



**DYNAMIC POSITIONING CONFERENCE**  
**October 9-10, 2007**

**Sensors**

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**Hydroacoustic Aided Inertial Navigation System  
- HAIN A New Reference for DP**

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## **Abstract**

No one disputes the statement "A Dynamic Positioning (DP) system can never become better than its references".

Automatic control of a vessel's position in a critical operation or location requires good redundancy of all the control system components. Whether it is a vessel's position extremely close to a fixed platform, or a construction platform vessel for a critical deep underwater installation, it will require automated, accurate and controlled position keeping.

A DP system is a controlling computer that feeds the thrusters and propellers with accurate signals of power required to hold the position of the vessel, or moving it in a controlled fashion from one position to another, in any environmental weather condition. The DP cannot function without input from position reference systems and operates often with many such systems in an integrated solution.

Each position reference system contributes by sending its present logged position data to the DP. Each reference system has different characteristics of strengths and weaknesses. They are often classified according to how stable they are in position accuracy, position deviation and position update rate.

There are many position reference systems available in the market, but when a vessel is alone in the open ocean a long way from shore it is only the satellite based Global Positioning System (GPS) and the seabed transponder based Hydroacoustic Position Reference (HPR) that can give reliable reference positions.

This paper focuses on the challenges of classifying, or weighting, the HPR to the same level as GPS in the DP algorithm, and data examples from deepwater operation will be presented.

## **Hydroacoustic Aided Inertial Navigation - HAIN**

### **A new reference for DP**

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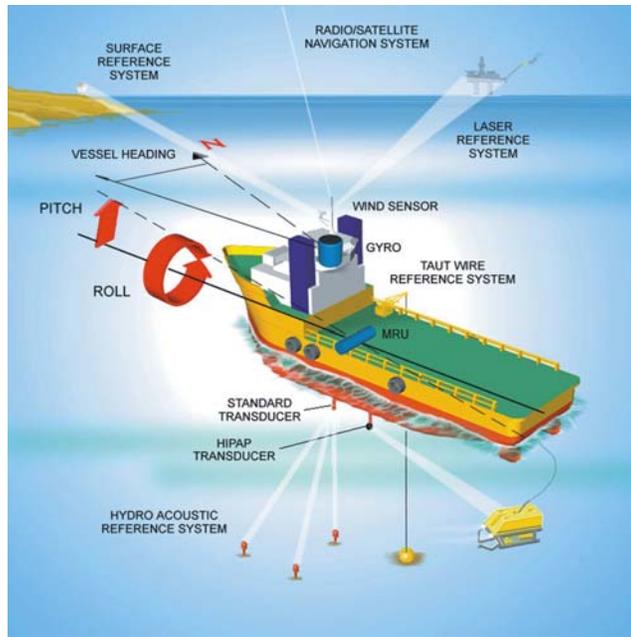
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### **The nature of a GPS system**

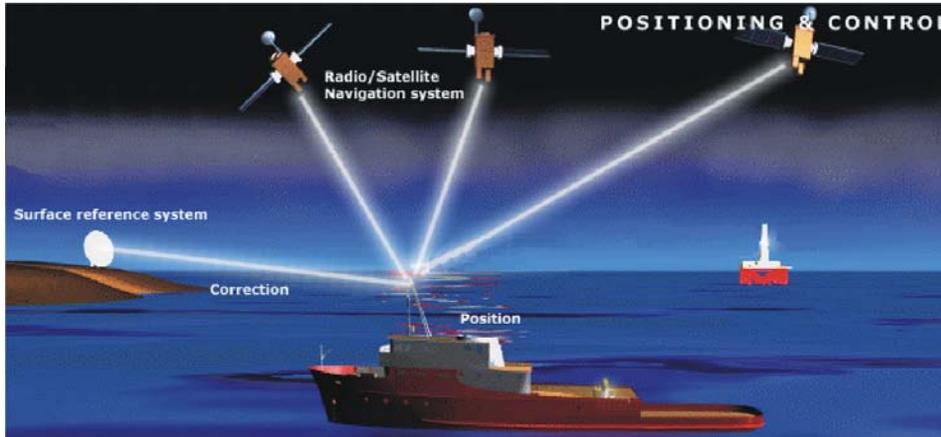
The Global Positioning System (GPS) is an American satellite-based navigation/positioning system giving 24-hour global coverage and is widely used onboard all DP vessels and often with more than one system. A Russian satellite navigation system has also existed some years, and soon also a European system will be introduced.

