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New interfaces for aided inertial sensors

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Abstract

Current DP specifications often require GNSS and acoustic Position Measurement Equipment (PME) to be integrated with inertial navigation systems (INS) for critical DP operations.

Simply writing "INS" in a vessel spec does not guarantee the technology will deliver the accuracy, availability and integrity improvements the vessel owner / operator expects or reduce DP incidents as a result of PME equipment or human errors. These benefits can only be realised if the inertial navigation system is integrated with the DP and PME in a robust manner.

This paper firstly examines the limitations of previous generation aided inertial reference systems that are loosely coupled and use legacy DP telegrams to transfer data to the DP system. Next, a more closely coupled design is detailed where the PME and DP make use of additional data from a tightly integrated aided INS. New interfaces enable the PME and DP system to utilise the INS signals more effectively with improved fault tolerance and better diagnostics. Case studies are reviewed where the new interfaces are in use to show the operational benefits they can provide.

To conclude, usability improvements facilitated by the new telegram are discussed including how ease of use is maintained despite increased technical complexity and more meaningful diagnostic information and alarms can now be displayed in the event of system failure.

Introduction

Our ability to reliably position an offshore vessel has improved significantly over recent years due to advancements in the fields of acoustics, and GNSS. Inertial navigation has begun to show its value in this area, and as operators see the benefits, it is beginning to be mandated in critical operations; however, simply requiring an inertial input into the DP system does not guarantee the expected benefits will be achieved. As an example of a state of the art position reference system (PRS), the latest Sonardyne Marksman DP-INS acoustic inertial position reference is shown below in Figure 1.

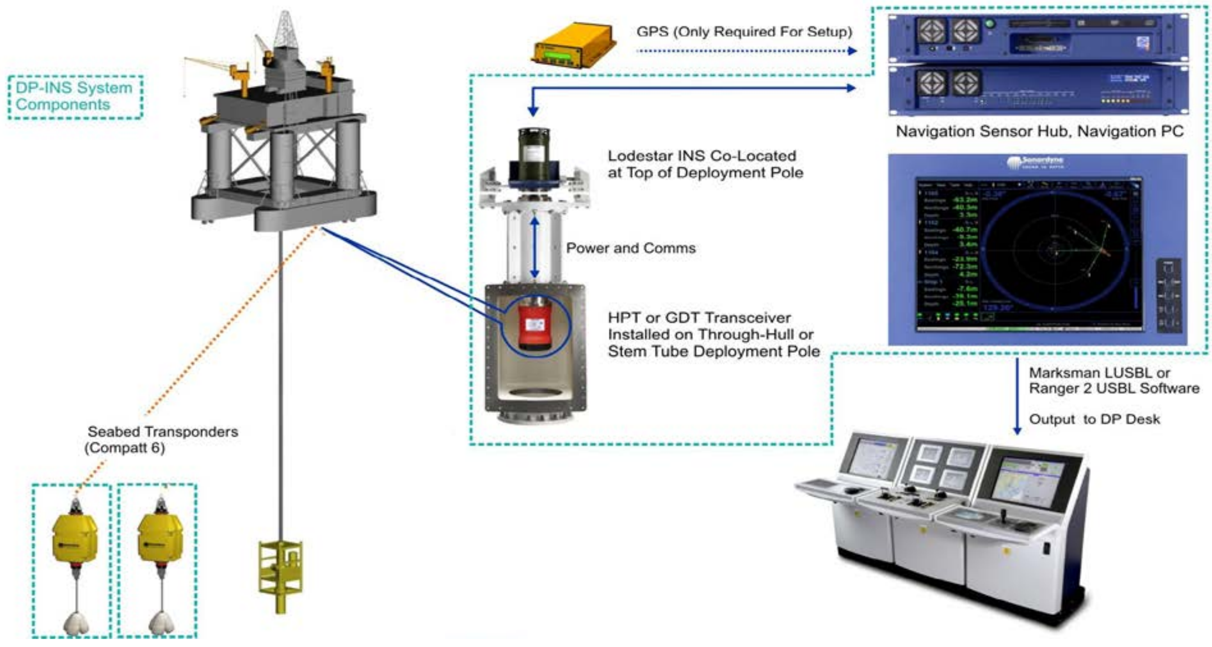

Figure 1 : Marksman DP-INS

It is easy when looking at a diagram like this to ignore the interfaces – they are represented by arrows – there are no pictures to latch onto, but they can be critical to how well as system actually works. A complex interface can be the source of significant problems.

