DYNAMIC POSITIONING CONFERENCE
September 17-18, 2002

Acoustic Positioning

Flexible Acoustic Positioning System Architecture

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Abstract:

The continuing push to develop oil and gas fields in deepwater, places increasing demands on acoustic positioning systems often installed on several vessels working in close proximity.

Current acoustic positioning solutions involve the use of different systems by different vessels. Whilst maintaining independent operations between vessels, this inevitably leads to an increase in the volume of acoustic signals being transmitted through the water column. In any field development, vessels, very quickly use up the available acoustic bandwidth.

In order to tackle this problem, it is important that we achieve the following:

1. Independence of operations between in field vessels.
2. Precision achievable must be maintained and if possible improved from current systems.
3. Set-up must be possible from DP vessel requiring position.
4. Flexible architecture which allows all current positioning requirements for vessels, ROV's, AUV's, structures, pipelines.

Sonardyne's future systems will use a combination of acoustic signal processing techniques integrated with external navigation sensors such as INS or DVL. These systems will allow several vessels to operate in close proximity with no interference.

These solutions will allow DP vessels to maintain full independence of systems from neighbouring vessels, therefore eliminating an element of risk associated with the use of a common reference system. This will also allow any DP vessel to be fully mobile and work anywhere in the world with a dedicated inventory of equipment, without the need for a pre-installed, calibrated and managed seabed reference system.

Sonardyne's future systems will allow more flexible operations and faster setup. These factors combined with those detailed above will enable vessel operators to save valuable time and money.

Introduction

Figure 1 – Simultaneous Offshore Operations

The picture above highlights the issues facing users of underwater acoustic positioning systems. In the picture above, every vessel is using underwater acoustics in the Medium Frequency Band (20-36 kHz).

A common requirement in field developments is to use multiple DP drilling units in order to bring a field online in the shortest time frame possible. All Class 2 DP drilling units require redundant surface and sub-surface equipment i.e. transponders installed on seabed. A typical Class 2 DP vessel will use 5 acoustic channels for operations. We have a limit of 15 channels and if there are two such vessels in the field drilling then there are only 5 channels remaining for all other vessels to use.

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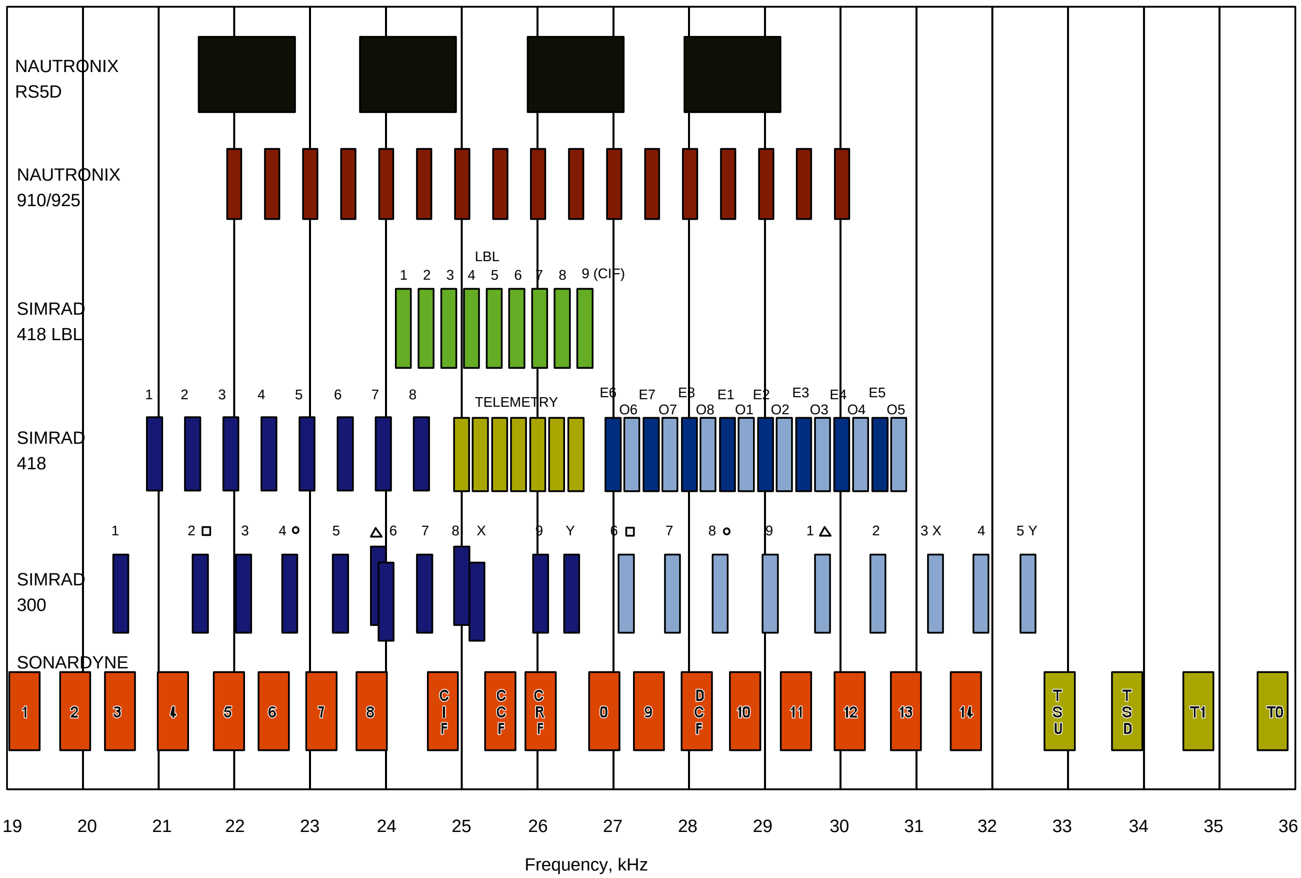
Figure 2 – The Medium Frequency Band



