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**SENSORS I SESSION**

# Acoustic INS Integration – The Options, Challenges and Benefits

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# Acoustic INS Integration – The Options, Challenges, and Benefits

## Introduction

In recent years, inertial navigation systems (INS) have become increasingly used in the offshore industry, both for subsea applications and for Dynamic Positioning. The pedigree of the systems generally is unquestioned, with decades of use in the aeronautical industry proving their reliability. As standalone sensors for DP applications, their use appears to be limited, providing only relative positions and movements with a high degree of inaccuracy over time. However when combined with other types of sensors, such as GNSS or acoustic positioning systems, INS can provide a valuable benefit to both quality and reliability of positioning.

One of the main attractions to combining sensor types is when complementary characteristics are present, allowing the weaknesses of each sensor to be compensated by the strengths of the other.

From a positioning perspective, the characteristics of acoustics are potentially accurate but imprecise positioning, with little change to this over time other than variations caused by environmental change. In contrast, INS offers excellent short term stability and extremely high update rate, with the limitation being that the sensors are subject to drift which means low accuracy in the longer term.

Combining the two systems should allow the high precision INS to be coupled with the long term accuracy of acoustics, as well as reducing the impact that environmental effects, have on positioning quality.

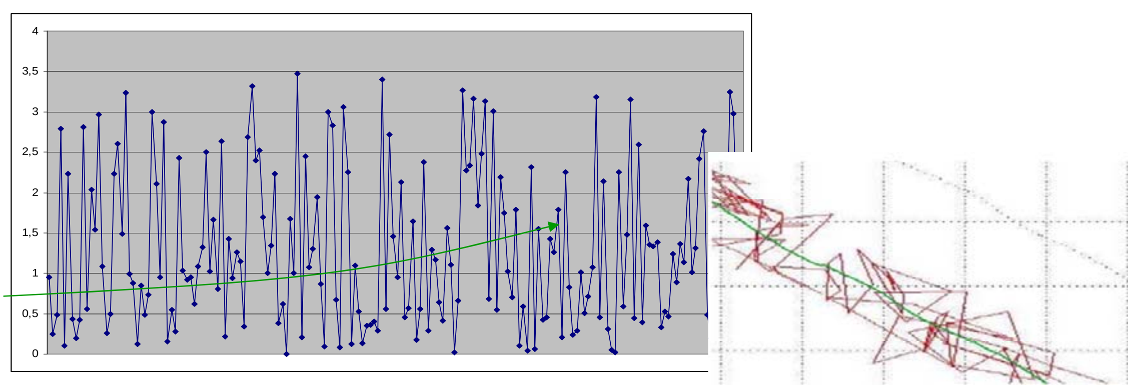


*Figure 1 – Raw acoustic versus acoustic aided INS data*

From a DP sensor view, the positioning provided by an acoustically aided INS should be of a quality comparable to high DGNSS with the significant benefit that the solution is immune to radio signal interference such as that caused by solar activity and the resulting ‘scintillation’ effects.

This paper discusses some of the options and challenges of integrating acoustic positioning systems with INS, drawing on experiences from the coupling of Nautronix NASNet® and IXSEA PHINS.

## General Integration Challenges

When providing 'aiding' to an INS the term usually relates to observations or computations which could be used to derive position, or a component of position. Simply put we are providing either positions, or the raw data used to calculate positions, to the INS which is using this information to constrain the errors in its own sensors.

In turn, the INS is comparing its own estimation of its position (derived from accelerometers, gyros, and previous aiding data) with the received data and if necessary rejecting any poor quality data.

There are of course many aspects to be considered when pairing an established acoustic positioning system and an established INS to hopefully provide superior results to either of their standalone performances

The first consideration is the source of the combined position solution – is acoustic data going to be provided to the INS, or vice versa? Or will both acoustic system and IMU hardware provide data to a '3rd party' computation solution. This to a certain extent depends on the connection between and the expertise level of both the systems.

Generally, an acoustic system is not designed to integrate inertial data which comes at extremely high data rates and requires sophisticated processing algorithms. It is more common for integration and calculations to take place in either the INS unit or a separate computer.

Most INS, due to their need for aiding sources, already support multiple standard input types and this was the case with PHINS, which carries out the position solution internally (as opposed to requiring a separate topside for calculations).