At the heart of the Marksman DP-INS system is a tightly integrated acoustic-inertial navigation system (AINS) that provides accuracy, update rate, robustness and hence DP weighting that is on par with state-of-the-art GNSS (GPS) when operating within a conventional array of transponders. This increased performance can also be used to reduce the number of transponders and the acoustic update rate. This extends the battery life of seabed equipment and reduces operational cost by saving vessel time [1].

The HPT acoustic transceiver and seabed transponders in Figure 1 represent the latest in acoustic positioning performance. This acoustic positioning system is now more reliable than ever before due to Sonardyne's 6th Generation (6G) hardware and Wideband 2 signal processing that offers increased resilience to noise and multipath combined with greater positioning precision.

The advantages offered by systems such as Marksman DP-INS are evident on numerous vessels world-wide ranging from survey construction vessels such as the Oceaneering Ocean Intervention II to the latest generation drill ships such as Vantage Drilling's Tungsten Explorer where Marksman DP-INS has been operational for some time and results have been widely reported at previous DP Conferences [1],[2]. However, the full potential of these technological improvements to reduce vessel downtime and position measurement equipment (PME) related incidents are only achieves by careful attention to interfaces:

- Rigidly mounting the INS to the pole one which the acoustic transceiver is mounted guarantees the INS and transceiver experience the same motion.
- Interfacing acoustic measurements directly to the INS provides perfect timing, and quality of individual measurements.
- New telegram to the DP provides more data to allow the DP to monitor changes in reported data.

This paper explores the operational benefits of tightly coupled acoustic inertial references and focuses on the interface to the DP itself.

Tightly coupled acoustic inertial reference systems

The first generation of acoustic-inertial systems was loosely integrated. The INS would in principle simply be inserted between the acoustic positioning system and the DP desk in order to reduce noise, increase update rate and bridge brief gaps in acoustic positioning. The performance depended not only on the position being generated by the acoustic system, but also it depended largely on whether the telegram being used by the acoustic system supplied reliable quality metrics for use in weighting the data by the INS.

In the simplest of implementations the INS would have to battle significant amounts of (low pass) filtering and latency all of which are hard to mathematically/statistically quantify. With a good understanding of the specific acoustic system, this configuration could provide performance close to that of a tightly integrated system in the simple case of using a single transponder close to the vertical but only when the acoustic system was operating optimally. When the signals began to degrade they would have to be rejected to protect the inertial model. If this situation persisted then the output to the DP would begin to drift. The point at which the INS had to begin rejecting the acoustic position was often when the noise on the position changed; often the acoustic position data would still have been good enough for DP – which was not ideal in a situation where the DP was depending on the acoustic/INS system.

In a tightly integrated system the INS has full access to the raw acoustic measurements and the associated low level quality metrics in their native format with effectively perfect timing. This allows a much more precise and optimal use of the available information, which adds integrity and reliability, particularly in challenging acoustic conditions. Figure 2 below shows the functional difference between tight and loosely coupled.

