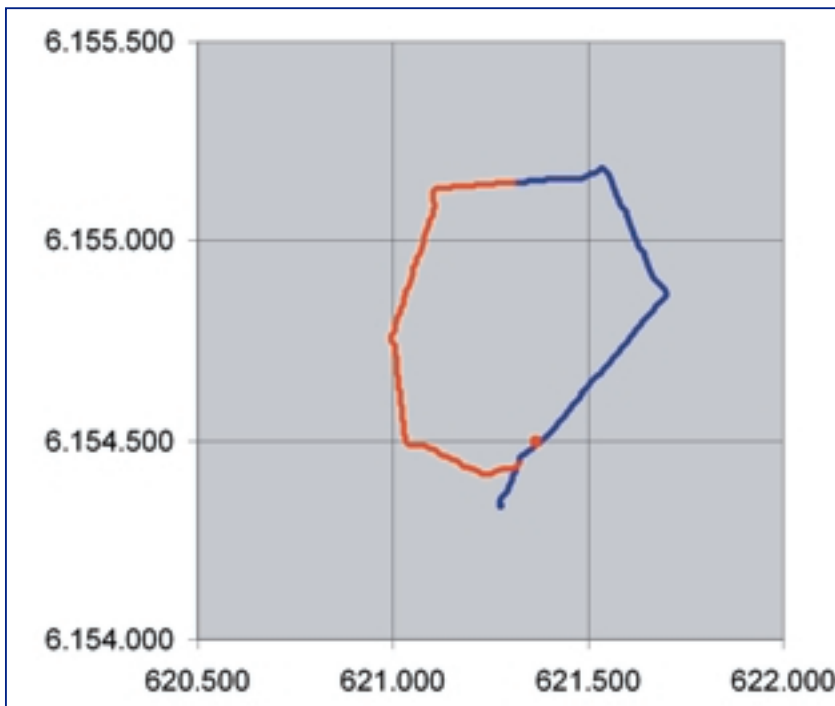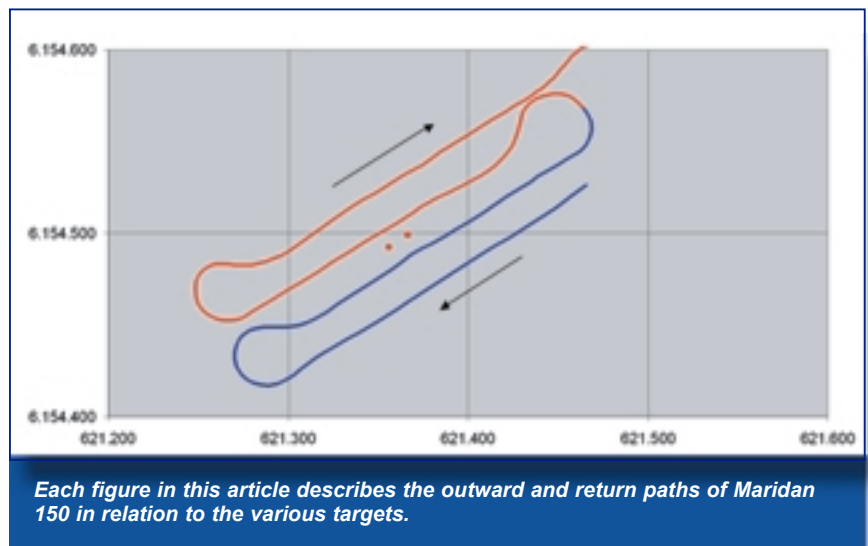# Navigation is Key to AUV Missions

Various Studies Have Been Made to Calculate the Savings That Could be Made by Using AUVs for Deepwater Surveys Rather Than Conventional Methods

By John Romeo
and
Graham Lester
RD Instruments Inc.
San Diego, California

As in so many other areas of subsea technology, the commercial development of autonomous underwater vehicles (AUVs) has been driven by the demands of the offshore oil industry.

As oil and gas exploration and production activities move into the "Golden Triangle" deepwater (1,000 to 3,000 meters) areas of the Gulf of Mexico, off Brazil and off West Africa, there is a requirement for high

Each figure in this article describes the outward and return paths of Maridan 150 in relation to the various targets.

accuracy surveys of the ocean floor and the first few hundred meters of sediments. The tasks include drill site hazard and pipeline route surveys, oceanographic data collection and providing data for subsea engineering design studies.