As Figure 2 shows, the medium frequency band is very crowded with all manufacturers trying to make as much use of the band as possible.

The diagram above only displays acoustic positioning frequencies. It is important to remember the presence of other acoustic systems operating, e.g. swathe bathymetry, current profilers.

In order to move forward and provide for more acoustic system users it is important to consider the requirements for an acoustic positioning system and not be constrained by current system methods and operations.

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Acoustic Positioning System Requirements – The specification

The requirements for an acoustic positioning system are detailed below and have been broken into technical requirements and commercial requirements.

Technical Requirements

Future systems must:

1. Improve precision and update rate from current systems, while increasing battery life
2. Allow independent operations between in field vessels
3. Allow positioning of a variety of targets
4. Be deployed and set-up from the DP vessel

Commercial Requirements

Future Systems must:

1. Maintain contractual independence between different in field vessels.
2. Maintain revenue streams for contractors
3. Allow vessels to operate on a worldwide basis
4. Minimise installation and set-up time

If we examine these factors in more detail it will allow a better understanding of the requirements before looking into potential solutions.

Techinical Requirements

1. **Improve precision and up date rates from current systems while increasing battery life.**

Update Rates

As operating water depths increase, acoustic update rates decrease, according to the following.

Acoustic signals travel through sea water at approximately 4600 feet per second. Hence in 10,000 feet the acoustic update rate will be a minimum of 6 seconds (2.5 seconds for travel time down, 2.5 seconds for travel time up and processing time).

All DP models require positional update rates as often as possible. Update rates of slower than 1 second would cause the acoustic position information to be rejected by some of the older DP desks. Modern DP systems are capable of handling slower acoustic updates as the DP models are Kalman Filter based and are less reliant on frequent updates. A common solution to the acoustic update rate issue in older DP desks is to issue repeat outputs from the acoustic system which will effectively provide a one second update rate where the actual value may only change every 6 seconds.

Some Pinger based systems used in DP applications are capable of achieving update rates once per second. These systems use pre-programmed pingers, which are set to output at a pre-set interval. These units will continue to operate at this interval until they lose power. The surface vessel will receive signals every second once the stack of signals has reached the surface. A significant disadvantage of Pinger based systems was the fact that the user has no control over the output of the Pinger. This inevitably led to problems with acoustic frequency management in areas where this interfered with other systems.

A more recent development introduced by Sonardyne is a technique known as ping stacking. This is where transponder interrogations are repeated at a preset interval and corresponding replies are received back at the surface at the same preset interval.
This method has the advantage of allowing the user to increase the real acoustic update rate for the system but at the same time retain control over the activities in the water column. This is essential for operations in congested areas where it may be required to change transponder settings.

This technique was developed to provide an update rate of better than 8 seconds for positioning operations in 21,000 feet water. The technique has also been field tested on the Transocean Discoverer Enterprise in 6,000 feet.