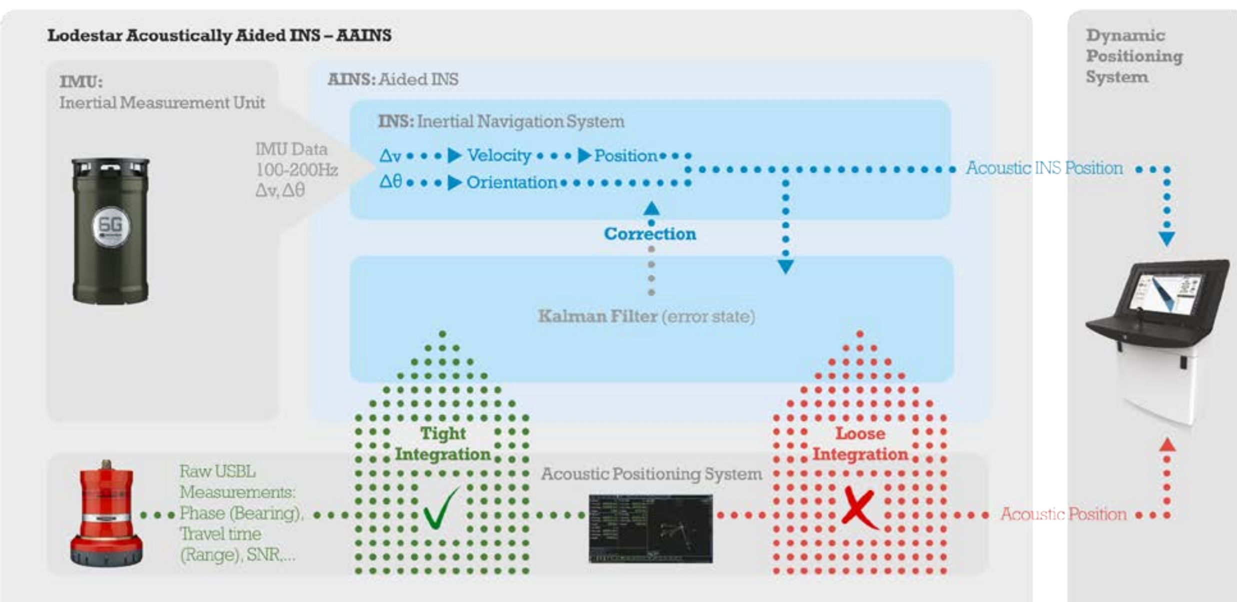

Figure 2 : Tight and loosely coupled architectures

In a tightly integrated solution the INS can model each individual measurement, and even use an individual range measurement, despite the fact that this would not be enough to compute an acoustic position by itself – this allows a tightly integrated system to continue operating in even the harshest environments long after a loosely coupled system would have lost integrity. Figure 3 below shows these performance advantages of a tightly compared to the loosely coupled solution.

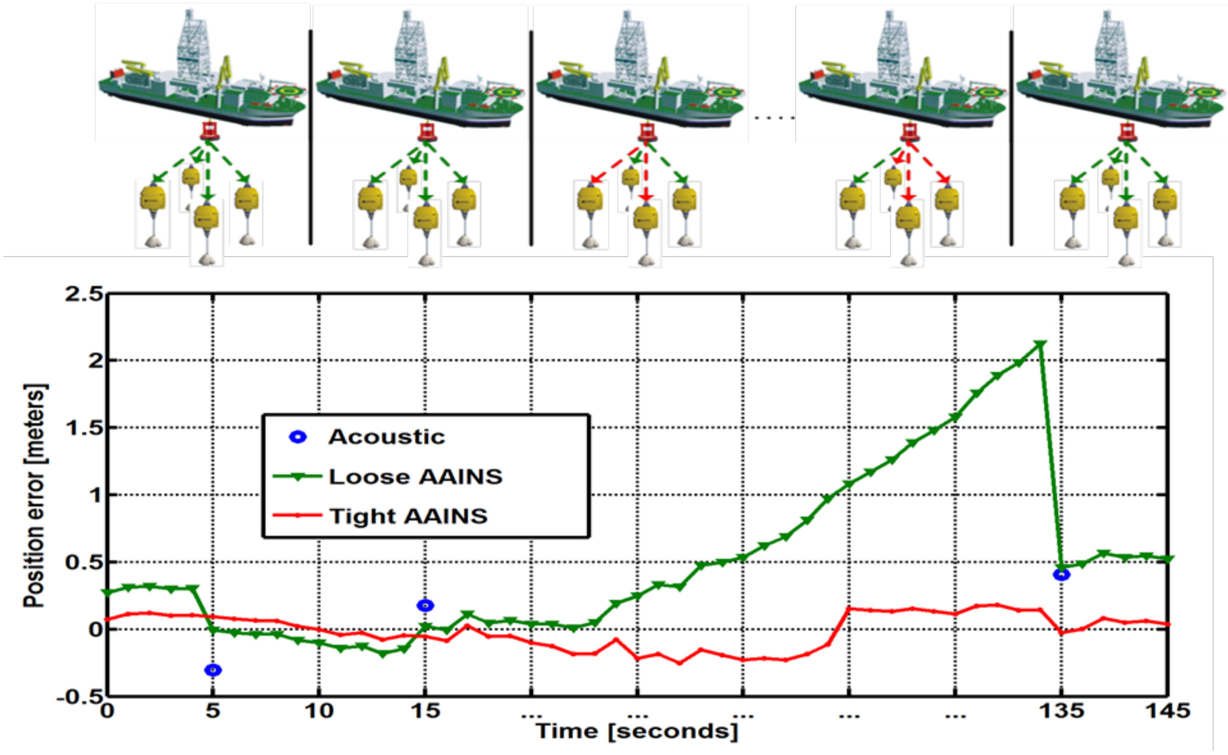

Figure 3 : Performance advantage of tightly coupled

Initially, replies are received every 10s from all transponders (green lines), but for a period of time some kind of interference (possibly noise of thruster wash from a workboat coming alongside) prevents 2 or 3 replies being detected (indicated by red returns). The loosely coupled solution loses aiding immediately, while the tightly coupled is able to maintain integrity using the remaining measurements.

