

Introducing Sonar Technology as a Tool for Underwater Cave Surveying

Christian Dobson, Applications Engineer, Tritech International Ltd., describes the technology of acoustic sensors, the fast update and real-time imaging and profiling options for sonar, and how the technology could benefit cave diving.

Laser scanning has now become an established technique in cave surveying and has been used to survey some of the world's largest cave chambers as illustrated in this issue (Walters, 2016). Handheld laser scanners – specifically the ZEB1 and the ZEB REVO – have also been used for surveying cave passages as reported by Williams (2014, 2015) and Reid (2016). However, the infrared radiation used by terrestrial laser scanners is very effectively absorbed by water, rendering laser scanners useless for surveying flooded caves. Here, an alternative technology that is inherently suitable for use underwater – even turbid water – is described. – Ed.

What is Sonar?

Sonar is an acronym for Sound, Navigation and Ranging. This technology is typically used for exploring and mapping the ocean because underwater, sound waves travel further than radar or light waves. Sonar has a variety of uses such as developing

nautical chart systems and locating underwater hazards, whilst navigating. Sonar also permits the search for objects on the sea floor, such as ship wrecks and can be used to monitor targets, such as mammals.

A sonar or acoustic sensor works on the following principles as illustrated in the first diagram below.

- Sonar transmits an acoustic signal (transmit).
- Wait a set period of time for a return from the transmission (receive).
- Make an angular movement.
- Repeat process.

Examining the Different Types of Sonar

Mechanically Scanning

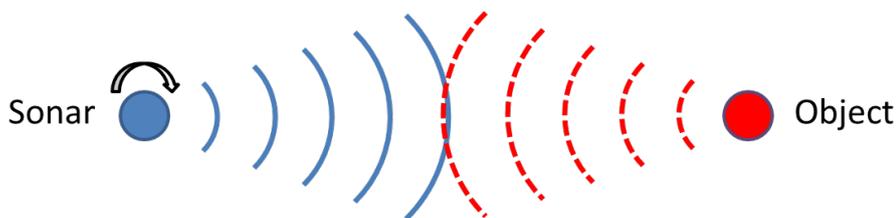
A mechanically scanning sonar rotates a transducer through a series of angular ping positions defined by a scan width. The sonar can continuously or part-scan a full 360°

sector in either direction. Typically, side-to-side scanning would be used for scanning a seabed while 360° scanning would be appropriate in a cave passage. Between successive ping positions, there is a fixed step, dependent on the resolution setting of the profiler head. Objects within the path of the acoustic beam will reflect some of the energy back towards the sonar.

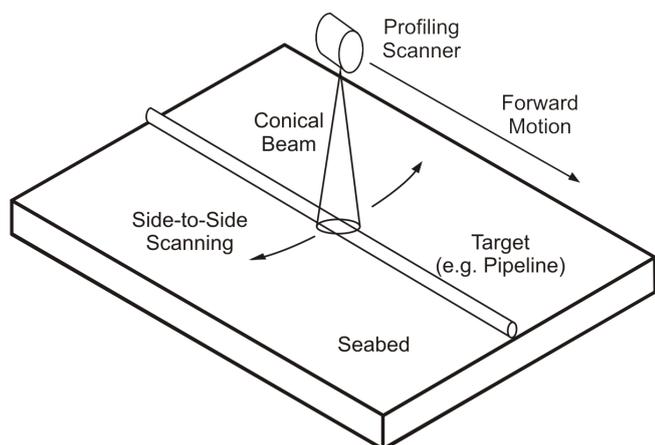
Profiling

Mechanical scanning profiling sonars provide an accurate cross-sectional profile of a surface such as the seabed surface which highlights any structural differences and objects on the seafloor. They are typically used for surveying pipelines on the seabed. Post-processing of the data is achievable using specialist survey software to create 3D mapping. Tritech offers mechanical and multibeam profiling sonars.