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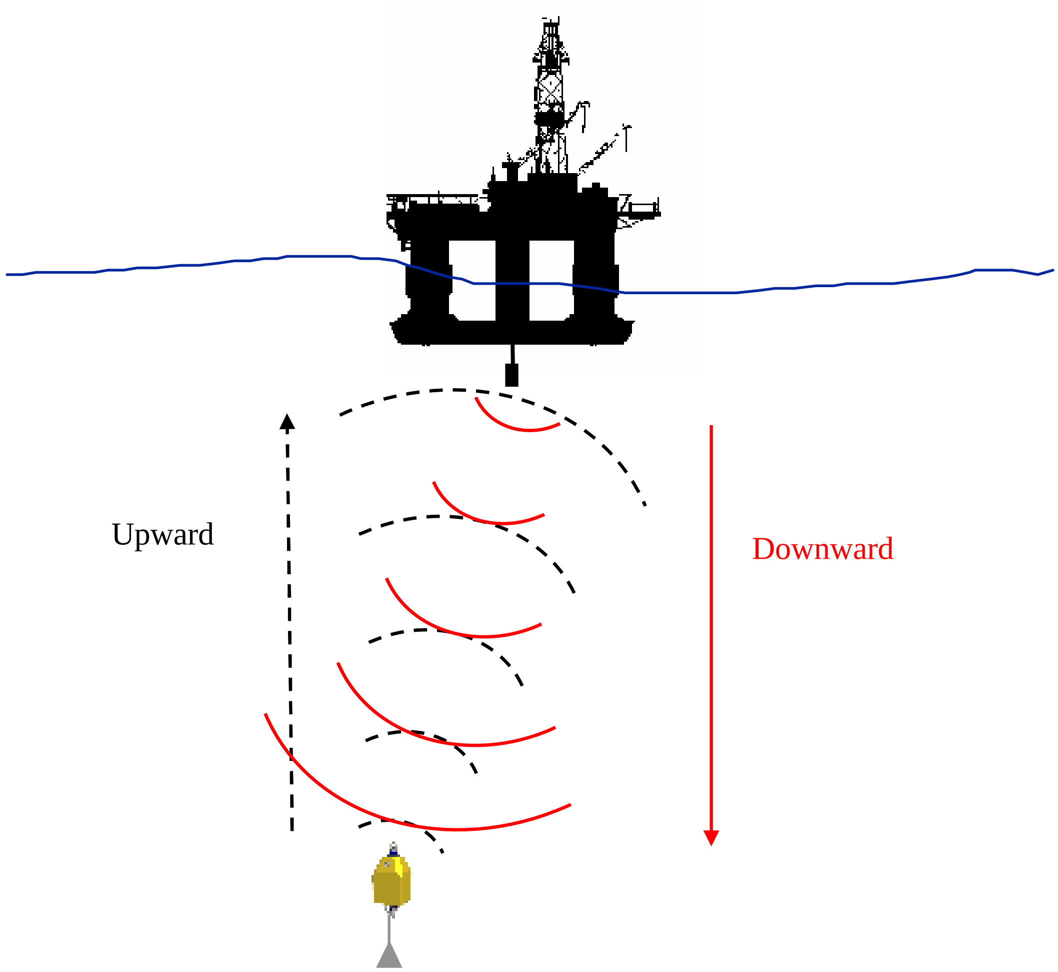
Figure 3 – Ping Stacking



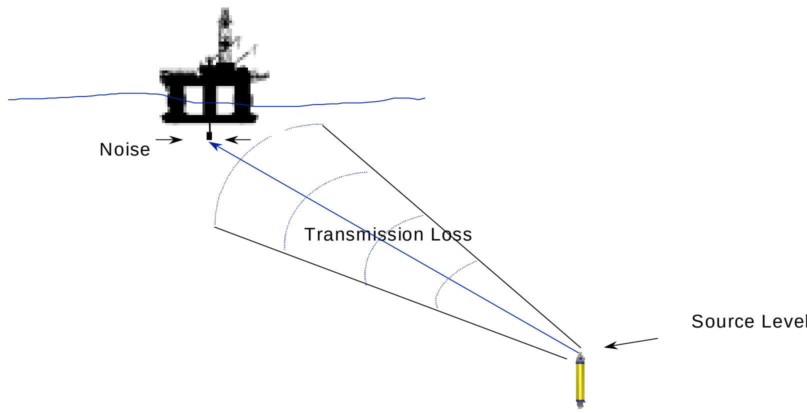
Battery Life

All deployed units should have a working battery life of at least 9 months in order that each unit can remain deployed for the duration of one well. Significant costs can result from a need to recover units and change batteries.

All acoustic systems regardless of signal type are required to output an analogue tone with a source level which is high enough to travel from seabed to surface and still be received in a noisy environement. As we move to systems which use digital signal processing techniques we are still reliant on the transmission of an analogue carrier frequency.

Transmission of acoustic signals through water is governed by the sonar equation which is explained in Figure 4 below.

Figure 4 – The Sonar Equation



$$SNR = SL-TL-N$$

Where SNR = Signal to Noise Ratio i.e. amount of acoustic signal detectable above noise.
SL = Source Level of Transponder
TL = Transmission Loss
N = Noise

A typical DP vessel will generate in the region of 90dB acoustic noise in the MF operating channel. Acoustic signals will lose energy as they travel through water. In seawater with an MF signal this is typically in the region of 80dB for 6,000 feet operations. With output source levels in the region of 192dB for most systems, it becomes clear that we are left with very little margin for safety.
It is possible to increase the acoustic output power of the beacon but this then has a negative effect on the on the battery life. Each 3dB increase in output source level halves the life of the battery. This shows that successful system operation will require high powered directional transponders regardless of signal transmission type.

