Return to Session Directory

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SENSORS 2 SESSION

DP INS – A Paradigm Shift?

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Abstract

The concept of combining USBL and Inertial Navigation Systems (INS) into an alternative and improved DP reference has been discussed at length and is now proven and gaining growing acceptance. Following one year of DP-INS systems operating onboard vessels in the Gulf of Mexico and Brazil and this paper presents the real-world benefits in terms of risk and performance. The key benefits discussed include:

- *Independence from GNSS - the best method of detecting GNSS outliers*
- *Improved operational efficiency, the "Single" reference transponder can be dropped close to the well allowing drilling operations to commence significantly earlier.*
- *DP-INS repeatability has up to a three fold improvement over standard USBL*
- *Compared to multi-transponder seabed systems DP-INS allows the rig to save money on transponders and batteries.*
- *"Ride through capability" during acoustic dropouts caused by aeration and noise.*

The paper then discusses the lessons learned from offshore operations with INS and explains system configurations can be optimized to further improve the robustness and integrity of the position measurement equipment and how the wealth of additional, precise navigation information available from an INS presents new opportunities for PME integration into a DP desk.

The availability of INS derived pitch, roll, heading, velocity and acceleration measurements effectively "perfects" accuracy and complements the conventional DP model based estimator. Through better integration with the PME the complete measurement set can be used to improve performance of a future DP system. The benefits would include tighter and more robust control, reduced wear and tear and reduced fuel consumption.

Key challenges In Dynamic positioning

Traditionally, two PME types have been available for deepwater operations, satellite positioning and underwater acoustics.

Two or more DGNSS systems are typically used, usually manufactured by different companies and with differential corrections delivered by various means in order to claim independence. This approach leaves the system vulnerable to satellite signal systematic errors and signal outages originating from the GNSS space segment. Also, phenomena such as scintillation are known to disrupt GNSS and differential signals for long periods of time. As a common error source, disruptions can cause all DGNSS receivers to suffer systematic errors and outage. The GNSS segment is also affected by constellation changes, particularly when using reduced constellations as satellites are taken out of service at the end of their operational life.

L/USBL systems are highly repeatable and robust positioning systems. Although, acoustic signals can be interfered with by environmental factors such as aeration clouds, momentary increases in the noise level and physical masking.

However, despite the use of independent technologies and redundancy, DP systems are still vulnerable. A simultaneous bias in multiple DGNSS references can cause the DP desk to reject a single L/USBL reference telegram as the multiple DGNSS references will have a higher update rate and combined weighting in the DP model. Subsequent increase in thruster activity to regain position using the acoustic reference, can result in excessive noise and cavitation that degrades the performance The consequences of these combined effects has been attributed to DP incidents and highlights the need to improve the robustness of PME inputs.

An additional driver is the need to improve vessel efficiency with a faster setup time on location, without compromising safety.

Current State of the art

DNV rules for classification of ships require 3 independent PME inputs. GNSS provides a "hook in the sky", acoustic positioning provides a "hook in the ground" but the third reference is not readily available in deep water.

While not a completely independent reference, the combination of absolute positioning and INS does provide a complementary solution with some important advantages:

- "Ride Through Capability"- resilience to short term outages in the acoustic reference due to noise increase and aeration.
- Faster update rate (1Hz – 5Hz) and high precision improves DP weighting that increases the probability of detecting GNSS disruptions
- Another independent PME output for the same amount of seabed transponders.

When INS is combined with the acoustic reference the ability to detect anomalies in the DGNSS system is considerably enhanced and even prolonged periods where DGNSS is unavailable can be managed. Figure 1 below illustrates the system configuration of the Sonardyne DP INS system. DP-INS combines the complementary characteristics of USBL acoustic positioning and INS.

Complimentary Acoustics and INS

INS is extremely low noise and very accurate in the short term but inherently drifts over time. Acoustic positioning does not drift but is susceptible to short term increases in noise and aeration. Proper combination of USBL and INS captures and even enhances the positive characteristics of both.

DP-INS implements this principle using a Lodestar unit configured for Acoustically Aided INS (AAINS) operation. Lodestar AHRS (released in 2007) and Lodestar AAINS share an identical hardware platform custom built for tightly integrated marine applications.

DP-INS optimally combines the complementary characteristics of the latest Wideband acoustic signals with high integrity inertial measurements. It uses a tightly coupled integration of range and bearing from at least one transponder to aid the INS and control integration drift. This approach makes optimum use of Sonardyne acoustics to exploit and enhance the positive characteristics of the inertial sensors. The tightly coupled integration also ensures almost zero latency between the raw acoustic and IMU observations. The resulting output is resilient to acoustic disruptions and maintains independence from GNSS. This is shown in Table 1 and Figure 2 below