Figure 4 shows a typical example of a problem from a system operating with 3 transponders in 2100m (nearly 7000'). At 10:36 there was a single fix in which 2 out of 3 expected replies were missed, and so the resulting acoustic fix degraded from LUSBL to USBL. The USBL position was 4m (13') away from the LUSBL position. This was a perfectly good fix, which can still be used to aid an INS, but conventional DP telegrams do not provide sufficient information to explain the change in quality of the fix, and so most systems would reject this fix. In a tightly integrated solution, the individual measurements are weighted, the acoustic geometry is fully modelled, and so the measurements are used as normal, and the blue DP-INS trace is totally unaffected.

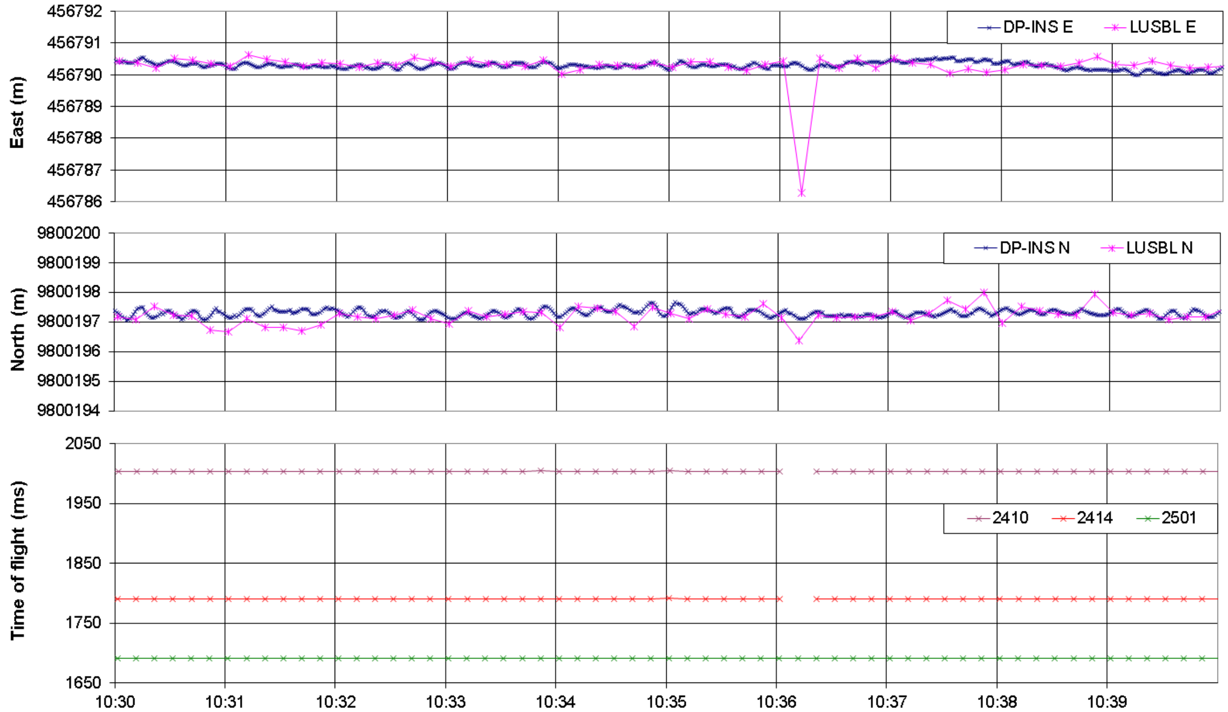

Figure 5 : LUSBL fix degrading to USBL

Accuracy

Accuracy, repeatability and precision are all terms that are used to judge the performance of a navigation system, and they are often used interchangeably. Accuracy is a measure of the error in position or the deviation of the reported position from the true position. However, real-time positioning systems have no knowledge of the true position so accuracy is reported as a statistical quantity associated with the distribution of the measurement errors. This is more correctly termed “repeatability” but the terms are often used interchangeably. Various terms are used to express the accuracy, each with a confidence level. Marksman DP-INS reports a distance root mean square error (1DRMS) or radial error at the 63% confidence level.

Figure 6 shows an alternative loosely coupled strategy in which the individual positions of 2 USBL transponders are used to aid the INS, rather than using the composite LUSBL solution from multiple transponders. The loosely coupled solution then is more robust as it has the ability to model each fix independently. The chart shows the difference in stability of the 2 systems when operating normally. In each case the data from the same 2 transponders is used. The first shows the result of using the USBL positions of the transponders, and the second graph shows the benefit from using the ranges and directions independently. The bright green shows the resulting 1drms figures. Clearly the tightly coupled solution is 2-3 times tighter than the loosely coupled solution. This benefit is achieved because the tightly coupled solution is still modeling the geometry of the ‘array’, and so is still able to get a geometric processing gain perpendicular to the baseline between the transponders.

