following:

- Survey Speed – AUVs operate at 3.5 to 4.0 knots, as compared to a deep-towed system's 2.0 to 2.5 knots, an improvement of 60% to 75%.
- Line Turn Capability – AUVs turn from one survey line and onto the next within a few minutes, as opposed to the 4 to 6 hours required by deep-towed systems, an improvement of >90%.
- Positioning Efficiency – The deep-towed tow fish is regularly towed many kilometres behind the vessel. This results in data being collected hundreds-of-metres offline, requiring additional unnecessary survey lines (along with corresponding 4 to 6-hour line turns) to rectify. In contrast, AUVs navigate along a pre-defined survey route.
- Procedural Efficiency – Points of Curvature (PCs) along a survey corridor place staggering restrictions upon deep-towed systems. Each PC must be treated as an end-of-line, precipitating a 4 to 6-hour line turn. AUVs do not have this restriction. Heading changes along a survey line become simple mid-course corrections, easily accomplished.
- Effective Aspect Ratio – Maintaining the correct height above the seafloor is crucial to obtaining quality survey data. Surveying an area of varied depth with a deep-towed system requires a delicate balance between vessel speed and cable-out to meet survey standards. To compensate for this deficiency, some deep-towed operations employ a chain-drag system. In this scenario, a heavy chain is dragged along the bottom and a positively buoyant deep-towed fish is tethered above it. Although this approach performs surprisingly well, the environmental risks are obvious.

  AUVs employ sophisticated echosounders and can be programmed to follow existing bottom terrain. Integrated with obstacle-avoidance sonar and precise digiquartz depth sensors, an AUV can be instructed to maintain a certain distance above the ocean bottom or below the sea surface.
- Acoustic Communication – In the strictest sense, an AUV with an acoustic link to the surface is classified as an Unmanned (or Untethered) Underwater Vehicle (UUV) and not an AUV, which is fully autonomous. Although the HUGIN is capable of operating fully autonomously, it would be foolish to do so except under extreme or unusual circumstances. Most of us have lost computer files due to equipment or software malfunction. Losing days of deepwater survey data for the sake of fully autonomous operation is a risk we are not willing to take.

  For this reason, the HUGIN was engineered with an acoustic tether, which provides the field engineers not only with control of data quality, but also control of the survey and ultimately its budget. Sub-sampled data are transmitted to the surface, providing supervised autonomy during each AUV mission. For example, should hazards be located during a pipeline route survey, the mission can immediately be altered to interject developmental survey lines. There is no need to expend days of surveying to later determine the data were collected in an inappropriate area.

  As a two-way data link, the acoustic tether provides active mission control to the AUV engineers. Changes can be effected in the volumetric weighting of the sensor data being transmitted and adjustments can interactively be made to command-and-control functions to maximise system performance. Full-density survey data are downloaded by fibre-optic cable at the end of each mission.
- Acoustic Incidence-angles – Reliable deep-towed USBL positioning in depths of greater than a few hundred metres is often the exception, rather than the rule. Complex water sound velocities, coupled with poor incidence-angles, create ray-bending, a major impediment to marine acoustic positioning. Deep-towed fish, typically towed at an angle of about 30 degrees down from the tow-vessel's positioning transceiver, are extremely susceptible to the effects of ray-bending.

  The adverse effects of complex water sound velocities are diminished during AUV operations because the acoustic incidence-angle, at approximately 90 degrees, is ideal. This is a consequence of the support vessel following directly above the AUV during survey operations. Poor acoustic interfaces are met head on, minimising the effects of ray-bending errors. Additionally, the AUV relies upon inertial navigation as its primary positioning source, so occasional USBL updates are adequate to provide accurate vehicle positioning.
- Support Vessels – AUV operations require only one vessel to support all processes including vehicle launch-and-retrieval, navigation and positioning, data collection and processing, and system maintenance.

  Deep-towed systems may also employ a single vessel, but only for depths of less than approximately 1,000 metres. For greater depths two positioning choices exist:
- Long Base Line (LBL).
- Two-Vessel Ultra Short Base Line (USBL).

  LBL positioning, as described earlier, is burdened with extreme costs and dangerous logistics. USBL positioning requires an additional survey vessel,

or chase-boat, for deepwater operations, which must be large enough to keep pace with the tow vessel. A chase-boat smaller than the tow-vessel may impede deep-towed survey, further exacerbating the cost of deep-towed survey operations.