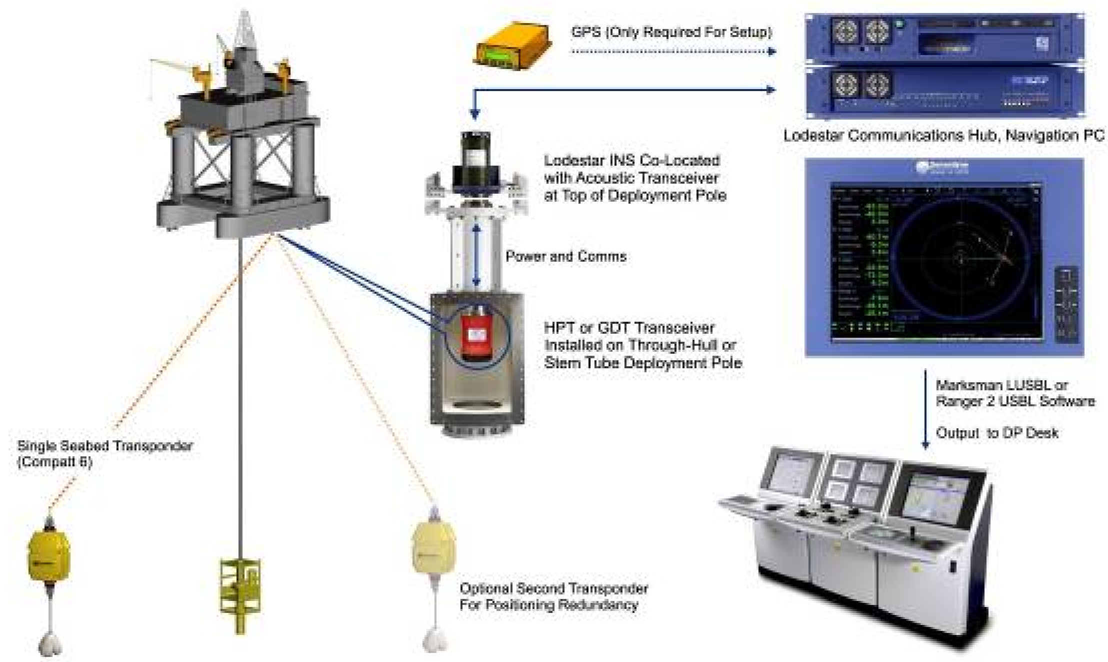

Figure 1: DP-INS USBL system configuration

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Complimentary Characteristics of Inertial & Acoustic technology		
	Acoustics	**Inertial**
Long term stability	Very good	Poor
Update rate	1-8s	Up to 200hz

Table 1 Acoustic and Inertial performance

A pre-requisite for a robust DP-INS solution is good underwater acoustics as this ultimately determines the system accuracy. Sonardyne's 6th Generation Wideband acoustics includes high performance transceivers with larger arrays and improved transducer design and signal processing to further improve on bore sight precision so critical to DP applications. Combined with wideband acoustics that put more signal power into the water the net effect optimizes the signal to noise ratio (SNR) and related precision, allowing systems to operate on noisy vessels.

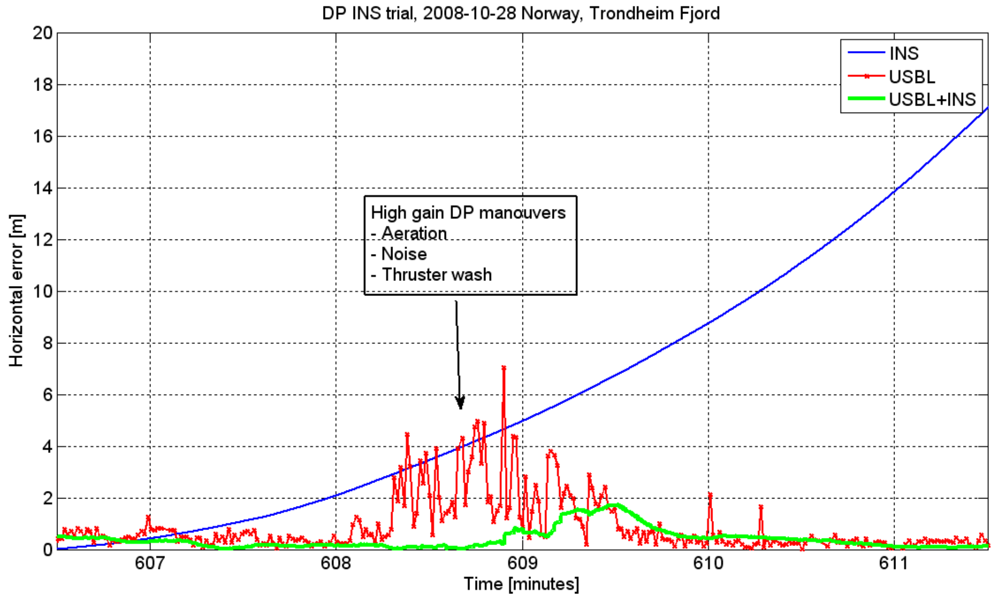

Figure 2 : Complementary characteristics of acoustics and inertial.

DP-INS Configuration

Various derivatives of the system configuration shown in *Figure 1* exist and flexibility needs to be offered to support the constraints of vessel retrofits and meet the requirements of different regional operators.

The system configuration in *Figure 3* is an example of how DP-INS can augment an existing dual redundant L/USBL system when the vessel has three deployment options. In this configuration the L/USBL system is unchanged and an independent DP-INS system is installed on a third pole. A Navigation Sensor Hub and PC running Marksman DP-INS software is installed on the bridge and a new interface connected to the DP desk. Subsea, the dual redundant L/USBL system will use a five or six Compatt transponder array whilst the DP-INS will make use of one or two independent seabed transponders. This configuration has the advantage of being low risk due to its simplicity and because the legacy L/USBL system is unaffected by the DP-INS installation. However, only a minority of vessels have a third deployment option and there are more cost effective configurations that do not require a complete new system and deployment machine.