In order to calculate a position based on GPS, distances are measured to a number of satellites. The distance measurements (pseudo ranges) are taken by measuring the time used by the signal from the satellite to the GPS receiver antenna. In order to do such measurements the GPS receiver has an accurate clock. However, there is still clock drift in the GPS receiver, which has to be solved in the position calculation. To calculate a three dimensional position, 4 unknowns have to be solved (latitude, longitude, height and receiver clock offset). To solve this equation with 4 unknowns it is necessary to have range measurements from 4 or more satellites.

The geometry of the position calculation varies with the number of satellites available and their location.

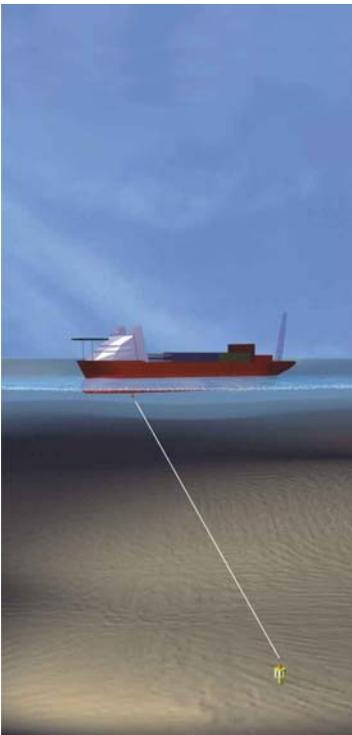
All major error sources, except for local multi-path, are significantly reduced by using differential corrections from one or more GPS Reference Stations. This principle is called differential GPS (DGPS).

A GPS system outputs a position to the DP every second, and normally the standard deviation is well within 1 meter.



### The nature of an HPR system

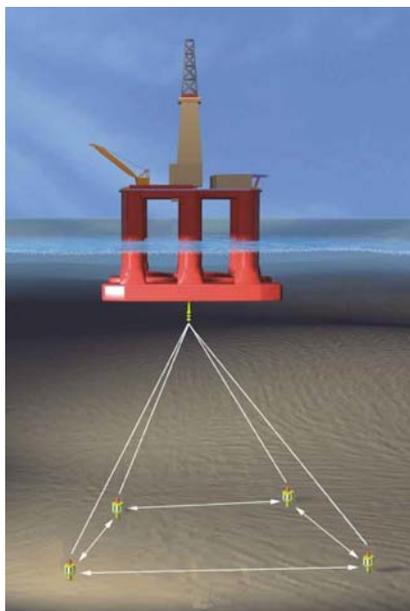
There are two commonly used modes of underwater positioning used for DP reference purpose.



The Super Short Base Line (SSBL) principle:  
(Some say Ultra Short Base Line or USBL)

Positioning based on distance and angle measurements from one vessel-mounted transducer to one seabed transponder.

- System accuracy (standard deviation) is approximately 0,2% of slant range.
- Update time is 1 second in water depths down to approximately 700 m water depth, and from then increasing with 1 second for every 700 m extra depth. I. e. update rate is from 1 to 6 seconds dependant on water depth.



The Long Base Line (LBL) principle:

Positioning based on distance measurements from one vessel-mounted transducer to one seabed transponder-array with known geometry.

- System accuracy (standard deviation) is within 1 meter regardless of depth.
- Update time is from 2,5 seconds to 6 seconds dependant on water depth

SSBL is the preferred mode by DP-operators due to its simplicity. The LBL principle requires more vessel time for deployment and calibration of 4 – 5 transponders.

## A DP system weights its references

The DP system calculates a variance for each of the position-reference systems in use. The system assigns different weighting to each position-reference system, based on its calculated variance. In this way, the system is able to place more emphasis on the position-reference systems that are providing the best measurements. The higher the system's variance is, the lower its weighting factor.

The ideal situation given the circumstances where only GPS and HPR are available would be to have 2 x GPS and 2 x HPR online in the DP system.

All these position reference systems should also have more or less the same accuracy, standard deviation and the same update rate. Any reference system with accuracy (standard deviation) less than 1 meter and with an update rate of minimum 1 second is allocated equal weight in the DP system.