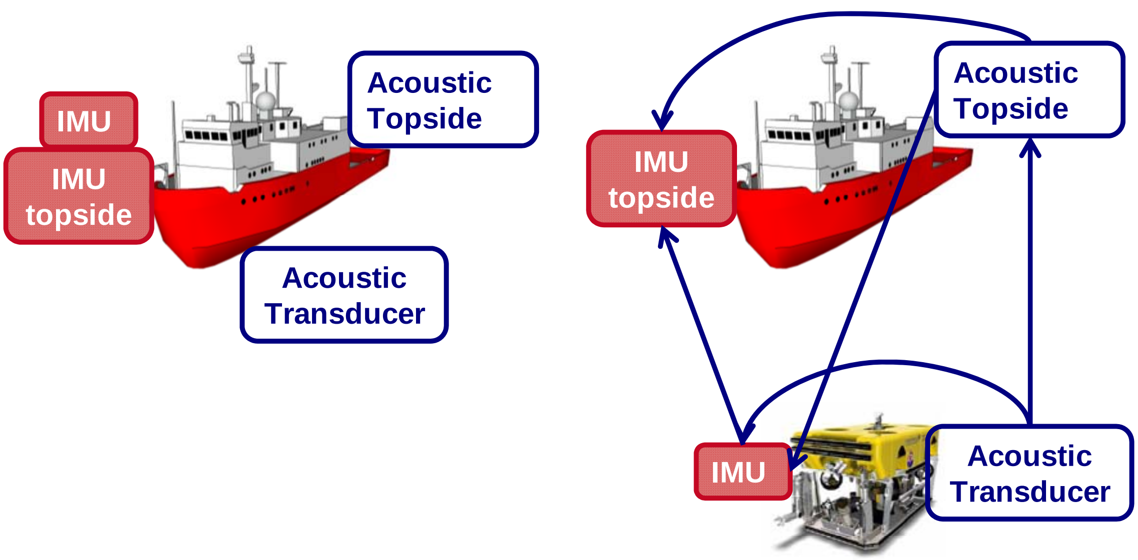


*Figure 2 - Physical Interface Options*

## Aiding Data

The next point is to decide what data is actually going to be provided. This in itself breaks down into different levels, from choosing position aiding or raw data aiding down to the nuts and bolts of the actual format of data string used.

### Position Aiding (Loosely Coupled)

The simplest approach is to provide position aiding – meaning that a series of acoustic observations are collected and used to calculate a purely acoustic position. This position is then provided to the INS which uses it to aid its inertial observations and generate a combined solution. In this mode, the INS is really acting predominantly as an expensive and sophisticated smoothing filter for positioning, while filling in the gaps between acoustic position updates with inertial data.

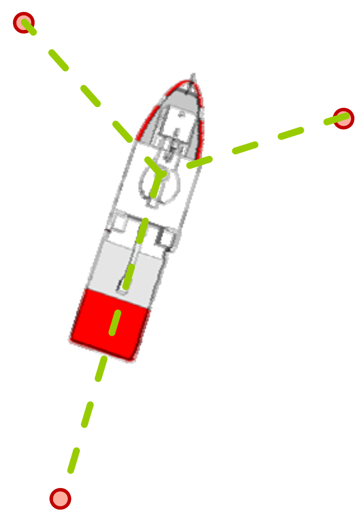

*Figure 3 – Position Aiding (minimum 3 ranges)*

The advantage this has is that has in deep water an acoustic system which is providing relatively slow and imprecise (jumpy) positioning can provide higher quality data, when combined with INS, in terms of stability and update rate. This increases the viable operational water depth for vessel based acoustic systems in DP applications.

Generic position aiding can be implemented most simply by the use of a standard interface string. For instance by using a NMEA GPGGA string (a standard GPS output) virtually any INS will be able to decode the position data. Where things become a little more complex is how the INS treats the data, and to what level it trusts it.

The judgment of the accuracy of received data by the INS is largely dependent on the QC information included with the positional data. This can pose potential problems when using a string not specifically designed for the purpose. For instance the GPGGA string is designed for transfer of GPS information and the quality information is suited to this purpose, although somewhat limited. It is not ideally equipped for transferring acoustic quality information and is therefore a compromise between ease of interface and optimisation of data provided.

The GPGGA quality information does not include estimation of position accuracy and so an INS or DP system may be set to base acceptance criteria on 'typical' expected GPS accuracy and update rate.

A GPS typically provides a high stability output at 1 second interval with accuracy of between 0.1 and 1m and so these might be reasonable values to use.

An acoustic system generally has quite different properties and therefore for the INS to use the same judgement criteria would be misleading, potentially resulting in high levels of rejected data and a suboptimal solution. This can be the scenario if we use, for example, the GPGGA string and the INS treats typical acoustic data (with an update every few seconds and an accuracy of several metres) as if it were GPS data.

This problem can be solved through specific position aiding, whereby a dedicated string is defined to include sufficient quality information to allow the INS to make informed judgements about the quality of received data. This quality judgement can be made based on the acoustic position calculation, with estimation of accuracy typically being based on error ellipse statistics, position geometry, and/or residual values.