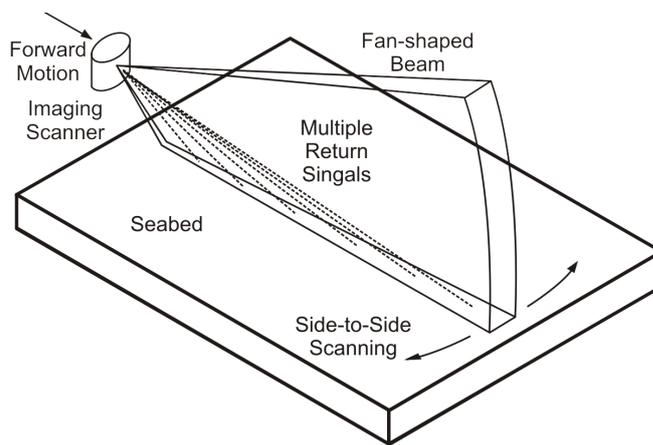
Once at the ping position, the profiler sends a narrow conical acoustic beam of energy towards the seabed as shown below left. Some of this acoustic energy reflects back to the profiler which records the travel time of the acoustic pulses. Only a single signal – either the first or the strongest return – is recorded for each ping. Once the ping is complete, the profiling sonar will send the travel time data to a topside console for interpretation and display.



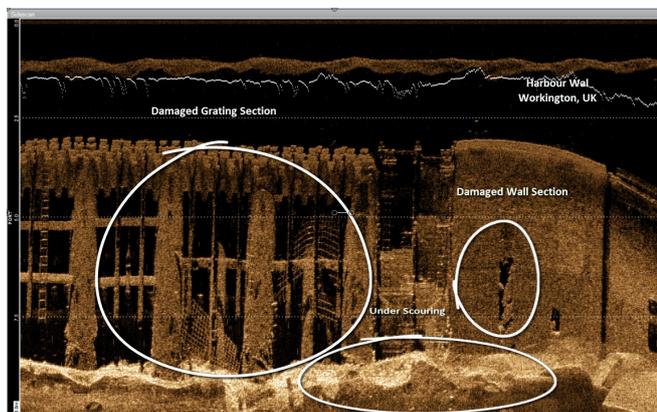
Basic Principle of Operation of Sonar



Mechanically Scanning Profiling Sonar



Mechanically Scanning Imaging Sonar



Side Scan Sonar Output

Imaging

Mechanical scanning imaging sonars allow identification of underwater targets, making these sensors ideal for ROV (Remotely Operated Vehicle) navigation and obstacle avoidance. Tritech offers the Micron, Super Sea-Prince and Super SeaKing range of 360° scanning sonars offering various range and resolution options.

Unlike the profiling sonar, an imaging sonar transmits acoustic energy in a narrow fan-shaped beam which usually intersects the target obliquely as shown bottom right on the previous page. Several return signals are recorded per ping, the time of each echo return representing the slant range. The sonar then sends data collected for each scan to a topside console, where the return signal's strength is mapped against a colour scale and plotted to create an image. These visual images produced by the sonar provide the operator with data to draw conclusions about the surrounding environment.

Side Scan

Side scan sonars, or towfish, provide sophisticated digital pictures of the sea floor surface, using acoustic energy (sound) to take measurements. Specialist software creates an image based on these measurements and in turn, displays this for the user to view. Tritech has a range of shallow and deepwater side scan systems available.

obstructions reflect some of the sound energy back in the direction of the side scan sonar (known as backscatter). The travel time of the acoustic pulses from the side scan sonar are recorded, together with the amplitude of the returned signal, as a time series which is sent to a topside console for interpretation and display.

Typical output is shown above. The image is of a port wall which identified a damaged grating section and wall as well as under scouring off the wall.

Echo-sounder

Echo-sounding is a type of sonar used to determine the depth of water by transmitting sound pulses into water. Tritech offers a suite of solutions including a Micron option.

A recording is made of the time interval between the release and return of a pulse, which is used to determine the depth of water beneath the transducer. This information is typically used for navigation or to obtain depths for charting.