Positioning Accuracy:

At this point it is important to qualify the term accuracy and what we require for DP applications.

Accuracy is a term used to describe a position which is free from errors. Although this is a desirable feature, more often we are concerned in a DP application with repeatability as we need to measure how the vessel is moving relative to the last measured point in time. This way we can

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provide the DP computer with the information required to make the necessary adjustments to position to keep the vessel where it is meant to be.

Current deepwater positioning systems allow positioning repeatability at the surface of less than 1 meter (1 sigma). This level of repeatability is achieved through the use of a Long & Ultra Short BaseLine technique (LUSBL). In an LUSBL system a minimum of one surface transceiver (usually two) is used to interrogate an array of 4 transponders, which are installed in a radius approximately 3,000 feet from the BOP [*Note 1*]. In an LUSBL solution the positioning accuracy is dominated by the redundant range information from multiple seabed transponders allowing for an integrated Long BaseLine (LBL) and Ultra Short BaseLine (USBL) solution.

Other positioning systems may offer less repeatable positioning, since they are based on technologies which offer less accuracy. A good example is an Ultra Short BaseLine (USBL) System. This system operates with a single seabed transponder and a single surface transceiver. The system measures range and bearing to the transponder. System accuracy is normally in the region of 1% slant range to the transponder which would equate to +/- 100 feet in 10,000 feet. In this water depth this is clearly an unacceptable solution. This would however be acceptable for shallow water operations (<1,000 feet) or for moored drilling units.

Figure 5 over the page shows some of the issues associated with USBL system accuracy.

Note 1 – Transponders should be deployed in a pattern with radius from the BOP stack equivalent to 22.5 degrees from vertical. Hence in 10,000 feet this would equate to 4,142 feet from the BOP stack. In reality, most vessels will deploy the transponders within ROV reach of the rig and the offset distance is therefore governed by the maximum ROV excursion possible.

The illustration below, although exaggerated in scale, demonstrates the importance of geometry to an acoustic positioning system.

As is clear from above, acoustic rays are bent as they travel through water, this is largely due to the different water layer densities and the changes in speed associated with passing through these different layers. Ray bending tends to be most severe at in the surface water layers where temperature changes are large. For an acoustic reception from a transponder with a large horizontal offset the arrival angle will be close to the horizontal before the effects of ray bending. For the surface acoustic system, position is computed from range (which is largely unchanged despite bending), bearing and elevation. Clearly in this case, the elevation will be incorrect. This can be fixed if we can force the system to use the correct depth of the transponder as well as applying the ray constant.

It is clear from Figure 5 that regardless of the signal type we are transmitting, acoustic waveforms will be bent as they travel through water. For this reason we must continue to ensure that geometry of seabed equipment in relation to the surface vessel takes this into account.