### Observation Aiding (Tightly/Closely Coupled)

Observation aiding involves the provision of raw data observations to the INS, which then uses these in conjunction with the inertial data to compute a combined solution. For instance in an acoustic Long Baseline context, raw data observations would comprise of ranges (distances) from the vessel to the various acoustic beacons in the array. Taking this one step further could mean providing TOF values with the speed of sound in water being applied within the INS.

Observation aiding for LBL provides advantages when a reduced number of ranges are available, whether by design or not. A reduction in available ranges might be caused by objects in the water column obstructing signals, acoustic noise, or a reduced number of deployed transponders.

In a purely acoustic LBL solution, ranges from a minimum of 3 beacons are needed to generate a position. Should less than 3 ranges be received then no LBL position can be calculated and, if in position aiding mode, no aiding can be provided. This means that the drift of the INS is unconstrained and significant position errors will occur within a few minutes.

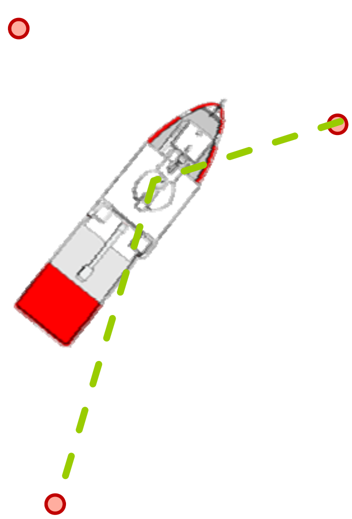

*Figure 4 – Range Aiding*

However if the same scenario occurs when observation aiding is being used then even ranges from an single beacon provides some constraint of the INS errors while ranges from 2 beacons combined with INS can provide reasonably reliable positioning.

## Weighting

Weighting is the method used to reflect the expected quality of the data provided by the acoustics and the inertial sensor when a position is calculated. A high weighting factor identifies data as being of a higher quality and therefore biases the solution towards that data. Weighting is an integral part of Least Squares Adjustments, and hence Kalman filters which are used within the calculation process. For an optimal positioning solution to be achieved it is important that the weighting factors used reflect the quality of the observed data as accurately as possible. As a very basic example an acoustic range which is in error, but is allocated a high weighting, will have an adverse effect on the generated position.

Depending on the type of aiding, the quality of the acoustic data can be easy or difficult to establish. Position aiding, as earlier mentioned, allows an estimation of quality to be determined from the acoustic position calculation, with an initial level of QC and automatic error rejection having already been carried out within the acoustic system. This estimation of accuracy can be provided to the INS which can then assign an appropriate weighting relative to the accuracy of the inertial observations.

The main issues in assigning data quality arise with observation aiding. In this case, a measurement is made and provided to the INS – there is no position solution to assist with identifying errors or assessing accuracy. In this situation, the expected accuracy has to be estimated based on predictable values. For an LBL solution, the estimation of range accuracy could be based on the box-in accuracy along with a proportionate error due to sound velocity inaccuracies applied to the range. Signal to noise ratio also has an effect on the detection accuracy, but one which generally pales in comparison to the other error sources.

It is then solely up to the INS to QC the acoustic ranges against inertial observations and carry out range rejection based on the respective weightings and the modelled motion of the vessel, through a Kalman filter.

## Specific NASNet® INS aiding Challenges

The use of NASNet® as an acoustic source to aid INS has been considered over the last couple of years and an interface has now been implemented between NASNet® and the PHINS inertial system. The following section explains some of the specific considerations and approach taken to complete this process.

The use of buoy mounted transmitters provides an additional factor to NASNet® when considering interfacing with an INS. For position aiding there is no issue – the movement of the buoys is tracked and corrected within NASNet® which then outputs a corrected position. As such, the INS has no need to know the source of the raw range data.

*Figure 5 – NASNet® Buoy Movement*

The requirement for this knowledge arises when observation (range) aiding. As distances are provided it is obviously a requirement that the source of the range is known. For frame mounted transponders this is not an issue – their calibrated locations are known and can be entered into the INS or topside software. For NASNet® the location of the buoys is not fixed and so the updated positions must be provided and accepted by the INS.

The interface format chosen to provide NASNet® range data to PHINS includes the geographical location of the range source on each data telegram. NASNet® therefore applies the latest value to each telegram for the appropriate buoy, as well as the measured range from that buoy to the receiver. This capability is not supported by all INS systems but is essential to be able to observation aid from NASNet®.

NASNet® offers a simpler interface in terms of latency than a conventional two way travel time system. This is primarily due to the removal of latency from the range measurement. The one way signal is correct at the moment of reception while a two way signal has a latency which varies with the distance to the transponder.