The system in *Figure 4* shows an alternative configuration where the vessel has two deployment options. If an existing, dual independent or dual redundant L/USBL system is fitted then one of the systems can be upgraded to DP-INS using an upgrade kit. The Lodestar is mounted either to the deployment machine or to the pole depending on vessel configuration and connected to the bridge installation using separate cabling that is independent from the transceiver power and communications. The software on the bridge needs to be updated and will be configured for DP-INS use. Optionally an L/USBL vehicle position and an INS vehicle position can be output to the DP. If external gyro's and VRU's are connected the L/USBL solution will continue to operate in the unlikely event that the Lodestar INS should report a fault. Subsea, a traditional dual independent system requires two arrays. With DP-INS the seabed infrastructure is reduced as the INS solution only needs one or two references as an aiding input rather than a full array. In addition, the seabed references do not need to be interrogated as frequently as a standalone acoustic system which will extend battery replenishment intervals. Overall, DP-INS can reduce both equipment inventory and vessel operating costs.

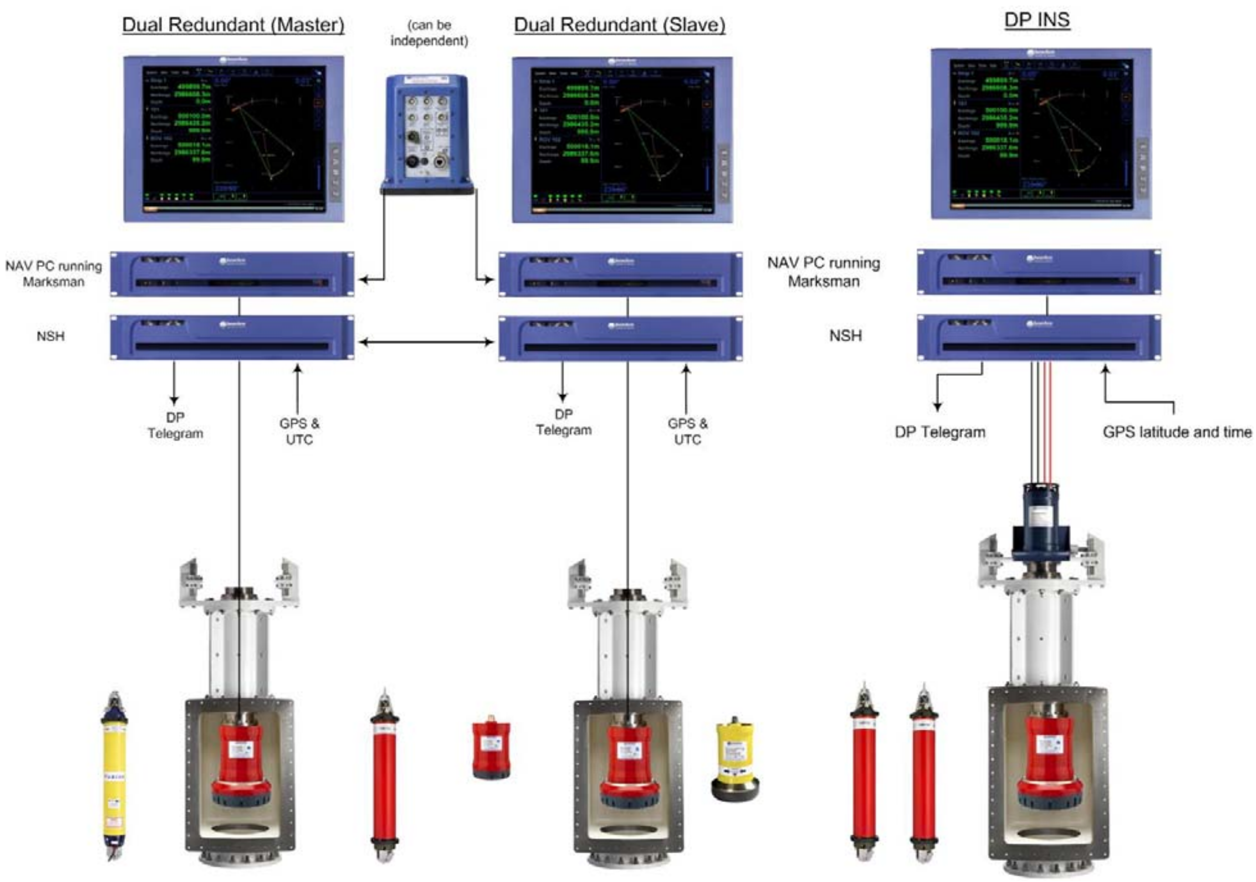

Figure 3 : System configuration with threes deployment options.

The figure shows an existing dual redundant L/USBL system on the left compatible with 5th generation hardware (yellow) and the latest 6th Generation (red). The system on the right is the DP-INS system installed on a third pole using 6th generation hardware and 2 seabed references (1 operational and 1 as a spare).

