THE JOURNEY FROM OIL AND GAS TO HOMELAND SECURITY AND BACK AGAIN

3D Sonar Technology

Since its introduction many years ago, survey sonar has evolved steadily, but is still a difficult and non-intuitive survey tool, requiring large amounts of processing to arrive at the most basic end product. Initially, anyone wanting to survey or inspect the underwater environment was limited to single beam echo-sounders, in simple terms one-dimensional sonar, yielding very little quantifiable data. These in turn were developed into mechanically scanned sonars, and subsequently into todayâ€™s high performance multi-beam and forward looking sonars which are the back-bone of the survey industry. Even the very best commercially available multi-beam sonar delivers only 2 dimensional data however, and true 3D sonars are only now becoming a commercial reality.

One of the first, possibly only 3D sonar is the Echoscope originally developed by Omnitech of Norway, and more recently, CodaOctopus. Since its original conception in 1987, this real-time 3D sonar has come a long way. Conceived originally as an acoustic sensor for underwater robots as part of a Norwegian academic project, Echoscope was designed to be capable of imaging in the range from 10cm to 4m. Initial applications for this real-time 3D sonar were as a â€˜vision systemâ€™ for underwater robot control, to provide the position and orientation of objects such nodes on oil rigs feeding into a control system to aid automated tasks using an ROV manipulator arm. Now commercially available, we can look at the concepts behind his real-time 3D sonar and the ongoing efforts to introduce the technology into new applications.

Real-time 3D vs Scanned Sonar
As with single beam and multi-beam sonars, most systems which generate 3D underwater images rely on multiple scans to build up a 3D image, whether this be of the seabed or other structures. During the acquisition of these scans, any movement of the sonar due to vessel motion etc. will have a detrimental effect on the data, requiring significant processing to resolve. Similarly, any changes in the scene during the scanning process, such as in a construction operation may result in a very confused image. To overcome these fundamental limitations, a true 3D sonar simultaneously acquires multiple beams across a 2D array; and in the case of Echoscopeâ€™ over 16,000 beams in an array of 128 x 128, equivalent to 128 individual scans by a conventional system. The end result is an instantaneous 3D image with no distortions due to vessel motion, and the ability to observe moving scenes such as live construction operations. A secondary, but important by-product is vastly increased coverage (128 times more than normal) and the ability to survey at much greater speeds without any reduction in coverage. Consequently, real-time 3D sonars lend themselves to many underwater imaging and survey applications where they offer massive improvements in data quality and quantity as well as being capable of operations not previously possible.

The 3D Sonar Concept
To achieve this extraordinary real-time performance, a 3D sonar needs to employ cutting edge technology. Equally, it needs to be sufficiently compact so as to be usable. As with all sonars, an acoustic pulse is transmitted in the conventional manner, but ensonifying a 3D â€˜volumeâ€™, as opposed to a narrow beam or fan.
Otherwise, the fundamentals of the real-time 3D sonar are the same as a conventionally beamformed systems, only the scale of the technology is different with a high number of simultaneous receiving channels; Echoscope has 2304. As with standard beamformed sonars, the real-time 3D sonar employs phased array techniques, which essentially means focussing acoustically in a specific direction by delaying, or phase shifting and summing the signals (i.e. from the multiple channels) for each desired beam. The length of the transmit pulse together with how fast the channel signals are digitised, and how fast the system can process the data dictates the range resolution (down to 1cm), which is in effect how accurately the hardware can discriminate between echo returns.
In Figure 1, transducer elements A, B, C, D are beam-forming in a specific direction as shown (i.e. listening in a specific direction). The acoustic wave front propagating from a particular direction, arrives at A first, then B, C and finally D, so attention is focussed (beamformed) by applying a delay to each of the transducer elements (A is biggest delay, D is zero delay) such that the signals from the desired direction are coherent so that when summed together, acoustic signals from the desired direction are reinforced, whilst the effects of signals from other directions are reduced. As the time delay is very small it is described as a phase difference as opposed to a time delay. This is exactly how human hearing determines directions of sounds, but in reverse; by figuring out the phase difference required for coherence, the direction from which sound emanates can be calculated.
This is very much a simplified explanation and in reality the technique for implementing this across 16,384 beams is somewhat different, however the underlying principle remains the same. In practice the real-time 3D sonar beam-forms for each discrete beam at a specific range and then repeats the whole process for the next range, effectively beamforming for all 16,384 beams on-the-fly, in real-time.
An alternative but effective way to appreciate the scale and complexity of real-time 3D sonar is to think of it as 128 high resolution multi-beam sonars, each generating 128 beams, stacked together and operating simultaneously.