Sound velocity is critical in the measurement of acoustic ranges and two methods were assessed for use within this application. These were either to apply the sound velocity within NASNet® and provide distances to PHINS, or to input acoustic travel times to the PHINS and apply the sound velocity therein.

The decision was taken to apply SV within NASNet® due to its more advanced SVP handling capabilities, producing consistently accurate ranges. PHINS uses a single sound SV value for all ranges but using a single averaged SV value in deep water is only valid if the depths of all transmitters are the same and the receiver depth remains constant. For DP applications, the difference is likely to be small, however for purely subsea applications there can be a significant variation and so the more accurate method of applying the relevant section of the SVP to each range was adopted within NASNet®.

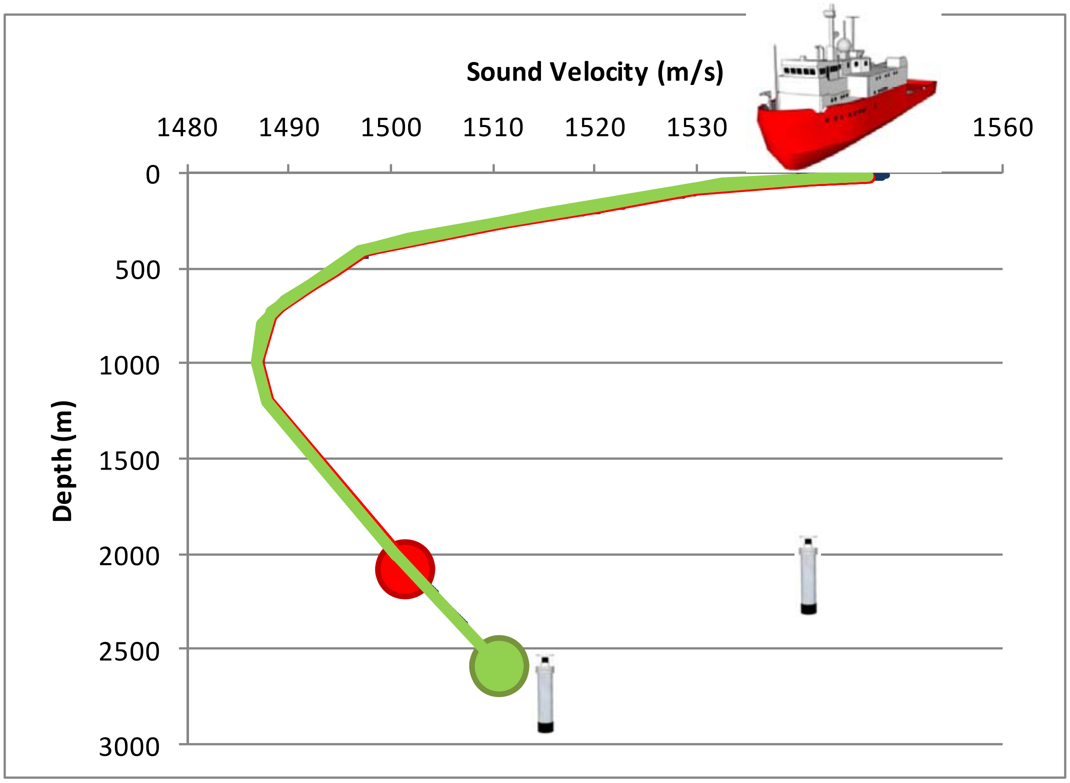


*Figure 6 – SVP variation for different Station elevations*

NASNet® receives ranges continuously and provides each range to PHINS as soon as it is received. PHINS uses a 4 slot approach for ranges, meaning that only 4 acoustic ranges are used in the combined solution at any time. For use with a conventional LBL system, this provides some limitations, as ranges are collected in a cycle, and then provided all at the same time. More than 4 transponders being used simultaneously provide no benefit.

When aiding with NASNet® the 4 most recently received ranges are used and therefore using more Stations provides a faster supply of ranges, improving the aiding quality.

## Summary


The use of INS with acoustic positioning systems, particularly in deep water, can provide an improvement in stability, reliability and position update rate.

It is relatively easy to establish an interface between an acoustic positioning system and an INS. However to optimise the positioning quality and reliability of the derived positioning an interface specific to the acoustic system should be considered. At a minimum, the interface should include sufficient QC parameters reflecting the quality of provided data to allow accurate use by the INS.

Acoustic position aiding of an INS provides undoubted benefits but, where possible, observation aiding provides a greater degree of flexibility and robustness. This is due to the ability to aid even when limited acoustic data is available (which may prohibit position aiding) as well as being able to compute a combined solution based on all raw data, rather than a derived or filtered subset from an acoustic system.