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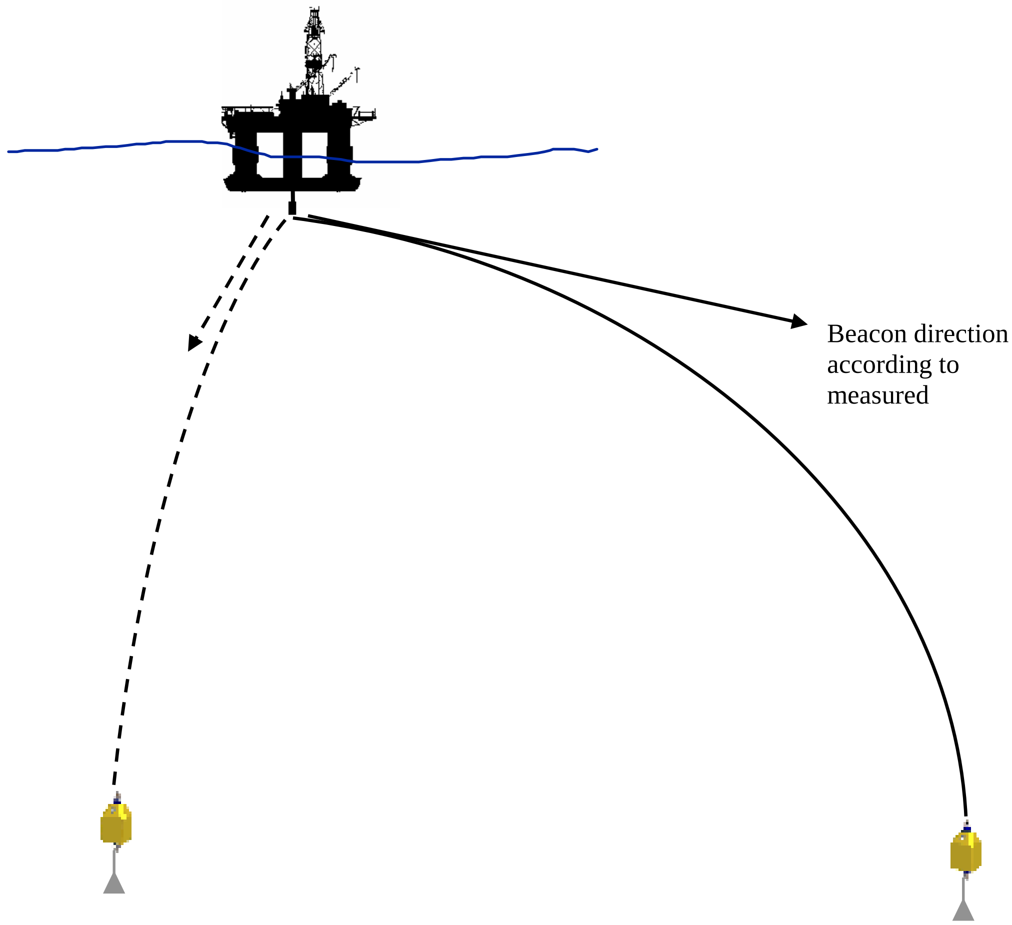
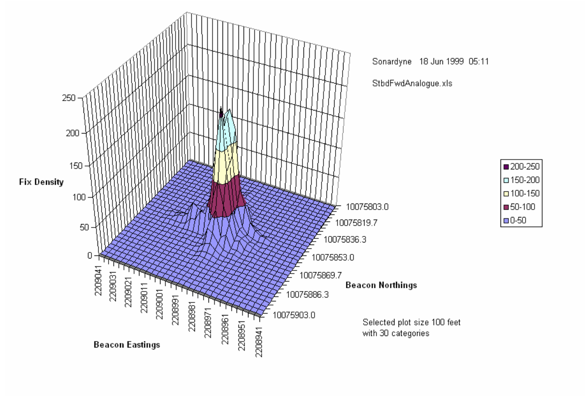
Figure 5 – Effect of Geometry on Vessel Based Acoustic Positioning Systems

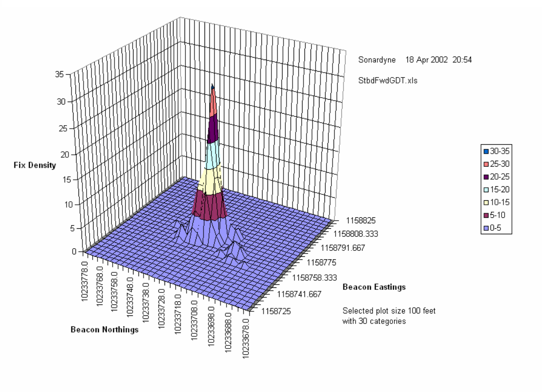


New generation USBL systems will use digital signal processing techniques which will enable operations with reduced Signal to Noise Ratio from noisy vessels. This will allow an improvement in accuracy although this will not be significant. A further improvement will come with the introduction of digitally coded signals for through water transmissions. This will enable a major improvement in range accuracy although the USBL system performance will still be limited by the precision of the bearing measurement which relies on phase measurement, hence the LUSBL system will continue to offer improved performance. Figure 6 below shows results from initial performance trials in the Gulf of Mexico, 6,000 feet of water.

<u>Figure 6 – Performance of Digital Transceiver against Analogue Transceiver</u>



Analogue Transceiver



Digital Transceiver

Results of Performance trials of digital transceiver. This involved a spin over the top of a COMPATT. The improvement in position repeatability is clear with any uncertainties or scatter in the beacon position removed.

2. Allow independent operations between in field vessels

As we see from Figure 1 showing vessels operating in close proximity, any new system must allow multiple operations from multiple vessels. This can be achieved in a number of ways outlined below:

a) sub-divide the MF band into more divisions
This will allow the creation of a greater number of independent channels.

This approach will solve the majority of problems which are seen at the moment. However it is important to make sure that the splitting up of the MF band allows for truly independent operations. Some systems have created more channels in the past through the use of split frequencies which are actually repeated. With such systems the number of truly independent channels is therefore limited to the number of different frequencies used.

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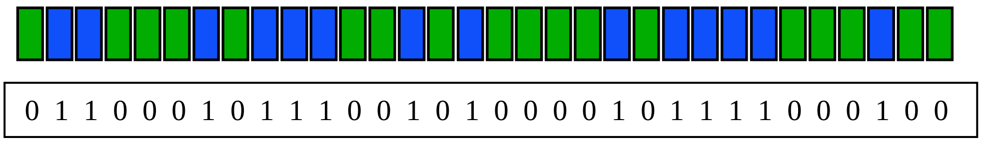
b) Use Digital Signal Processing

Figure 7 – Example of a digitally coded signal



This will be superimposed onto a carrier frequency or analogue tone. Each time the signal changes, the phase of the signal will be changed. On receipt it is possible to recognize the precise point in the code when the incoming signal was received. This helps to improve the resolution of the incoming signal.