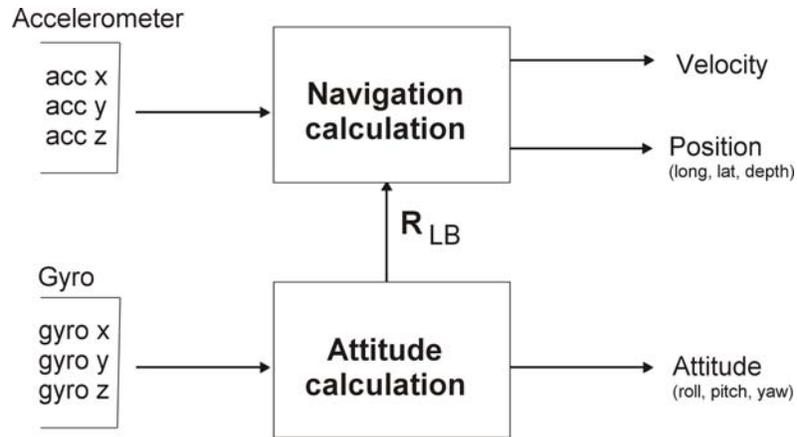
For physical reasons mentioned above, the HPR systems will very often have either a reduced update rate or a reduced standard deviation compared to the GPS systems (see the HPR chapter above). This implies that the two HPR systems have an influence on the DP model that is significantly less than the GPS systems. Two HPR systems with update rate 2 seconds, will contribute 33% to the overall model and two HPR systems with update rate 3 seconds will contribute 25% to the overall model.

Putting more than 2 x GPS systems online implies even less influence from HPR. Also there are situations or periods where HPR, even in LBL mode, will have accuracy worse than 1 meter, meaning that the weight on HPR is reduced. Two HPRs with standard deviation 2 meters will contribute only 7% when the update rate is 3 seconds.

The implication of this is that the DP system is vulnerable against GPS failures, which tend to be common between the GPS systems when they occur at some rare situations.

## The nature of an Inertial Navigation System

An Inertial Navigation System (INS) integrates the output of three accelerometers and three gyros to compute the **position**, the **velocity** and the **attitude**.



The sensors in the Inertial Measurement Unit

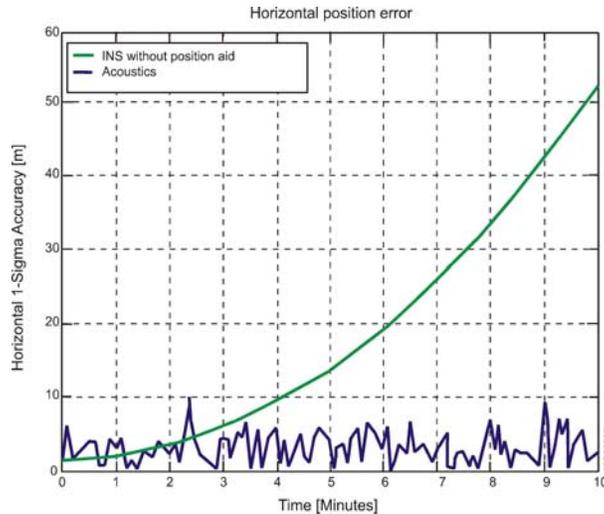
- The three accelerometers are mounted perpendicular to each other. Each accelerometer measures the acceleration relative to the inertial space. Integration of acceleration gives **velocity**, and integration of velocity gives **position**.
- The three gyros are mounted perpendicular to each other. Each gyro measures the angular rate relative to the inertial space. Integration of angular rate gives **attitude** (roll, pitch and heading).

The position accuracy of an INS is dominated by the position drift over time (See the curve in the next chapter). However, it is very stable over short time.

The output rate is normally higher than or as high as, 1 second.

### The nature of a Hydroacoustic Aided Inertial Navigation (HAIN) system

Acoustic and Inertial positioning principles in combination are ideal, since they have complementary qualities. Acoustic positioning is characterised by relatively high and evenly distributed noise and no drift in the position, whilst inertial positioning has very low short-term noise and relatively large drift in the position over time.



In addition to an Acoustic Positioning system (HiPAP or HPR) a HAIN system consists of two physical units only. These are the HAIN Computer and the Inertial Measurement Unit which interfaces over a Serial Line.

The HAIN position reference system provides several important advantages for DP operation.

- **improved acoustic position accuracy**

The HAIN system will typically improve the accuracy some 2-3 times.