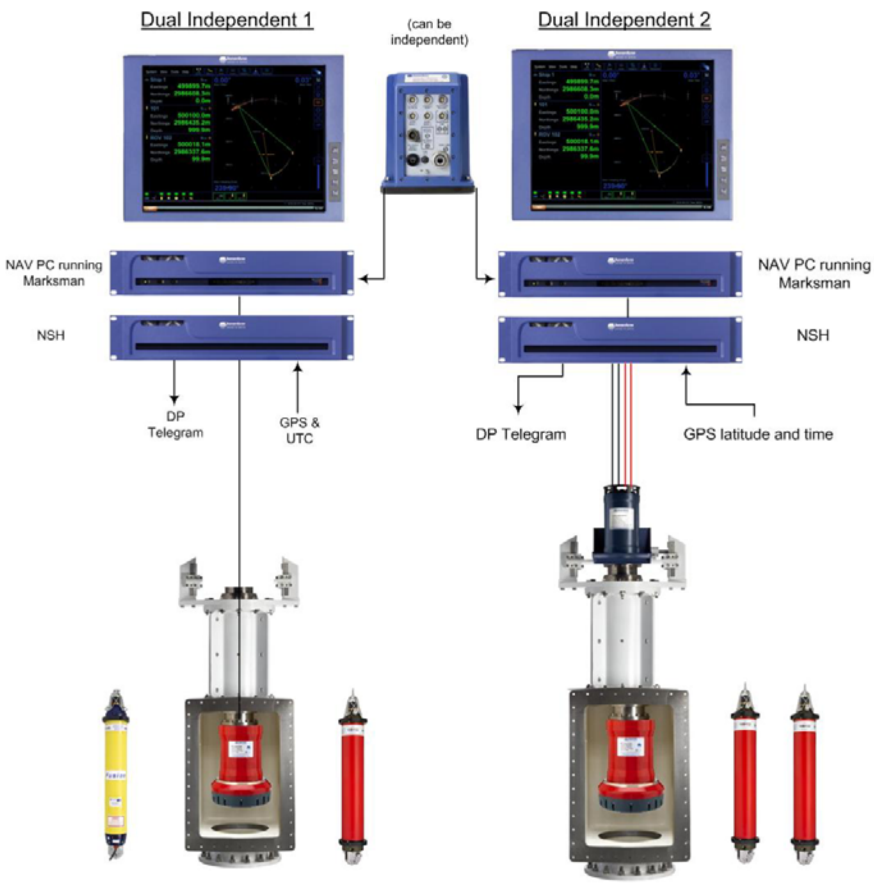

Figure 4: System configuration with 2 deployment options

The figure shows an existing dual independent L/USBL system compatible with 5th generation hardware (yellow) upgraded to DP-INS with the addition of a Lodestar and updated software. The system will fall back to the original dual independent L/USBL system using the external AHRS should the DP-INS system report a fault.

DP-INS Installation

It is important that the inertial and acoustic systems experience the same dynamic motion and therefore the Lodestar INS and USBL transceiver should be co-located on the same deployment pole, rigidly mounted to the vessel.

In the case of a vessel equipped with through hull deployment machines the Lodestar can be bracket mounted on top of the pole. Top mounting is the recommended method as the Lodestar INS remains accessible without compromising performance.

Where stem tubes are used a GyroUSBL transceiver is recommended. A Lodestar GyroUSBL combines a Sonardyne 6th (6G®) generation high performance HPT USBL transceiver and a Lodestar Attitude and Heading Reference System (AHRS) / Inertial Navigation System (INS) in the same mechanical assembly. This enables unparalleled precision and accuracy of position estimation by removing high and low frequency movement of vessel stem tubes during normal operations (this is discussed further in a later section). In addition, because many of the system parameters are now fixed, a full USBL calibration can be replaced by a performance verification check for some operations which can produce significant savings in vessel time and therefore operational costs.

The Lodestar and USBL transceiver are connected through to the bridge where they interface to a Navigation Sensor Hub (NSH). The NSH provides power and serial communications via a junction box at the deployment pole or machine. For the Lodestar, 1x CAT6 or better is needed for the INS comms and 1 copper pair used for power. For the USBL transceiver a second CAT6 is used for acoustic transceiver comms and a second copper pair used for power. The variety of new and legacy vessel types with systems installed highlights the need for installation flexibility. The system has been designed to minimize the requirements on ships wiring and to date, we have always been able to work with existing cabling.

On the bridge the NSH connects via an Ethernet link to a Navigation PC that runs Sonardyne's latest Marksman navigation software. The total height of the 2 units is 4U, and easily able to fit into a DP cabinet as shown in

Figure *5* below:

Figure 5 Bridge installation

The software in Figure 6 displays both the vessels L/USBL position and the INS position in an intuitive format alongside essential status information. The display gives the system operator access to all the information required to monitor DP-INS performance without significantly increasing their workload. The conservative tuning of the INS Kalman filter and built in redundancy of a parallel AHRS and INS algorithm allows expected accuracy to be computed and any loss of integrity identified. For example, divergence of the AHRS and INS computed roll, pitch, heading solutions will be highlighted on the user interface via the status indicators at the bottom of Figure 6 as well as in the DP telegram for display in the DP desk.

Figure 6 : L/USBL and INS vehicles available for use

The NSH provides output Telegrams compatible with Converteam, L3, Kongsberg and other DP systems. For example the HPR 418 BCD type 1 telegram is supported over a RS232 or RS485 link.

Real world Performance

Sonardyne DP-INS has been used operationally and accepted as "fit for purpose" offshore in Brazil and the Gulf of Mexico. In order to demonstrate the benefits to a major drilling contractor a Lodestar DP-INS was installed on a drillship in February 2011 and interfaced to the Marksman L/USBL topside hardware. One of the two existing dual independent L/USBL systems was upgraded to DP-INS with the Lodestar mounted on top of the deployment machine.

DP-INS outputs were made available to the DP desk and the series of trials conducted demonstrated that the system is suitable for operational use.

Figure 7 shows all PMEs receiving approximately equal weight in the DP desk apart from input A (GNSS-1) that was manually de-weighted by the operators . In the Figure input D (HPR-1) is the DP-INS input.