Multibeam

A multibeam sonar does not have any moving parts. Instead, it works on the principle of beam-forming multiple acoustic beams across the field-of-view as opposed to the single beam from a scanning sonar.

Tritech offers the Gemini range of multibeam imaging and profiling sonars which complements the standard SeaKing range.

Profiling

Multibeam profiling sonars provide a high-speed cross-sectional profile of the seabed where data can be post-processed using specialist survey software to create 3D mapping.

The profiler transmits a narrow beam acoustic pulse to view a slice (profile) of the seabed and using beam-forming techniques on the receiver, the reflected signals are detected across multiple narrow conical beam receivers. The received signal is then amplified and processed before placing a profile point at the position of the strongest acoustic return. The resulting data is a plotted line from which you can identify the range, depth and undulation of the profiled area.

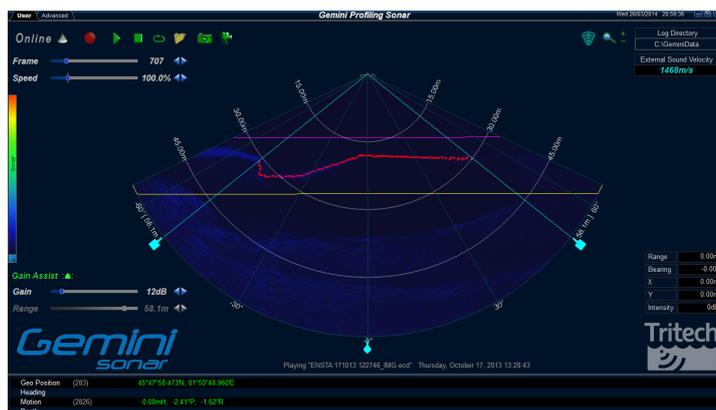
Typical output of a profiling sonar is shown below left. Although this is from a Gemini multibeam sonar, similar results can be obtained using a mechanically-scanning sonar but the process is not as quick.

Imaging

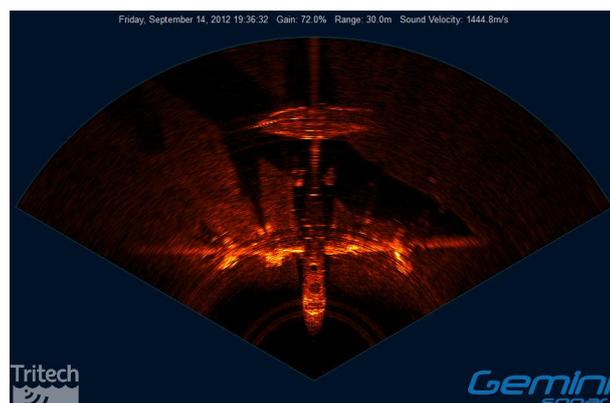
Multibeam imaging sonars provide users with high-speed, real-time, crisp imagery for applications including obstacle avoidance, target detection and close-range inspection.

Typically a wide angle acoustic pulse is transmitted into the water and using beam-forming techniques on the receiver the reflected signals are detected across multiple narrow beam receivers. As with mechanical scanning sonars, the data is transmitted to a topside unit for data collection and interpretation.

Typical output of an imaging sonar is shown below right. This image, captured in Washington Lake, USA, clearly shows an aircraft on the seabed. Although this is from a Gemini multibeam sonar, similar results can be obtained using a mechanically scanning sonar but the process is not as quick and the image would not be as detailed.



Profiling Sonar Output



Imaging Sonar Output



Hammerhead mechanically scanning sonar fitted for deployment on a tripod



Gemini multibeam sonar fitted for deployment on a pole



Applications for Sonar Technology in Cave Diving

Typically, large cave chamber surveys are carried out by laser scanners to produce 3D models of cave rooms, however lasers only operate in air.