Offshore operators are increasingly calling for better quality data from these surveys. Until now the data has been produced by instrumented towfish towed many thousands of meters behind and below a surface craft at slow speeds. Positioning of the fish cannot be made to the required accuracy; ship time is wasted by the long turns that have to be made at the end of each survey line.

The answer is seen by many to lie with AUVs to take on the basic deepwater site survey tasks of bathymetry, seabed mapping and sub-bottom profiling. The time-wasting long turn and run-in on a grid pattern is overcome by having a vehicle that can make relatively short, sharp turns. Speed, too, is

increased, and thus survey productivity - an AUV should be able to operate at four knots compared with the present 1-2 knots of a survey vessel with deeptow fish trailing behind.

Various studies have been made to calculate the savings that could be made by using AUVs for deepwater surveys rather than conventional methods. Shell, for example, calculated that over five years it could save $100 million in terms of direct operational costs and by reducing design conservatism.

Since then, others have looked at the Shell figures and extrapolated on them. Kongsberg Simrad is one of them: it says that overall savings on deepwater developments worldwide could amount to $772 million over five years!

The Vehicles

Given this delightful prospect of better data combined with cost savings, it is not surprising that AUVs are now making their appearance in the commercial survey market. Currently there are four main contenders:

• *C&C Technologies, Lafayette, Louisiana*, has conducted deepwater missions on BP's Gulf of Mexico Mad Dog and Holstein fields using its Hugin AUV, designed and built by Kongsberg Simrad, Norway. It is rated to 3,000 meters, powered by a unique aluminium oxygen fuel cell for 40-hour endurance and has a Simrad EM2000 multibeam sounder, EdgeTech chirp sidescan and sub-bottom profiler, Seabird CTD and a magnetometer. On extended missions, the performance of internal control systems (including navigation) was "exceptional," reports BP.

• *Bluefin Robotics, USA* is about to deliver the first of two Oracle vehicles for Thales Survey, U.K., which will have a depth capability of 3,000 meters.

• *Maridan A/S, Denmark*, delivered the first M600 AUV to De Beers Marine, Cape Town to search for diamonds using a survey sensor payload which includes RESON 8125 imaging sonar, Klein 2000 digital sidescan, GeoAoustics Geochirp sub-bottom profiler and SRD autonomous visualisation system. A further M600 is conducting surveys for BP in the Gulf of Mexico; another is working for BP/Shell in the mid-North Sea, operating with Gardline Surveys on a combine geophysical-geotechnical survey.
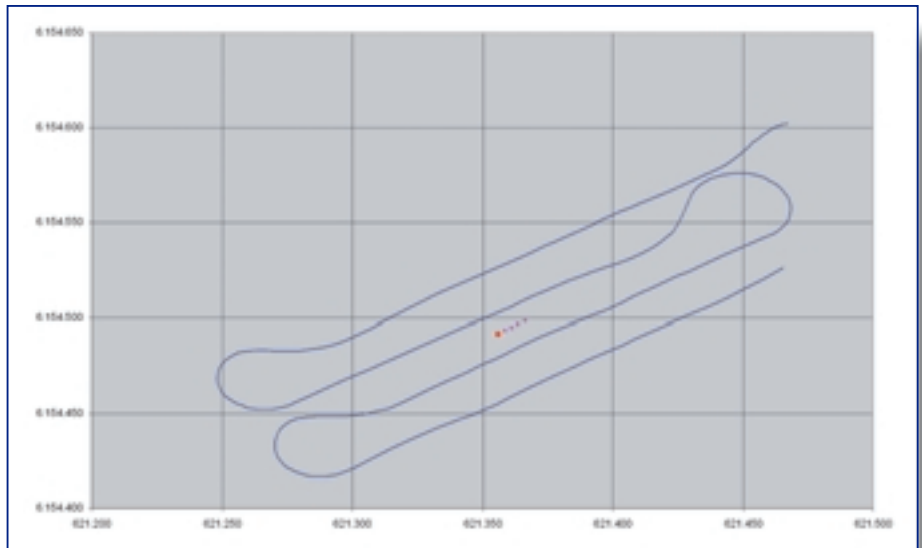
• A potent teaming is that of Boeing Company, Fugro GeoServices Inc and Oceaneering International Inc. by the end of this year they will have in the water a 5.7 meter long vehicle that weighs 5,300 kilograms in air, has a 10-ton handling system, 3,000 meter depth rating and is fitted with sidescan sonar, sub-bottom profiler, multibeam sounder and TV.