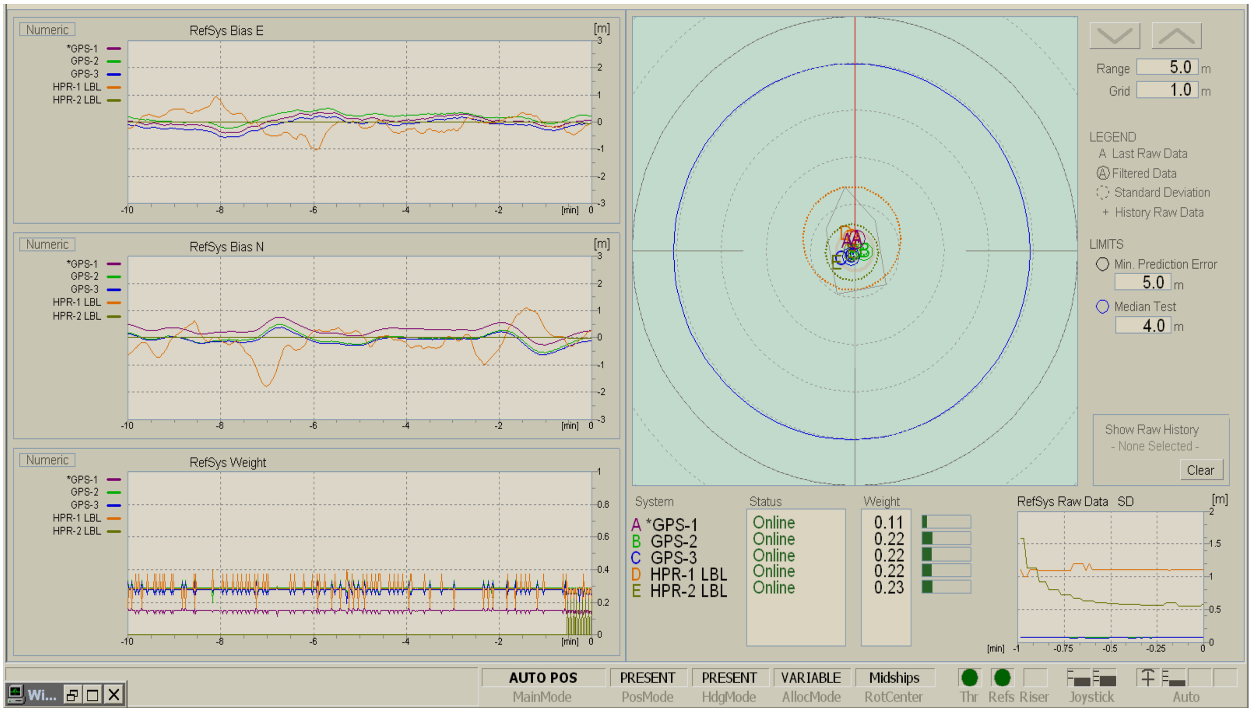

Figure 7 : All PMEs receiving an approximately equal weight.

The estimated accuracy of the DP-INS solution (difference from Veripos ULTRA GNSS) shown in Figure 8 was 0.93m 1DRMS over a long term test. Note that this figure includes errors from a GNSS system of decimetric accuracy and is not the absolute accuracy of the DP-INS.

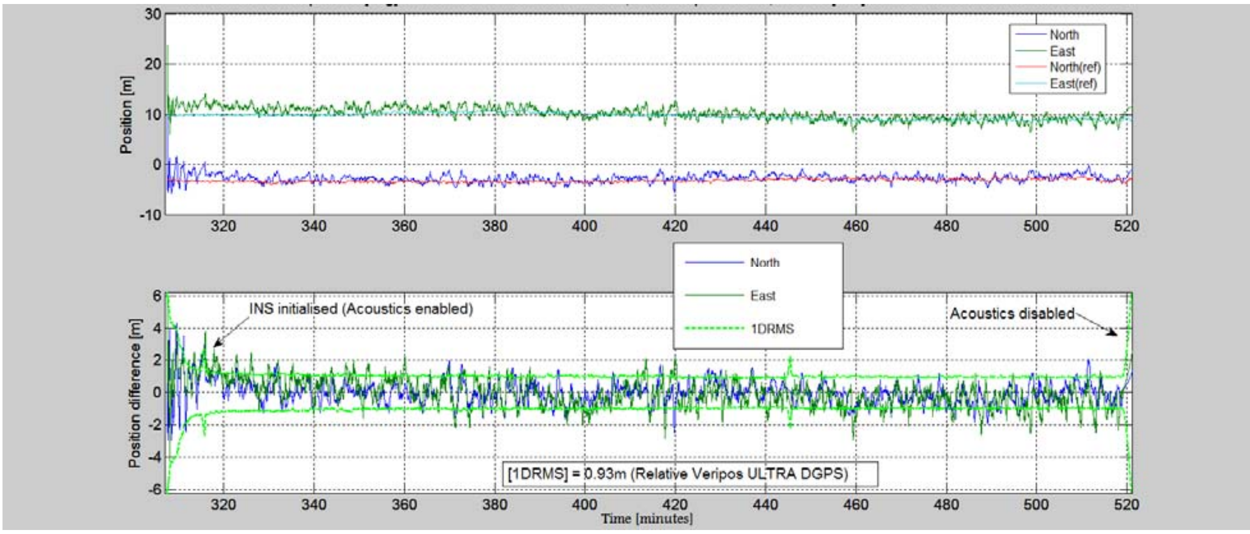

Figure 8: DP INS vs Veripos ULTRA GNSS

Figure 9 below shows the performance under a simulated GNSS outage. Two independent inputs are still available with the figure showing the DP-INS solution updating between L/USBL updates.

