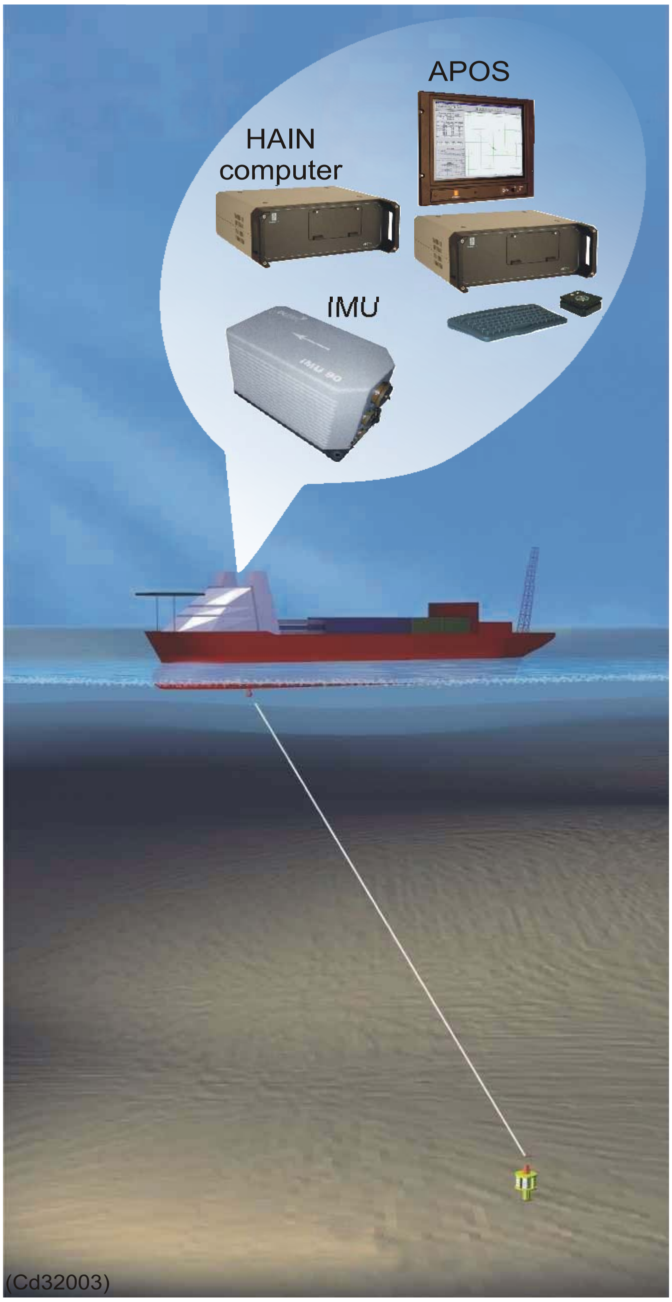
Product Description

KONGSBERG

HAIN Position Reference

Hydroacoustic Aided Inertial Navigation



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KONGSBERG

Contents

INTRODUCTION

This product description covers the Hydroacoustic Aided Inertial Navigation (HAIN) product. It provides a general description of the systems, modules, functions and technical specifications.

Abbreviations

The following abbreviations are used:

APC	Acoustic Positioning Computer
APOS	Acoustic Positioning Operator Station
COS	Common Operator Station
DP	Dynamic Positioning
dGPS	differential Global Positioning System
HAIN	Hydroacoustic Aided Inertial Navigation
HiPAP	High Precision Acoustic Positioning
HPR	Hydroacoustic Position Reference
IMU	Inertial Measurement Unit
INS	Inertial Navigation System
LBL	Long Base Line
MULBL	Multi-User Long Base Line
SSBL	Super Short Base Line
SSLBL	Super Short and Long Base Line

HAIN SYSTEMS

General

Exploration on deeper water puts high requirements on underwater positioning for both Dynamic Positioning (DP) operations and survey applications. Acoustic positioning systems are continuously improved to meet new requirements.

The HAIN system is developed as an extension to the High Precision Acoustic Positioning (HiPAP) and Hydroacoustic Position Reference (HPR) systems. The acoustic measurements are used as position aid for the Inertial Navigation System (INS).

The following system is described:

- HAIN Position Reference
  - HAIN Position Reference is for vessel positioning, and is used as position-reference for the Dynamic Positioning (DP).

The complementary solution

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.

INERTIAL NAVIGATION

Principles of inertial navigation

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

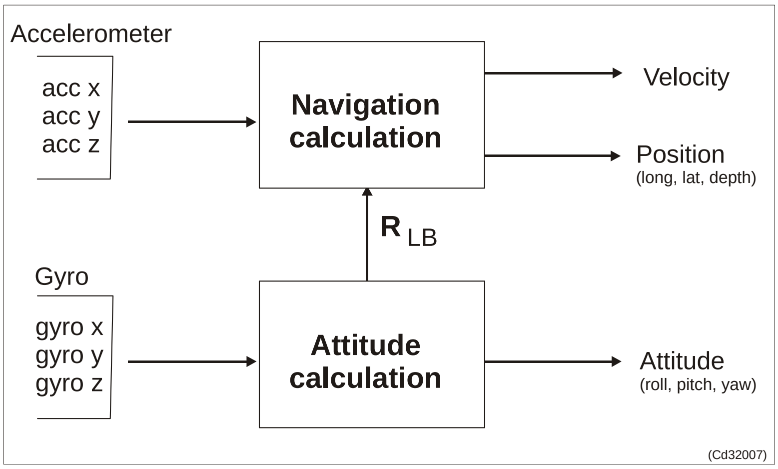


***Figure** 1* *The sensors in the Inertial Measurement Unit*

- 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 accelerometers and the gyros are contained in an Inertial Measurement Unit (IMU). The figure below shows a Honeywell HG-1700 IMU.