Example: If the “ping to ping” deviation is 2 meters, the HAIN will reduce this to approximately 1 meter. This means that the preferred SSBL principle can be used as a highly weighted reference in deeper water than normal.

- **higher position update rate**

The HAIN calculates a new position every 1 second regardless of water depth as it will “fill in the acoustic gaps” with calculated values based on measurements from the IMU. This means that the HPR system will maintain its weighting versus the GPS update rate.

- **extends operational depth capabilities**

Since both the accuracy and the position update rate are improved, the HAIN therefore allows DP operation in deeper waters.

- **longer transponder-battery lifetime**

The HAIN position update rate enables the slowing down of the acoustic update frequency. This will result in less “ping” per hour, and thereby longer battery duration.

- **position update during acoustic drop-out**

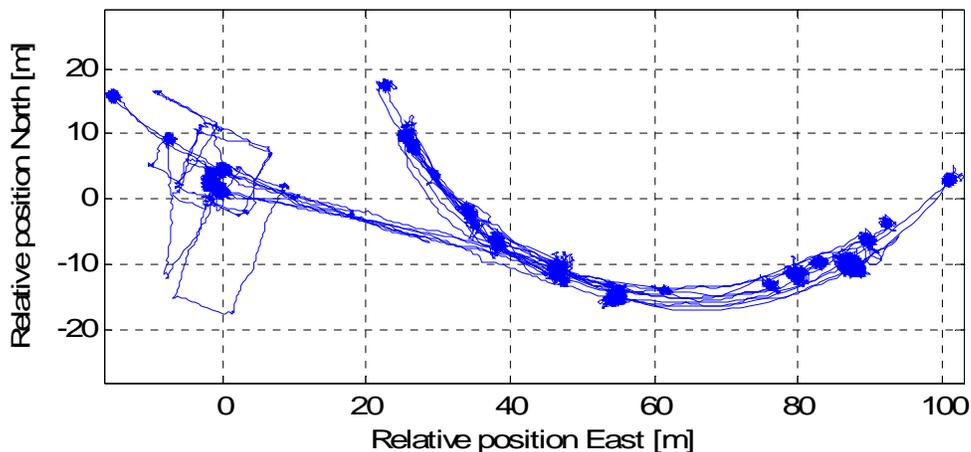
The HAIN gives continuity in position output even when the acoustic position should fail, by providing reliable position data in periods of up to a few minutes.

## One month of HAIN data recorded onboard Ocean Rigs “Eirik Raude”

The HAIN system onboard Eirik Raude was running in “Monitoring mode” while the vessel was in drilling operation in the Gulf of Mexico 2007-07-07 to 2007-08-09. The water depth was approximately 2700m.

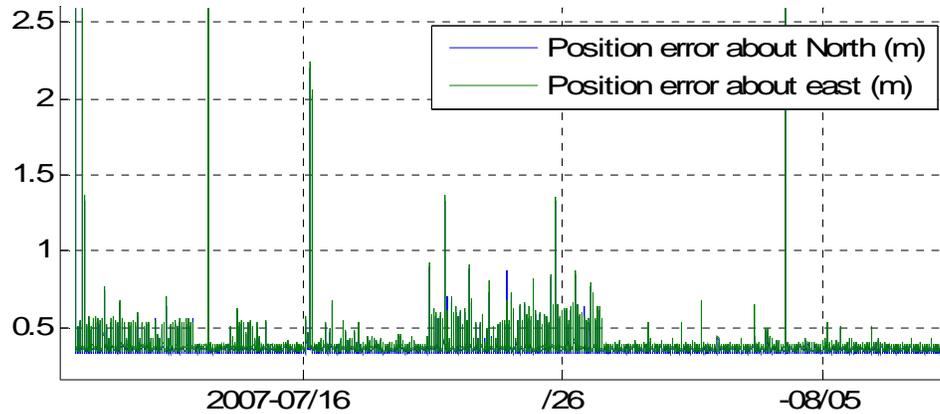


All the logged HAIN navigation data recorded in that period has been examined in a report, and the conclusion is that the HAIN system performed expectantly well.