Proof of Concept
Having been used mainly in niche sectors of the oil and gas and subsea construction market for the past ten years, real-time 3D sonar was a relatively well proven concept, but, it is fair to say, not a technology widely used or demanded. During the last eighteen months however, real-time 3D sonar has found a number of new applications within the rapidly expanding Homeland Security market, specifically for

underwater inspections in ports and harbours where the risk of attack is of major concern.
Building on the existing track record, and working in conjunction with a number of high profile partners with funding from the US Navy, real-time 3D sonar has been refined and developed as part of a system for carrying out fast, accurate harbour and vessel inspections. Ship hull data collected in the US on behalf of the US Coast Guard during the evaluation phase has received critical acclaim and resulted in interest from many international navies and security organisations. Specific tasks during the evaluation included harbour surveillance with the real-time 3D sonar mounted on a small ROV, as shown in Figure 2, and as part of the Mobile Inspection Platform (MIP) equipment package developed specifically for harbour security needs. During the evaluation, 1km of harbour wall was scanned to a high level of detail in ten minutes, a fraction of the time that a large team of divers would have taken to cover the same area. Using the real-time 3D sonar system, we were able to guarantee 100% coverage of the wall including intricate detail of the mine-like objects attached to both the harbour wall and ship hulls. A section of the wall is seen in Figure 3.

Applications Past, Present and Future

Prior to the growing interest from the defence sector, real-time 3D sonar has been used since the early 1990s by many companies involved in the oil and gas market. These include: pipeline inspection, touchdown monitoring, ROV flight control, trench surveys in very turbid water conditions, structural inspection, real-time dredge monitoring, volume measurements and drill cutting removal.
Other applications include structural inspection of rigs and platforms, real time visualisation and calculation of cable trench depths, pipeline touchdown monitoring, and bridge pier inspection (Figure 4). Perhaps the largest commercial application of real-time 3D sonar to date has been the monitoring of shallow river pipeline crossings, looking for free-spans, where the use of divers or a full survey spread and traditional detection methods are unsuitable. Today, many ports and harbours around the world are considering this technology to detect foreign objects attached to any of the numerous underwater pipelines that cross under most ports and harbours.
A 3D sonar which is platform independent, can be operated with ease from any size vessel, either small craft designed for inspection applications including ROVs and RIB-type vessels or large ocean going research vessels. Its ability to operate as a accurate visual inspection tool without the necessity to correct for motion or positioning errors allows usable data to be generated in the field, in real-time.
Future applications will see real-time 3D sonar fitted to AUVs where it can operate as a multi-role sensor used in both 3D forward looking obstacle avoidance mode, forward looking terrain mapping and for target imagery and inspection in a â€˜fly-byâ€™ mode. Research and development is also underway to develop variants of the 3D sonar technology to fit specific applications.

Conclusion

Real-time 3D sonar is a revolutionary acoustic imaging development which promises to deliver underwater image data of a quality and quantity not previously available in a commercial product, and at a price comparable with existing conventional 2D systems. This independently tested, field-proven solution has many potential uses, both in offshore oil and gas applications as well as port and harbour security markets. Users of the technology have been immediately able to see the potential uses for instantaneous high resolution 3D image data and recognise that this markedly reduces the time and resources associated with underwater inspection, minimising the risk to personnel involved and removing the need for diver operations, whilst significantly reducing the impact of such security activities on commerce.

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