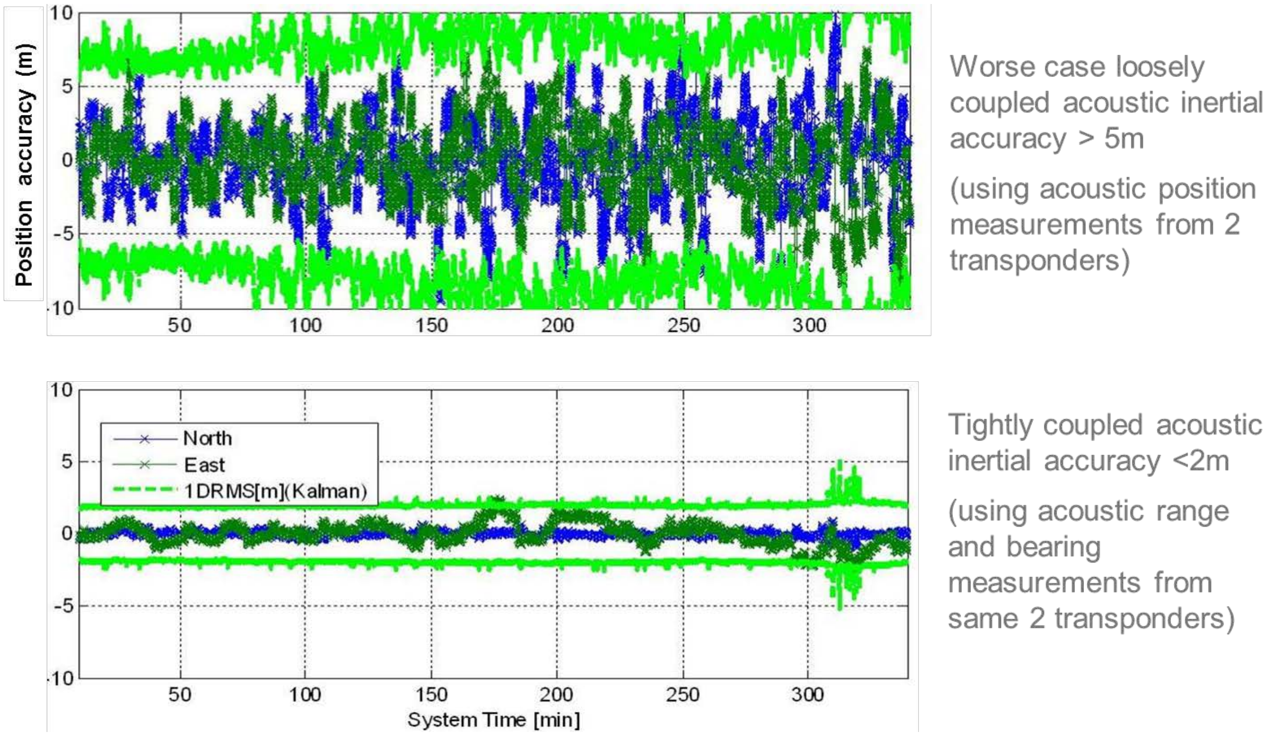

Figure 7 : Comparison of USBL aided loosely and tightly coupled performance

Figure 8 shows data from a deep water drillship operating in Asia in 1100m water depth and the typical accuracy achieved over a 30 minute sample period. The top chart shows the DP_INS position of the vessel compared to the GNSS. The lower chart shows the difference between the positions and also the computed 1 DRMS of the DP-INS with respect to the GNSS. It can be seen from the 1DRMS (bright green) that an accuracy of approximately 20 cm is achievable compared to a Precise Point Position (PPP) GNSS solution that has been taken as “truth”. The enlarged portion of Figure 8 shows close correlation between the independent Marksman DP-INS and GNSS solutions.

These results highlight the precision, accuracy and update rates achievable from Marksman DP-INS and the resulting resolution needed for DP telegrams to support these parameters in full when sending data to the DP system if performance is to be maintained.