There are up to 1,000 codes which can be used for transmissions. This is clearly more than sufficient channels for any area of operations with any number of vessels. In reality, only 60 codes would be used, which are robust and can withstand a moderate amount of corruption. These 60 codes can be combined with a number of different carrier signals enabling the generation of multiple unique channels.

Sonardyne have considerable experience in the use of Digital Signal Processing in harsh marine environments with Deep Marine Seismic operations where this technology has been working successfully for 3 years. When a digital signal passes through a bubble cloud the digital signal is corrupted. In this scenario it is often impossible to recover the real signal and therefore the definition of a position is not possible.

On any DP vessel the thrusters cause severe disturbance of the water, particularly in the surface layers. It is not clear at this stage how a digital signal will survive in this environment. It is important that the capability to revert to analogue tone positioning techniques is retained in order that positioning is still possible when conditions dictate that reception of the digital coded signal is not possible.

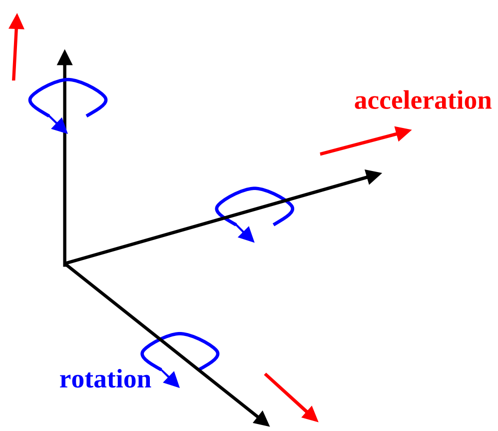
It is also important to note that the angle of the incoming acoustic signal will determine the effect of cavitation on a digital signal. According to the diagram in Figure 5, a signal coming from a transponder some distance away will have a low elevation angle on arrival. This signal will then spend more time travelling through the bubble cloud generated by the thrusters and will be most susceptible to corruption.

c) Use non-acoustic devices

Inertial Navigation Systems (INS) can be used to aid acoustic positioning systems. Before outlining the benefits of this method, a discussion on the concepts behind Inertial Navigation is useful.

An underwater Inertial Navigation System measures the accelerations and rates of rotation about three orthogonal axes, as shown below, using an inertial motion unit or IMU comprising typically three accelerometers and three rate gyros. The INS then integrates the acceleration data to produce a velocity. This data is then used to produce an estimate of position and orientation (attitude). However, an INS is a dead reckoning device and its estimates of position and orientation will suffer from accumulating sensor errors over time that can only be limited by taking one or more absolute measurements. The frequency of these measurements will depend upon the quality (i.e. error drift) of the sensors. These errors can be constrained or limited in two practical ways.

<u>Figure 8 – Measuring Rates Of Rotation And Acceleration In Relation To Orthogonal Axes</u>



The first is to use gyros that are sensitive enough to measure the direction of the earth's rotation (15.041 °/hour) and use this as a reference. This requires a knowledge of the latitude, but it does give an absolute heading and rotation rate reference to the sensors. The unit can be 'calibrated' by holding the IMU stationary for a period of time such that it is only measuring the earth's rotation and applying corrections for this (zero velocity update or ZUPT). Clearly in most offshore applications this is impractical. Note also that sensors capable of measuring the earth's rotation require strict export license control when being shipped around the world.

The second technique is to provide the INS with data from an acoustic positioning system. This can be in the form of absolute positions (i.e. Lat. and Long) or ranges and / or bearings to known

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positions. The frequency with which this data has to be provided will depend upon the accuracy's of the IMU sensors and the overall accuracy requirement of the operation.

However, even low grade sensors (and hence rugged, low cost and with little or no export restrictions) can bring improvements to an acoustic only derived navigation solution.

How can this be applied to a multi user acoustic positioning scenario?

We could slow down the acoustic position updates and use the INS to provide estimates of positions between acoustic fixes. This would offer two benefits:

- Decreasing the volume of acoustic traffic in the water column allowing neighbouring vessels different allocated time slots. This would need some form of time synchronization between vessels and the practical reality of this is questionable. Using GPS time as a method of synchronisation takes away the independence of GPS as the other position reference system when drilling.

- Reducing the number of ranges required for system position updates. This is probably the more attractive benefit as it allows a possible reduction in the number of transponders deployed or offers additional redundancy, although this solution still requires field testing in order to determine the robustness of the solution for DP station keeping.