Sonars are for underwater use. There is however precedence in using sonar for cave diving and Tritech has observed a number of associated challenges such as poor visibility, due to silt and other debris. The benefit of sonar technology is that these sensors do not depend on light, as a video imaging camera or laser scanner does, instead, sonar uses sound as the medium to conduct and receive signals as explained in this article's introduction. Consequently, poor visibility is not an issue for sonar in underwater visualisation. Furthermore, dive sites and changing environmental conditions can often be in secluded or out-of-reach spots, sonar equipment is largely portable and typically works in turbid and salt/silt/debris-laden waters.

There are many other applications for sonar technology such as: military, energy – oil and gas, marine science/ environmental as well as Search and Rescue (SAR) and in academic and research development and discovery operations.

The survey of cave networks is achievable using the most basic handheld echo-sounder; to check the depth to real-time multibeam imaging sonars for high-speed visualisation of an area. In addition, sonar technology, originally developed for the military market, has become readily available for cave diving where products such as diver-

propulsion vehicles, fitted with mechanically scanning and multibeam sensors, allow safe navigation and real-time viewing, specifically in poor visibility.

Operating Sonars in an Underwater Cave Survey

ROVs Deployed for Cave Diving

Smaller observation and inspection ROVs are frequently used for cave exploration. Their on-board sensors are suitable for a variety of tasks including: diver observation, cave mapping and modelling, SAR and object recovery.

These smaller ROVs are portable and lightweight, enabling exploration of potentially inaccessible caves. Tritech does however acknowledge that due to space constrictions, the use of ROV systems is not always possible and in this instance, other deployment methods could be called upon such as pole-mount or diver propulsion vehicles, (discussed later in this article).

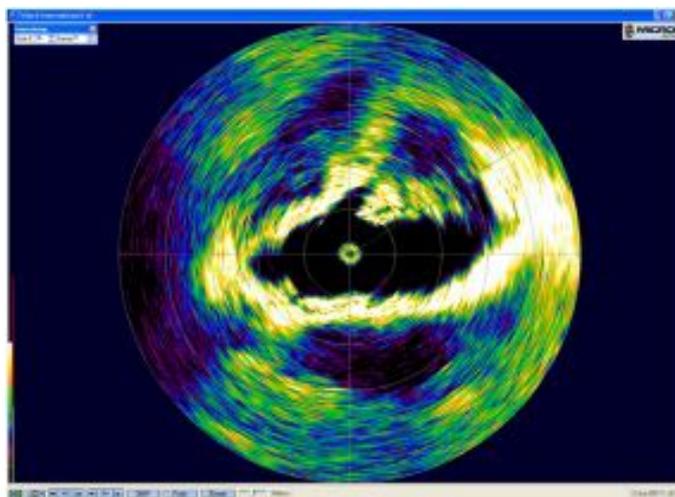
Tritech offers multiple sensory packages such as ROV side scan sensors which fit onto the ROV allowing the safe inspection of a dive site prior to divers entering the water.

This, combined with a multibeam imager, allows the ROV pilot to view the mission in real-time, regardless of the environmental conditions.

In a documented cave mapping mission in VilinaSpilja Caves in Montenegro – (Stipanov et al, 2008) and see below – the operators used a Tritech Micron scanning sonar for cross-section sampling. The group captured profile samples along with the current ROV orientation gained from the built-in electronic compass. Current depth was taken from the built-in depth sensor and the current length of tether released at two metre increments was recorded.

Navigation/ Location Systems

ROVs and divers can be tracked via an USBL (Ultra Short Baseline) tracking system



Mechanically Scanning Imaging Sonar Image (Micron) clearly displaying a cross-section sample of a cave (Image courtesy of Brodarski Institute LLC)



Sonar units fitted on an ROV

which involves a modem configured in transponder or responder mode.

In transponder Mode

USBL systems send an acoustic signal to the modem from the dunking transducer which interrogates the modem and the modem then responds back with its position.

In responder Mode

The modem is combined with a Micron sonar which provides the power and communication link. The responder is activated through the serial data communications and the acoustic signal is then received by the dunking transducer.