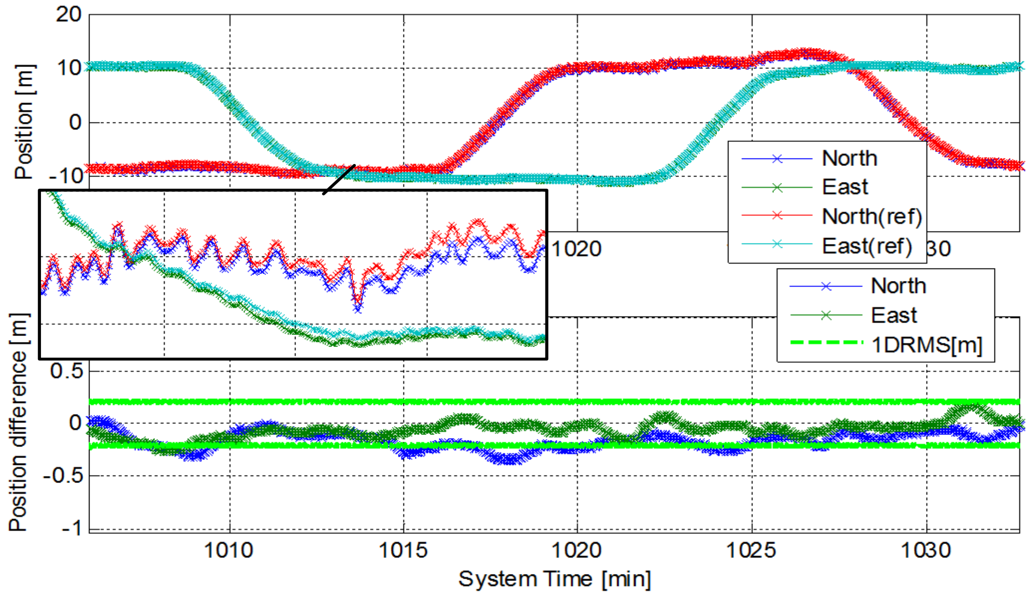

Figure 8 : Telegrams need to reflect the accuracy and Precision of systems such as Marksman DP-INS

Beyond Accuracy

Although accuracy is easy to understand it has some limitations as a metric for measuring navigation system performance in a DP context. In deep water a position accuracy of a few meters is often acceptable (based, for example, on riser angle tolerances) and the latest Marksman DP-INS systems are well within the accuracy requirements of today's specifications of typically between 0.2% and 0.5% water depth.

A second metric, as important to mission critical applications but often ignored, is the integrity of the navigation solution. Integrity relates to the level of trust that can be placed in the reported position and position error. If the reported error is less than the actual error then it can be said that there is a loss of integrity as the PRS is reporting misleading information. Maintaining integrity is key to the correct functioning of a PRS and DP system and has been at the forefront of the Marksman DP-INS design philosophy since day one.

Firstly, the 1DRMS error estimates associated with the position information reported by Marksman DP-INS are intentionally conservative. As can be seen in Figure 9, the 63rd percentile 1DRMS reported error (bright green line) is actually closer to the peak error when compared to a GNSS "truth" than the 63rd percentile.

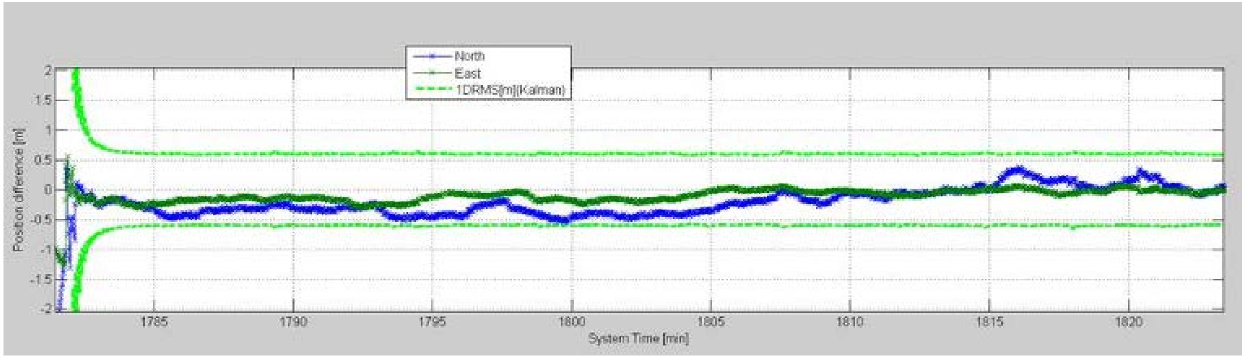

Figure 9 : Conservative error estimates ensures integrity

In order to maintain these conservative error estimates and therefore the integrity of the Marksman DP-INS solution it is important to correctly configure the Marksman DP-INS system by deploying enough transponders considering the criticality of the application and maintain an appropriate acoustic update rate. For example at least 3 seabed transponders are recommended with an acoustic update rate of at least 12 seconds to ensure integrity during drilling operations [1].