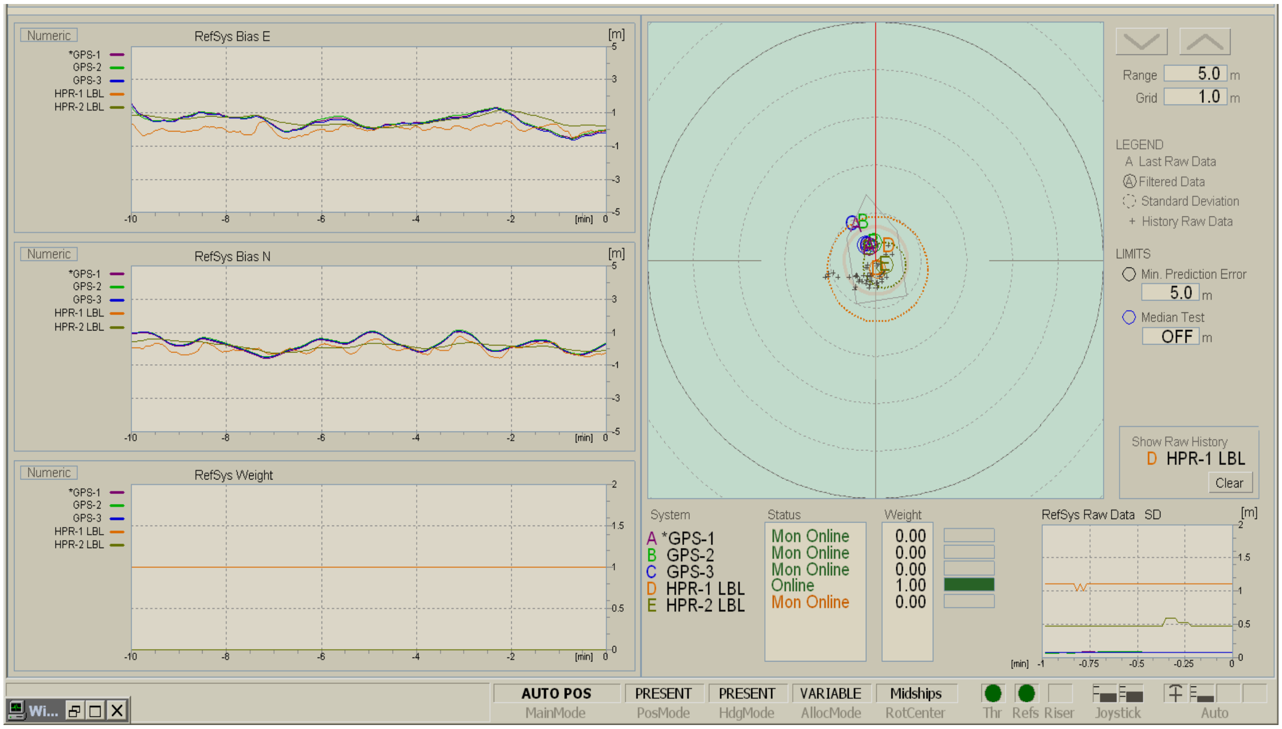

Figure 9: 2 Independent PMEs station keeping during simulated GNSS outage : DP INS (HPR1) and L/USBL (HPR2)

Operational experiences and Lessons learned

Sonardyne DP-INS has now had thousands of hours of running, analysis and tuning to optimize the algorithms and exploit the full performance and reliability from the system. This has been an essential part of the development, needed to give customers confidence the system is fit for purpose. Operationally, lessons have also been learned through real-world experience and reflected in the current design standard. The key lessons are discussed below.

INS installation

The significance of the inertial and acoustic systems experiencing the same dynamic motion has already been discussed along with the recommendation that the Lodestar INS and USBL transceiver should be co-located on the same deployment pole, rigidly mounted to the vessel. The result of a trial that highlights the importance of this is summarized in *Figure 10*. The figure compares the pitch and roll measured by a Lodestar on the bridge and a Lodestar co-located with the transceiver over a 1 minute period during a vessel maneuver. When thruster wash from a thruster 50m away is directed towards the transceiver, pole movement in pitch and roll is observed. The pole resonates in the roll axis at around 2Hz and exhibits a bias of up to 0.3 degrees in pitch which equates to 15m of position error in 3000m of water. Persistent biases such as this can be difficult to detect and will degrade the DP-INS performance. The results confirm that with stem tubes or over the side poles, fitting a GyroUSBL transceiver at the bottom of the pole is the best solution to correct for bending of the pole. However, when using a rigid pole through a deployment machine the Lodestar can be mounted at the top of the pole where the Lodestar is more accessible.