A spin off benefit from using the INS to reduce the acoustic interrogation rate is a significant saving in battery life. Such a battery saving technique would be adaptive in terms of slowing down acoustic position updates in stable conditions of low vessel dynamics, and conversely increasing acoustic update rates in times of unstable conditions e.g. bad weather, or during a critical operation.

Doppler Velocity Logs (DVL) can also be used to aid some positioning tasks. The DVL unit uses the Doppler effect to measure speed over the ground from transmitted acoustic beams. This is then combined with compass data to produce a velocity. The unit can be used to augment an acoustic positioning system in a similar manner to an INS and may allow a reduction in the number of acoustic transponders required. However, a DVL like an INS is a dead reckoning device.

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d) Share the same seabed array

Figure 8 – Shared Seabed Array

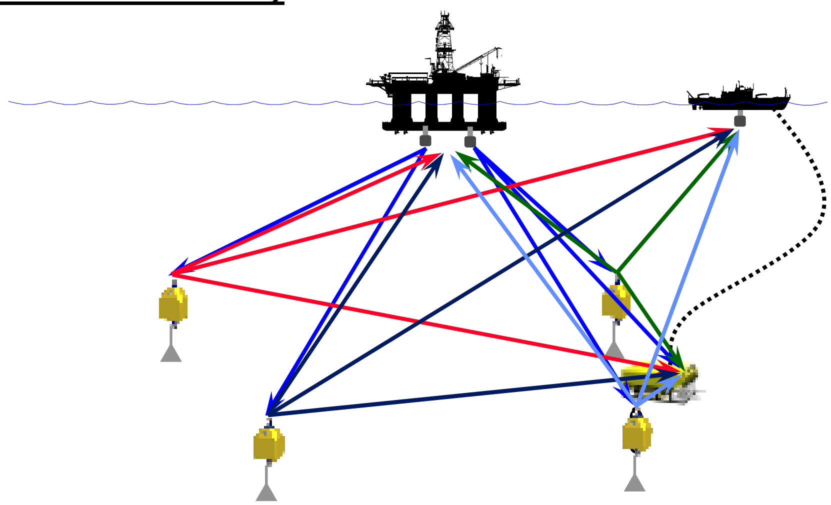

Figure 8 above shows 2 vessels and a ROVs all being positioned within the same seabed array of transponders and in one acoustic cycle. This concept can be extended to include more vessels and ROVs.

This proven technique would appear to be an ideal solution as we have reduced the number of acoustic transponders to be deployed without having any impact on the ability of vessels to operate and position in water objects.

In reality however, we need to think a little more about the practicalities of this scenario.

Proximity of Vessels

It is rare that operating vessels are so close together that they can benefit from the same seabed equipment. As a minimum all vessels requiring position must be situated within the transponder array. The simple solution to this problem would be to make the transponder array much wider, but this will then cause issues with ability to receive and disturbance of signals as they pass through the bubble cloud generated by vessel thrusters.

In reality a shared array is probably not a realistic practical option for a large area deployment for use by several vessels. It may however be applicable to a smaller area with close operating vessels e.g. an FPSO and Offloading tanker scenario.

Transponder Design

Transponders for DP applications are required to achieve maximum power output to surface and relatively low output power across the seabed for internal calibrations. In a large shared array scenario, the DP vessel is no longer the only user of the array and there will be other objects in the water column requiring position such as ROV's which require significant ranges across the seabed and minimal surface communications. Some transponders have been developed which have a switched beam which can be switched from super directional to horizontal using the acoustic operating system.

Geometry and Accuracy of Operations

A single seabed array may not provide sufficient positional accuracy for all tasks throughout the whole array area. For tasks which require high precision such as structure installation or jumper measurements, it is likely that additional transponders will need to be installed to improve geometry and positioning redundancy in the area of operation.

3. Allow positioning for a variety of targets

Any acoustic system must allow for positioning of a number of different targets that we are likely to encounter in an offshore environment. These include, but are not limited to, drilling vessels, construction vessels, survey vessels, seabed geophysical equipment, ROV's & AUV's.

Each vessel will have a slightly different requirement from a positioning system. For example, a drilling unit is most concerned with positional stability and repeatability over a small area at the surface whereas an AUV required accurate positioning over a wide area close to the seabed. The differences in requirements are too numerous to mention here and this in itself dictates that one single system, which will meet all of these requirements is the ultimate solution. In reality it is not possible for a dedicated field wide positioning system to meet these diverse requirements.

4. Be deployed and set-up from DP vessel.

Offshore vessels are required to operate in pretty much any geographic region of the world where there may be additional vessels or they may operate alone.

In order to ensure that a positioning solution can be provided it is important to ensure that the positioning system can be deployed and calibrated from the vessel requiring position. This places restrictions on the size and weight of seabed units and also on the calibration routine (if any) that the surface vessel will be required to follow.