Boeing brings its 30 years of experience in developing and operating vehicles for the government [it is currently the prime contractor for the U.S. Navy's Long-term Mine Reconnaissance System (LMRS)]; Fugro will provide the sensor payload and data analysis technologies; Oceaneering will be responsible for surface ship handling and the vehicle launch and recovery system.

Navigation Systems

It's fairly obvious that one of the key requirements for an AUV is its navigation system: if you are going to let your multi-million-dollar baby go roaming round the deep ocean unsupervised for two days at a time you need to be sure that she will pop up to greet you at a pre-arranged location, having gathered high quality data accurately referenced to her pre-programmed route.

So, it's in underwater navigation that some of the greatest innovations are to be found in the current AUV front-runners.

C&C's Hugin is positioned by a Kalman filter-aided INS system which integrates inertial navigation with RD Instruments' doppler velocity log, fiber optic gyro, depth sensor, altitude/forward-looking sensor and

Kongsberg Simrad super short baseline (SSBL) HiPap positioning.

Maridan reports that "underwater navigational technology is a primary focal point" for its engineering team. For its AUVs, Maridan developed the Marpos system in association with the Danish Technical University and Kearfott Guidance and Navigation Corporation, USA.

Marpos is an integrated doppler-inertial system at the core of which is a high precision ring-laser-gyro strapdown inertial navigation system (INS)—the KN5053—developed by Kearfott. The INS is mechanically aligned with RDI's 1200 kilohertz DVL - which measures vehicle speed over the ground or through water - and, for surface navigation, a DGPS receiver. A Kalman filter resident in the INS performs real-time integration of the sensor measurements to provide accurate position, attitude and attitude rate information in all axes.

Orientation (including heading) is determined by Marpos in an alignment process where the Kalman filter uses the gyros and accelerometers to determine local gravity vector and the Earth's rotation. Alignment is performed either statically or moving (using DGPS or RDI's DVL) to an accuracy of around 0.03° rms.

Marpos calculates relative position from start-point by dead reckoning. Sea tests with Maridan M600 have delivered a positioning accuracy of around 0.03 percent of total distance traveled—the equivalent of 1.7 meters per hour at a vehicle speed of three knots.

Marpos can accurately determine absolute position of start-point on the

seabed in water depths less than 200 meters. At greater depths, the start-point may need to be determined after transit to the seabed—perhaps by using USBL—because of accumulated drift during the dive.

For deepsea applications Maridan has developed a new concept called synthetic long baseline (SLBL) which uses a single transponder instead of a full LBL spread. Since the AUV is able to follow a straight line very accurately using Marpos, it can trigger the transponder from different locations and thus calculate its position after a few pings.

Maridan demonstrated the accuracy of the Marpos dead reckoning system in a mine reconnaissance survey for the Royal Danish Navy in Storebaelt, Denmark. The graph shows the path of the survey by the Maridan 150 vehicle with an enlarged section showing the targets. They were obtained by a Tritech International SeaKing 675 kilohertz sidescan sonar.

The Thales-Bluefin Oracle vehicle looks to achieve 0.1 percent accuracy of distance traveled (or about 30 cm at 3,000 m depth). Thales' Stewart Cannon describes the system:

Oracle has a single board computer running software produced by the C. S Draper Laboratory of MIT and interfaced to several sensors. The software mechanises the "shadow navigator" concept by using data from the actual linear acceleration and angular motion of the AUV in an external inertial navigation algorithm (i.e. outside of the INS) and is combined with measurements from additional sensors in an extended Kalman filter to yield the overall best estimate of the navigation state.

The main navigation sensor is the Litton LN-250 MIMU, a fiber optic gyro-based, navigation grade (1n.m./hr free inertial accuracy) system consisting of three interferometric fiber optic gyroscopes and three accelerometers mounted on an inertial block assembly.