For diver use, these sensors can be fitted to the diver and powered via a diver battery. For ROVs, both modes can be used depending on the user requirements. The USBL tracking system, with an overlaid chart, can provide a visual aid to the user. The tracking system can track multiple targets out to a range of 500 metres and down to depths of 150 metres.

Handheld Diver Navigation Aids

These were initially developed for the naval mine clearance diving EOD (Explosive Ordnance Disposal) market to replace conventional fixed datum methods. The diver can either navigate underwater using the sonar, or by following a series of waypoints, programmed into the computer. The diver can select functions such as a

playback mode during the dive or programme a dive with a new mission.

Diver Propulsion Vehicles

Underwater battery-powered vehicles range from smaller, low-powered leisure class, to higher powered specialist models with bespoke modifications

such as forward-mounted HD (High Definition) video lighting systems and video camera housings. Some military applications use forward-looking multibeam sonars for inspection and navigation underwater.

Recording/ Playback of Log Data

In remote locations and inclement weather conditions, it is a challenge to record and playback log data; therefore, rugged laptops could be used.

Power

Powering sonar equipment in a cave environment presents its own set of challenges; however, using battery power resolves this.

Diver Batteries

The use of diver batteries for powering sonar equipment has been practiced before. In a recent customer project, Trittech successfully powered a multibeam imaging sonar which was fixed to the end of a pole and powered using two 12Ah diver batteries. This provided sufficient power for up to four hours of operational use.

Conclusions and Further Information

Sonar is proven in many demanding environments and due to its adaptable and portable nature, the technology lends itself well to cave diving expeditions. With greater

understanding of constraints and dive requirements, a suite of sensors could be deployed to enable an accurate survey and map of a cave site, with or without the use of underwater vehicles.

For more information on Trittech International Limited (Trittech), a Moog Inc. Company, visit: www.tritech.co.uk.

Further Reading

What is Sonar?

<http://oceanservice.noaa.gov/facts/sonar.html>

Echo-Sounding

www.history.noaa.gov/stories_tales/poletobeam2.html

How are ROVs used for Cave Exploration

<http://oceanexplorer.noaa.gov/explorations/09bermuda/logs/sept25/sept25.html>

Cave Mapping and Modelling

https://bib.irb.hr/datoteka/357125.ROV_use_for_cave_mapping_and_modelling.pdf

Side Scan Sonar

http://oceanservice.noaa.gov/education/seafloor-mapping/how_sidescansonar.html

Laser Scanning

www.int-arch-photogramm-remote-sens-spatial-inf-sci.net/XL-5/181/2014/isprsarchives-XL-5-181-2014.pdf

Trittech Knowledge Base and Training Materials

www.tritech.co.uk

References

Reid, Mark (2016) *Introducing ZEB REVO: a Major Improvement in Handheld Laser Scanning*, CREGJ **93**, pp. 23-24

Stipanov, M.; Bakarić, V. & Eškinja, Z. (2008) *ROV Use for Cave Mapping and Modeling*, IFAC Proceedings, Vol. **41**, Issue **1**, pp. 208-211

Walters, Richard (2016) *Laser Scanning the World's Largest Cave Chambers*, CREGJ **94**, pp. 6-10

Williams, Emily (2014) *Handheld Laser Scanning: a Radically New Approach to Cave Surveying*, CREGJ **86**, pp. 21-24

Williams, Emily (2015) *ZEB1 in Skirwith Cave*, CREGJ **89**, p. 20

Christian Dobson, Applications Engineer, Trittech



Christian joined Trittech in January 2015, after serving with the Royal Navy as a Mine Warfare Specialist. He accomplished three operational tours of the Arabian Gulf, where he participated in ROV Operations.

Christian holds RYA Powerboating levels one and two as well as having completed the PADI Open Water Diver course in Sardinia whilst deployed in 2007. Following this, Christian has also dived in the warmer waters off of the Omani Coast.

Christian is responsible for bringing new products to market and pursuing new applications for Trittech's existing product portfolio. Christian works at Trittech's Westhill office and is currently studying towards an HNC in Electrical Engineering.