Secondly, Marksman has its own, inbuilt, integrity monitoring. One of the unique advantages of the Lodestar INS is the independent attitude, heading reference system (AHRS) and INS algorithms running in parallel within the unit. Both of these algorithms compute pitch, roll, heading, with the AHRS algorithm being extremely robust and immune to bias that can be introduced by external aiding sources. The difference between the two pitch, roll, heading calculations are continuously monitored in real time and any divergence is a potential indication of loss of integrity. A further check is the on-going monitoring of the gyro and accelerometer biases. Bias estimates that exceed fixed thresholds based on the gyro manufacturer's technical specifications could potentially indicate a loss of integrity or a hardware fault. The internal integrity monitoring can be viewed on the detailed diagnostic pages in some system variants as shown in Figure 10.

Alarms are automatically raised in the system where integrity is lost. Communicating loss of integrity to the DP system is another important parameter to be included in the DP telegram so that appropriate action can be taken.

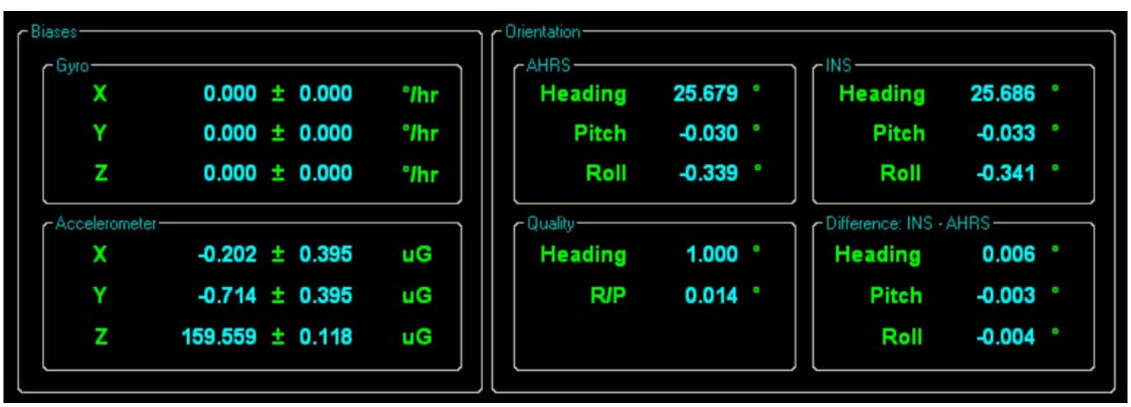

Figure 10 : Marksman DP-INS Internal integrity monitoring

DP System Interface

Due to the number of Marksman DP-INS retrofits and upgrades, installations need to be compatible with existing DP telegrams. Kongsberg's HPR418BCD and various other legacy proprietary NMEA style strings are commonly used by DP vessels for the transfer of data from the DP-INS to the DPS.

The legacy telegrams support position information and a basic indication of accuracy that can be populated with the DP-INS positon information making the integration fairly straightforward. However, when using legacy telegrams with Marksman DP-INS, great care needs to be taken with the setup to make sure the integrity is not lost as the old strings don't support all the available DP-INS metrics.

An example of where problems with legacy telegrams can arise is shown in Figure 11 using data from a deep water drillship operating in benign conditions. Due to the precision of the Marksman DP-INS system the reported position in the telegram is only changing by less than 1cm for several seconds. This can trigger “Freeze alarms” in some DP systems due to a legacy failure mode which was intended to protect the DP against a failed PRS outputting constant data, but are now being falsely triggered. As a result, some DP systems need to be reconfigured to expect this higher precision and update rate when the inertial reference system is added.