The other sensors include: a Digiquartz pressure sensor to measure ambient water pressure (which is converted into depth); an ultra short baseline (USBL) positioning system between the ship and a vehicle-mounted transponder; and the RD Instruments 600 kilohertz DVL.

At the pre-launch stage a moving baseline alignment of the LN-250 is performed by acquiring position and velocity data from the shipboard navi-

gation system while the ship maneuvers in a slow circle for up to 20 minutes.

When the AUV is descending, the INS is in barometer-aided mode and uses the Digiquartz to sense depth. The USBL system may also be used to track the vehicle, with updates made by the shipboard navigation computer telemetered to the AUV. On arrival at the seafloor the RDI DVL bottom-locks and begins providing velocity data to the AUV navigation system.

Data acquisition now begins with time, position, velocity, heading and attitude data provided to the vehicle control computer for both guidance and control. When the vehicle ascends the same procedure as for descent is followed and once on the surface the GPS system is used to bring ship and vehicle together.

The Boeing/Fugro/Oceaneering vehicle's navigation system is based on the full integration of all available sensors including INS, a hybrid RDI DVL, altimeter, depth, LBL and USBL. Inputs into this Kalman filter can include roll, pitch, heading, vehicle accelerations, vehicle velocity, height above seafloor, depth, ranges to transponders on the seafloor or USBL data from a vessel at the surface. Position calibration of the AUV on the seafloor may be performed with a single seafloor transponder of use a vessel-based USBL.

What all four of these main contenders in the commercial AUV business have in common is the RD Instruments doppler velocity log. This measures velocity relative to the seafloor and altitude over the seafloor. It uses four beams at 30° from the vertical in convex configuration to insonify the seafloor and measures the doppler shift of the return. This shift is then converted onto an accurate velocity vector.

RDI systems for the Racal, Boeing/Fugro/Oceaneering and C&C AUVs are 600 kilohertz versions with a minimum range of 0.7 meter and maximum of 90 meters and with an accuracy of ±0.2 percent at 1 millimeter per sec - around 0.004m/sec at three knots. The Maridan RDI DVL is a 1,200 kilohertz instrument. A further instrument in the standard RDI Workhorse Navigator DVL range operates at 300 kilohertz. Across the range, therefore, the DVLs operate between 0.5 meters and 200 meters above the seafloor with a depth rating of 2,000 meters standard, 6,000 meters optional.

Customized units are also produced —a recent example is for a number of specialized systems for Coastal Systems Station (CSS) in Panama City, Florida. These took the place of four competing systems that did not meet requirements on CSS AUVs, with the RDI DVL noted in the *Commerce Business Daily* bulletin as "the only unit proven to meet all operational requirements." RDI reconfigured its smaller DVL to fit in the footprint of the competing model, to suit the retrofit requirements. RDI's navigation device is not only smaller but also less expensive than the original equipment.

The CSS experience with RDI's DVLs led it to recommend them to Boeing Company, which was experiencing similar problems with a navigation system on its Long-term Mine Reconnaissance System (LMRS) under development by Boeing for the U.S. Navy. This is an unmanned surveillance system that provides a clandestine capability to determine the existence of mines in potential threat environments.

Boeing was having problems with the existing navigation units on the LMRS—they easily lost bottom track and were slow to reacquire it. The U.S. Navy's Coastal Systems Station, Florida, (CSS) had also had problems with the same units on its own underwater vehicles and had replaced them with RDI. These performed well and CSS recommended Boeing to make the same replacement on the LMRS.

The RDI customized DVLs use broadband bottom track technology to give a unit that is smaller, more accurate (0.2 percent of depth) and which reacquire bottom track far more quickly than the narrow band units they replace.

RD Instruments has installed its Workhorse DVLs on more than 90 percent of the world AUV fleet and on over 100 ROVs. /st/

John Romeo has worked on the development of a wide range of RD Instruments products for the past 14 years. He has a formal background in manufacturing engineering along with international business and marketing. He is navigation business unit manager for RD Instruments.

Graham Lester is RD Instruments' technical sales manager for the Navigation Business Unit. He applies his market development knowledge to underwater navigation based on his background in avionics and his experience in marine survey systems.