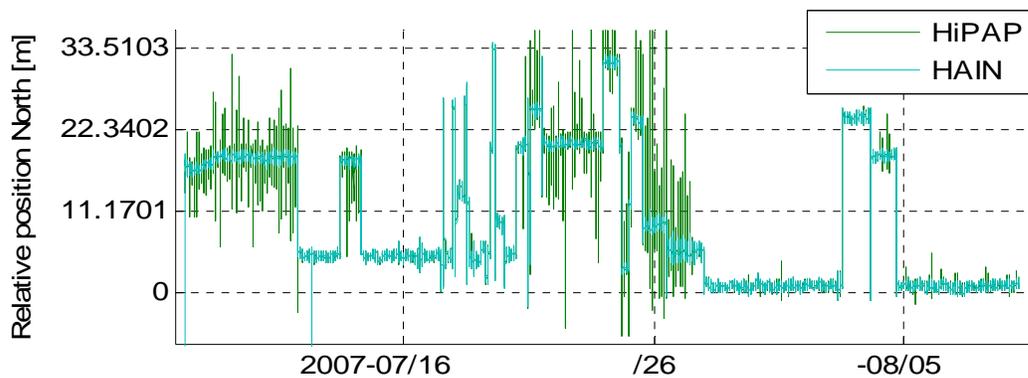


The figure shows the Trajectory of the relative positions of the IMU on board the Eirik Raude during 1 month operation. The somewhat circular motion pattern is caused by the ship rotating and the IMU being placed some 50 m away from the center of rotation.

HAIN's mean estimated position accuracy was during the entire period on about 0.4 meters, meaning the combined horizontal standard deviation mean is 0.55 meters. The development of the standard deviations in position is shown in the figure below.



We see from above that the standard deviation is on the scale of a meter for the entire period, except for incidents on 2007-07-12 and 2007-08-03. There are periods where the reported accuracy is slightly poorer than others. This may come from acoustic or other operational conditions.



HAIN and HiPAP are compared in above figure. Measurements are of North position. HAIN positions are smoother than HiPAP positions as expected. HAIN and HiPAP correspond well in the measurements.

## **HAIN Navigation sum up from one month of data onboard Drilling Rig Eirik Raude**

Navigation is working excellently except for two distinct situations.

- On 2007-07-12 the HAIN computer is booted. Most likely caused by power failure or other forceful shutdown of the computer.
- On 2007-08-03 HAIN resets navigation and are missing external measurements.

The Eirik Raude will be contacted in order to find out what happened on those two incidents. The former is quite possibly the result of some operational problems on board the vessel, which required the HAIN-computer to be forcefully shut down or loose power. Therefore this one is not as interesting as the latter. The latter should be examined closer to find out what happened. Kongsberg Maritime shall and will on later examinations of log files also log the ships GPS position. This can be used as a reference to the position provide by HiPAP and HAIN.

## Conclusions of HAIN used as DP reference

Any reference system with accuracy (standard deviation) less than 1 meter and with an update rate of minimum 1 second is allocated equal weighting in the DP system as mentioned in the DP chapter above. The GPS is of such nature.

If we look at HPR (or HiPAP) the following **typical** figures will be valid when operating in 1000 meter water depth.

	HiPAP SSBL	HiPAP LBL	GPS
Standard deviation	+/- 2 meters <sup>1)</sup>	+/- 0,5 meter	+/- 0,5 meter
Update rate	1,5 seconds <sup>2)</sup>	2,5 seconds	1 second

1) Accuracy of 0,2 % of depth

2) Travel time of 1,3s plus computation time

The above shows that neither SSBL nor LBL will be able to achieve as high weighting as GPS in the DP.

The SSBL will suffer due to that both standard deviation and update rate is “worse” than GPS, whilst the LBL will suffer due to the update rate only.

By introduction of HAIN, the following will be the result.

	HAIN SSBL	HAIN LBL	GPS
Standard deviation	+/- 1 meter	+/- 0,5 meter	+/- 0,5 meter
Update rate	1 second	1 second	1 second

We can see that by introducing HAIN both to the SSBL and the LBL will take the acoustic positioning up to a point where these references will be given the same weight as GPS in the DP algorithm.

The above also shows that the HAIN SSBL principle could be used with **high DP weight** in 1000 m depth compared to only 500 m without HAIN.

The reliable LBL positioning will by introduction of HAIN also obtain the **high DP weight** as the update rate to DP will be 1 second, which is the same as the GPS gives.

With all the other benefits mentioned above it is sure that the Hydroacoustic Aided Inertial Navigation (HAIN) system has come to stay, and will ultimately also ensure a more reliable DP operation.