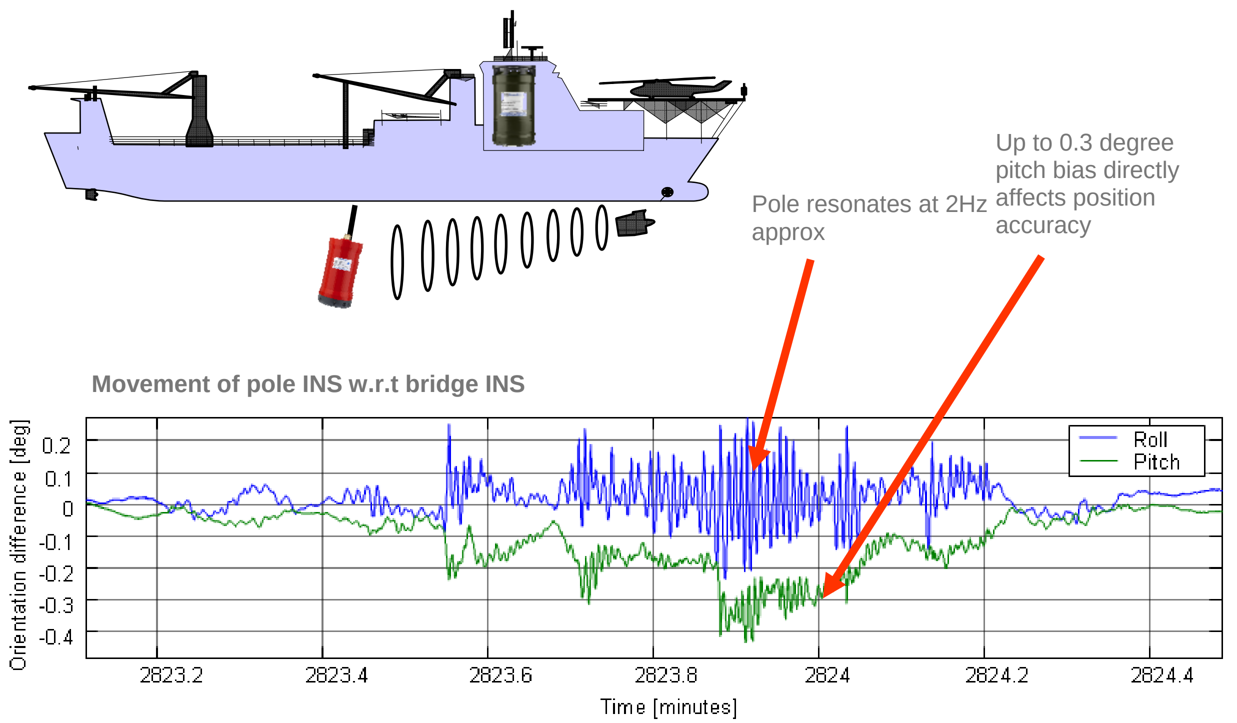

Figure 10 Movement of pole w.r.t. Bridge INS

DP telegrams

Due to the number of retrofits and upgrades DP-INS installations need to be compatible with existing interfaces to DP desks. The HPR 309, HPR 418 BCD and HPR 418 F output telegrams are all industry standard formats used by DP vessels for the transfer of Hydro-acoustic Position Reference (HPR) beacon data. NMEA output telegrams such as NMEA GGA are usually used for GNSS data. Most of these telegrams support position, velocity and attitude data with some level of QC information. These telegrams can therefore be populated with the DP-INS solution making integration of the new PME fairly straightforward. However, when using legacy telegrams for DP-INS, great care needs to be taken with the setup to make sure the QC is acceptable as the old strings don't support all the available DP-INS metrics. If DP-INS looses all aiding it will appear to drift slowly with a high degree of precision when only the position data is monitored by the DP desk. There a risk that the degraded performance goes undetected and if the input continues to be used, vessel positioning integrity could be adversely affected. There are a number of measures in place to prevent this happening:

- Position quality information can be transferred to the DP desk using a PSONDP extended message set that informs the DP desk when the INS is unaided by acoustics and when internal integrity checks fail, resulting in loss of confidence in the reported position error. Some major DP manufactures have already implemented this message.

- The position quality information, as estimated by the INS algorithms is intentionally conservative and has inherent integrity monitoring designed to detect faults. For example if the independent AHRS and DP-INS algorithms diverge in pitch, roll or heading the quality of the output can be flagged as degraded.

- The DP-INS user interface will immediately highlight system faults and alarm conditions will notify the operator that the position output is degraded.

Array design

DP-INS does not require a full seabed array and can operate with a single seabed transponder deployed directly below the vessel. It is recommended however that a second transponder is deployed and calibrated as a wet spare to provide seabed redundancy. Once deployed, the transponder absolute position can be established within a few minutes via a “topdown” calibration. Having both DP-INS and DGNSS almost immediately available at each new location can significantly reduce setup time. Where L/USBL is also used, the latest transceiver arrays, combined with Sonardyne 6th (6G®) generation wideband acoustics mean the transponder array can be deployed within the tether reach of the ROV avoiding vessel maneuvering and saving further operational time.

Deploying fewer transponders closer to the vessel not only speeds up deployment, it also improves performance. The acoustics are operating closer to the vertical, away from vessel noise sources when compared to wide area transponder networks where the acoustic line of sight is closer to the horizontal plane. With the vessel in full control of the array, it is able to optimize the positioning to suit its own, independent positioning requirements.

Future trends

Unlike any other PME type, DP-INS computes the full navigation state of the vessel including velocity and measured acceleration. For DP purposes the accuracy of this INS navigation data can be considered as a near perfect measure of true vessel motion:

- Position: Better than or equal to GNSS or acoustic positioning.
- Roll, pitch: ~0.01 deg and heading: ~0.05deg secLat
- Velocity (3D): < few cm/sec
- Angular rate (3D): < 0.001 deg/sec
- Acceleration (3D) << 2 mm/sec2 (fully compensated for gravity)
- Latency: < 1ms, Update rate: +100Hz, configurable

The availability of this robust INS navigation data including velocity and measured acceleration to effectively perfect accuracy may complement a conventional DP model and could thus provide a strong basis for improved performance of a future DP system including:

- Tighter and more robust vessel control
- Reduced wear and tear
- Reduced fuel consumption

Additionally, the tight integration of INS data may relax the dependence and accuracy requirements for hydrodynamic models within the DP as the INS navigation data is totally independent from, and will not be degraded by un-modelled external forces.