Commercial Requirements

1. Maintain contractual independence between vessels

With current contracting methods, vessel contracts can be awarded in a number of ways. Essentially they will be awarded for a particular work scope or an extended contract, which covers several work tasks over a prolonged time period. Contracts may include the provision of acoustic positioning equipment, or this may be free issued to the contractor and purchased by the operator.

The nature of the contract with the end client is not necessarily an issue, but what could cause a problem is the contractual scenario if one vessel's activity disrupts the activity of another. For example an introduction of a drilling unit with a pinger based acoustic positioning system may prevent a construction vessel from commencing work due to the inability to obtain a position.

This type of scenario is a regular occurrence in current field developments with various downtime being accumulated between vessels and subsequently being apportioned to whomever is responsible. In many cases, this will be the client with whom you have a contractual relationship.

Another problem may arise if one contractor installs and calibrates a seabed array incorrectly. If another contractor then uses this system to install a structure which is installed in the wrong place due to the incorrect installation of the seabed array, the contractual chain is quite complex and several lengthy & costly contractual disputes would result.

It is clearly desirable with an acoustic system to ensure that we are developing positioning systems where downtime will not occur and we will not be faced with the task of apportioning downtime.

2. Maintain revenue stream for contractors

Everyone is in this business to generate profit. All companies are striving to maximize revenue that they generate from their assets. A drilling contractor has a prime asset in the drilling unit, but this is made up of several sub-systems which include position reference systems. The same can be said of the positioning contracting companies and construction contractors, where the supply of hardware is very important for revenue generation.

The removal of acoustic positioning equipment from a contract may seem insignificant in connection with a large drilling unit but it is fairly substantial with a survey vessel. If revenue from acoustic equipment is removed from some of these contracts then this will impact the ability for companies to complete the operation as they can then only generate revenue on people.

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3. Allow vessels to operate on worldwide basis

As detailed above, it is important to maintain systems, which can be deployed from any vessel anywhere in the world. This ensures that contractors are able to take up a contract at any location and operate with full capabilities and no reliance on third party services or hardware.

4. Minimise installation and set-up time

It is obviously desirable to minimize operational time required to set-up and install equipment. If we can get a vessel working sooner, we save time and money.

We need to be aware however that sufficient time must still be allocated to installation and set-up to ensure that we do not compromise system performance. There are numerous examples of operations which have been compromised by an effort to reduce time. This ultimately will cost contractor and operator money.

Conclusion

It is clear that current available acoustic positioning systems, although successful in stand alone operations are not able to operate in multi user environments. The acoustic architecture that they employ has a finite limit to the number of independent operations possible and current requirements exceed this. Additional channels cannot be squeezed from current systems any more than we already have. We must now re-design system architecture and take all of the requirements into account.

The deployment of a single seabed array for field wide positioning seems like an ideal solution in theory. This approach is usable for some applications but has several practical, commercial and performance limitations in a deepwater multi vessel field development.

Acoustic signal processing techniques continue to develop and will further enhance current positioning techniques and performance. Digital Signal Processing techniques will not be the solution for all problems. It is important to retain a tone burst capability in order that systems can revert to this reliable transmission technique in order that systems are able to perform in harsh environments. Any system employing Digital Signal Processing will require significant testing and validation in a DP environment to ensure that the detection of signals is reliable and robust.

The use of data from non acoustic sensors will also allow us to improve system performance and potentially reduce the volume of acoustic traffic in the water column. The true benefits of this integration has yet to be quantified. These techniques will require extensive testing and validation before they can be applied in a DP environment. A simple example of the investigation which is required is the question of INS data integration with other positioning sensors. Should this take place within one of the PME's or should this be a DP task and incorporated into the wider DP model?

Revolutionary approaches to the problem of acoustic pollution have raised awareness of the issues and forced all manufacturers to re-evaluate requirements and solutions. The most likely and most practical solution will probably come from the development of existing technology and a re-design of the acoustic architecture. This approach offers the least risk to operators and contractors and builds on existing equipment inventories with solutions based on sound technical and proven solutions.

Acoustic positioning systems are often given little or no attention in the planning and pre-engineering stages of field developments. This often leads to problems with acoustic interference as the interaction of vessels is not considered until it is too late and all that we can do is try to manage the problem. The reason that acoustic positioning systems receive so little attention is probably explained in the following table showing usage of acoustics in terms of field area, task duration throughout the 20 year life of a large development.

It is important to remember that although acoustic positioning systems may appear to be of little importance in a field development scenario, the lack of performance of an acoustic system can very quickly cost the contractor money and potentially delay the development and perhaps first oil. Hence, an ill thought out acoustic positioning system which fails to perform will very quickly find itself on the critical path.