- Portability – The HUGIN 3000 can be maintained in three 20-foot cargo containers, which may be airfreighted throughout the world. One container holds the AUV vehicle and the launch-and-retrieval system. In this container, the AUV's survey data are downloaded by fibre-optic cable and the vehicle is serviced at the end of each mission. A second container acts as a maintenance shop and is utilised for the storage and transfer of battery fluids and aluminium rods needed to replenish the AUV's fuel cells. A third container utilised for mission control, data processing, and reporting, can be omitted if a vessel-of-opportunity provides an adequate alternative.

  Very little of a deep-towed system can be economically airfreighted; the towfish and spare parts, perhaps.

EXAMPLE SURVEY COST COMPARISONS

AUV *versus* deep-tow cost comparisons were performed on the following two proposed surveys. Costs for mobilisation, demobilisation, bottom sampling, weather downtime, and office processing are not included (see Table 1).

Table 1.

1. 45-MILE GULF OF MEXICO PIPELINE HAZARD SURVEY

This pipeline route includes 15 PCs, each precipitating a 4 to 6 hour line-turn for a deep-towed system.

Specifications of this proposed pipeline route survey include:

Depths	= 400 to 2,200 metres
Total line-distance	= 600 kilometres
Line spacing	= 300 metres

	DEEP-TOWED SYSTEM WITH TWO-VESSEL USBL	AUV WITH SINGLE-VESSEL USBL
DAY RATE COST	$26,000	$55,000
SURVEY ECONOMY	27.2 days @ 2.5 knots	5.3 days @ 3.5 knots
TOTAL SURVEY COST	$707,200	$291,325
AUV COST SAVINGS	$425,875 or 59%	

2. 26-KILOMETRE X 17-KILOMETRE WEST AFRICA SURVEY

This proposal was submitted as a regional, high-resolution mapping project.

Specifications of this proposed regional survey include:

Depth	= 1,500 metres
Total line-distance	= 6,274 kilometres
Line spacing	= 100 metres x 250 metres

	DEEP-TOWED SYSTEM WITH TWO-VESSEL USBL	AUV WITH SINGLE-VESSEL USBL
DAY RATE COST	$54,000	$55,000
SURVEY ECONOMY	96 days @ 2.5 knots	58 days @ 3.5 knots
TOTAL SURVEY COST	$5,184,000	$3,190,000
AUV COST SAVINGS	$1,994,000 or 39%	

CONCLUSION

C&C recognises the need for a more efficient and cost-effective approach to high-resolution deepwater surveying. Kongsberg Simrad, in conjunction with C&C, is developing the HUGIN 3000 AUV to provide industry with an alternative to the standard of costly and inefficient deep-towed systems. Kongsberg Simrad is developing the vehicle and vehicle control system. C&C is developing the payload system.

The HUGIN 3000 will provide engineering quality data to aid in the development of deepwater oil leases and be employed for MMS Block Surveys and Pipeline Hazard Surveys. It will be integrated with an acoustic tether to monitor data acquisition and optimise system performance. Manufacturing of the new HUGIN 3000 is currently underway and sea trials begin in May of 2000. One major oil and gas company has already committed to HUGIN 3000 survey work and C&C is offering discounts for other early commitments.

REFERENCE

1. Øistein Hasvold, Kjell Hårvard Johansen, Ole Mollestad, Sissel Forseth and Nils Størkersen; *Journal of Power Sources*, Vol. 3299, November 1998; Norwegian Defence Research Establishment (FFI).

ABOUT THE AUTHORS

Thomas S. Chance, President, C&C Technologies Inc., holds a BSc. in Electrical Engineering from Louisiana State University and two MSc. degrees from Purdue University, Survey Engineering and Industrial Management. He has over 18 years of offshore surveying experience, including a former position as Senior Vice President at John E. Chance and Associates.

Art A. Kleiner, Hydrographer, C&C Technologies, Inc., has a B.Sc. in Business Administration from the University of Southwestern Louisiana. He has over 20 years of experience with high-resolution geophysical surveying, ten of which have centred upon multibeam technology. He is a member of The Marine Technology Society, Society of American Military Engineers, The Hydrographic Society, The Southwestern Louisiana Geophysical Society, and the American Geophysical Union.

Jay G. Northcutt, Geophysical Projects Manager at C&C Technologies, Inc., is a graduate of Tampa Technical Institute. He has over 24 years of experience in high-resolution geophysical data acquisition. His experience includes the management of over 75 deep-towed projects. He is currently responsible for commercial AUV contacting for C&C Technologies.

IF YOU HAVE ANY ENQUIRIES REGARDING THE CONTENT OF THIS ARTICLE, PLEASE CONTACT:

Art Kleiner
C & C Technologies Inc.
730 East Kaliste Saloom Road
Lafayette
Louisiana 70508
USA

Tel: +1 (318) 261 0662
Fax: +1 (318) 261 0192
E-mail: aak@cctechnol.com