Sonardyne can provide the full INS navigation state data for use by a DP control system. A potential architecture for closer integration is shown for illustration in *Figure 11*.

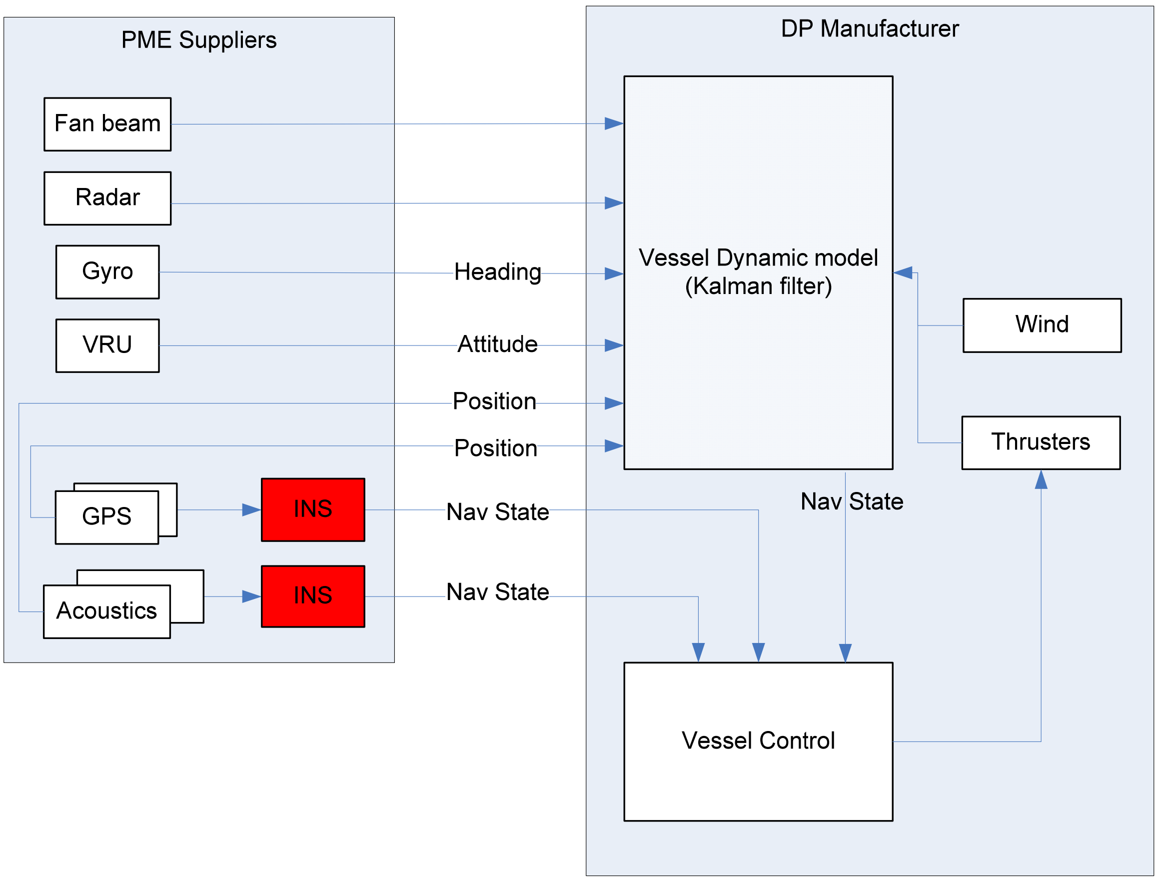

Figure 11: Candidate architecture for closer integration of INS

Conclusion

DP-INS is a complimentary system to existing PMEs that can be introduced with a low risk, evolutionary approach that does not replace or compromise existing systems. However, the combination of absolute positioning and INS provides some important advantages:

- When INS is combined with the acoustic reference the ability to detect anomalies in the DGNSS system is considerably enhanced and even prolonged periods where DGNSS is unavailable can be managed.
- "Ride Through Capability"- resilience to short term outages in the acoustic reference due to noise increase and aeration.

- Faster update rate (1Hz – 5Hz) and high precision improves DP weighting that increases the probability of detecting GNSS disruptions

- Another independent PME output for the same amount of seabed transponders.

Lessons learned after more than a year's operational experience have exploited additional potential and increased the performance and integrity of the system by paying attention to the following:

- The Lodestar INS and acoustic transceiver need to be rigidly mounted relative to each other to avoid errors due to pole movement.

- DP telegrams need to be carefully selected and configured to make sure metrics specific to INS operation are adequately reflected.

- Array deployment can be optimized to reduce the equipment inventory on the seabed, save operational time and improve performance.

The current state of the art DP-INS system paves the way for further operational improvements through working with DP manufactures to exploit the full potential of a complete INS measurement set. Using precise velocity and measured acceleration information it is possible to more closely integrate INS measurements into the DP desk and further improve vessel control which could reduce wear and tear, extend maintenance intervals and reduce fuel consumption.

In addition to the technical capability and engineering, adequate verification and validation facilities, support systems worldwide and training centers are an essential part of the success of new technology. The Sonardyne sea trials and training centre on the south coast of the UK, used for development trials and system acceptance, has been extended to include DP-INS. INS trained personnel offer 24/7 operational support from each local regional office and offshore support as required.