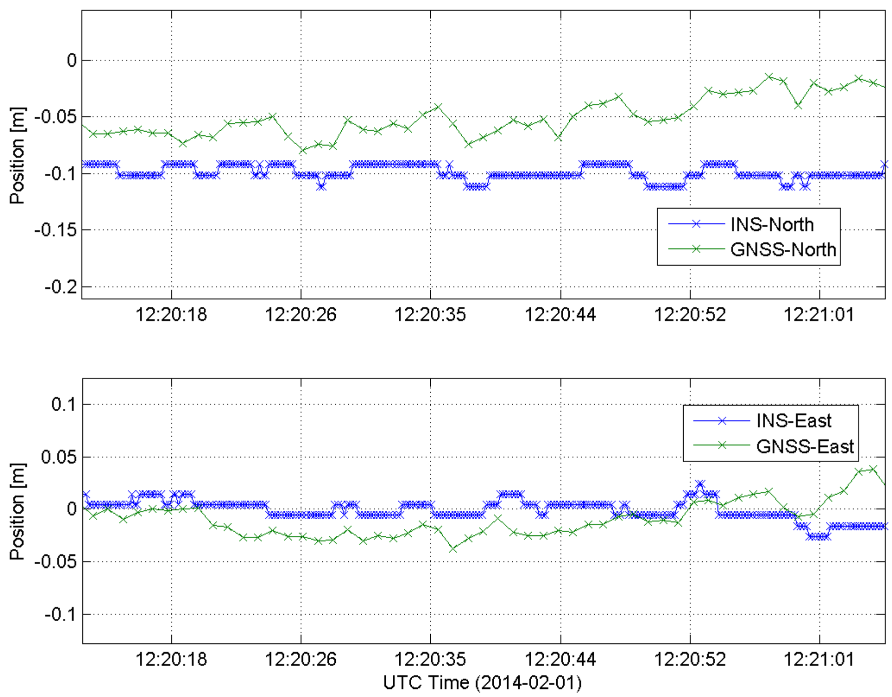

Figure 11 : INS position stability can cause "freeze alarms" in some DP systems using legacy telegrams

As well as supporting typical conditions such as those in Figure 8 the DP telegram needs to support parameters needed for more challenging operational conditions and cope with failure modes such as loss of aiding data to the INS.

It is well-known that an inertial navigation solution will drift with time unless it is constrained by aiding data [2]. In the event of loss of aiding data the reported 1DRMS error will increase with time even though the precision over a few seconds will initially remain very good. For this reason, it is important that the DP systems make use of the reported position error rather than internally computing the error from position alone with limited hysteresis. It is also helpful if the DP system has knowledge of the aiding source (L/USBL / GPS / None) and time since the last valid aiding update was received. A telegram supporting these additional parameters allows the DP manufacturer to implement logic to stop using an

INS based solution after INS aiding is lost for a period of time and display appropriate alarms to the DP operator.
Legacy telegrams designed before the introduction of INS offshore do not support these parameters so the same logic has been implemented in Marksman DP INS as shown by the alarms display in Figure 12.

Figure 12 : Alarms reporting loss of aiding and exceeding error thresholds

Although this approach is functional, improved ease of use as well as better engineering design (avoid cascading alarms) results if the DP telegram contains enough information for the logic in Figure 12 to be implemented in the DP system. The DP could then gradually reduce the weight given to the inertial position as the reported 1 DRMS increased, rather than applying full weight to the data up to the point that it is rejected.

The accuracy and integrity parameters discussed so far that need to be transmitted in a high integrity DP telegram are summarized in Table 1. The additional parameters, which are in addition to the basic position error, that are provided for optimum performance are highlighted. This information is at an architectural level and further work is needed with DP manufacturers to fully define this interface.

	Existing Telegram	High integrity telegram	Comment
Header	Y	Y	
Time	Y	Y	
Target ID	Y	Y	
Integrity	N	Y	PRS can flag loss of integrity
Last aided	N	Y	Time since last acoustic update
Position	Y	Y	Resolution to reflect precision of latest systems
Position error	Y	Y	Full error ellipse data used by the DP system to weight inputs
Depth	Y	Y	
Speed	N	Y	Speed information can refine control
Course	N	Y	
Speed error	N	Y	Full error ellipse of speed data.

Pitch	Y	Y	
Roll	Y	Y	
Heading	Y	Y	
Aiding source	N	Y	Check for unaided INS

Table 1: Definition of a basic high integrity DP telegram

Conclusion

As has been seen, when considering adding an INS to an acoustic system for use in DP, there are 2 important interfaces that must be considered, namely the interface between acoustics and INS, and then the interface from the INS to the DP system. The interface to the acoustic system will be specific to the measurements and timing of that system, whereas the interface to the DP needs to be more generic.

With good attention to detail the performance of the AINS can be similar to that of a good quality GNSS, with improved weighting of the acoustic data in the DP, and greater robustness. The AINS data, however, cannot be considered to be independent of the aiding data, and so it is important to add protection to pevent both the acoustic system data, and the AINS data both being sent to the DP at the same time, otherwise there is a risk of artificially increasing the weighting given to the acoustic data, and potentially 'out-voting' other inputs to the DP.

Cost savings are achievable using AINS because the number of transponders that need to be deployed can be reduced, and in situations where dual independent acoustic systems are used, even greater savings can be achieved by using transponders that support multiple concurrent users so that arrays can be shared.

Using improved telegrams on the interface to the DP provides more data, as well as better metrics to allow the resulting data to be monitored, and used more effectively.

References

[1] Tightly Integrated Second Generation Acoustic-Inertial Position Reference System - Deep Water Operational Results, Mikael Bliksted Larsen, Sonardyne International Ltd, 2013

[2] DP INS – A Paradigm Shift, Mark Carter, Sonardyne International Ltd, 2011