***Figure** 2 Honeywell HG-1700 IMU*

Most inertial navigation systems to day are strap-down systems, with the IMU rigorously connected to the body that is positioned. For HAIN, the body is either a surface vessel or an ROV.

- **The integration of the accelerometers** - gives the velocity in the body co-ordinate frame.
- **The integration of the gyros** - gives the attitude, which is used to convert the acceleration / velocity from the body co-ordinate frame to an earth-fixed co-ordinate frame.

Different co-ordinate frames, Earth gravity and rotation must be handled. This is done in well-established strap-down navigation equations.

Complexities also arise because all measurements have noise added to them. The noise consists of a white part and a coloured part. The white part is random Gaussian noise. The coloured noise is often referred to as a bias on the measurement. The bias changes slowly, with a time-constant of many minutes.

Initial values for the integration

An integration gives a change from an initial value. Integration of acceleration gives change in velocity. Integration of angular rate gives change in attitude.

Attitude

It is possible to calculate the attitude by using the IMU readings and the knowledge about the Earth gravity and rotation. The latitude must also be known within some degrees. The IMU sensors must be of good quality to manage this task, because the Earth rotation is slow compared to the movements of the body.

Position

It is not possible to calculate the initial position based on the readings from the IMU sensors. An Inertial Navigation System must therefore get a position aid from outside.

External measurements

In addition to the accelerometer and gyro readings from the IMU, an Inertial Navigation System gets external measurements.

External measurements to HAIN Vessel are:

- Aiding position in latitude / longitude and depth. It is used both to get an initial value for the position and to limit the drift that is inherent in inertial navigation systems.
- Heading
- Velocity (Optional)

The external measurements are used by a Kalman filter to compute corrections of the filter’s estimates. The corrections are weighted according to the expected accuracies of the measurements and to the filter’s estimate of its own accuracies.

HAIN processing

Basic principles

The figure below shows how the readings from the IMU and the external sensors are used.

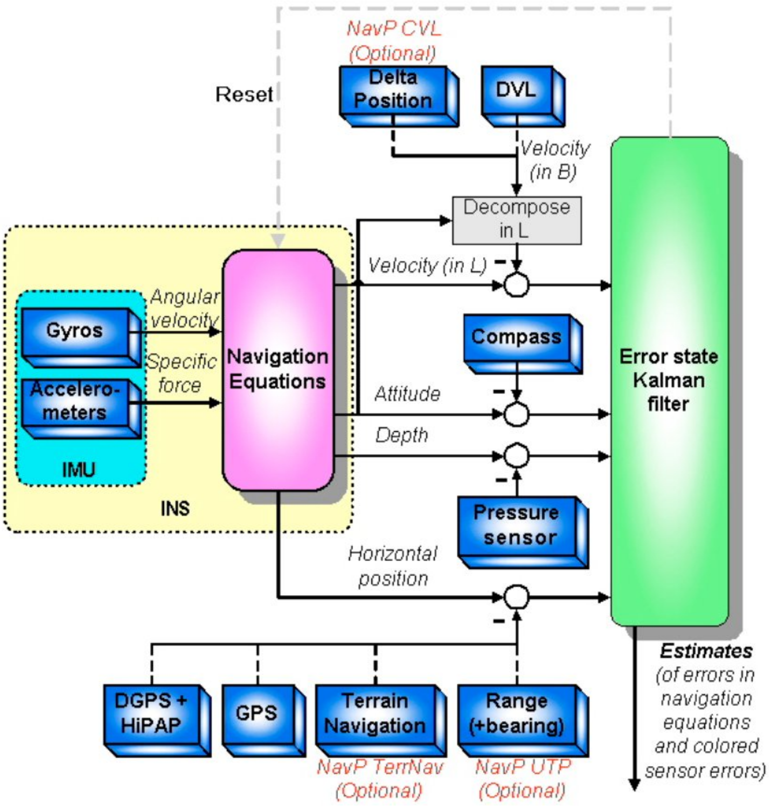


***Figure** 3* *HAIN processing - block diagram*

To the left, we see the IMU with its gyros and accelerometers. The navigation equations read the three gyros and the three accelerometers with 100 Hz. Based on these readings, the navigation equations calculate the change in position, velocity and attitude. Due to noise and errors in the readings, errors in the calculation increase with time if not corrected for.

To the right, we see the Kalman filter. It estimates both the attitude, velocity and position and sensor errors. It also calculates the accuracy of each estimate.

The input to the Kalman filter is the difference between the values calculated by the navigation equations and the external measurements.

Example:

Depth measurement - The measured value is subtracted from the depth calculated by the navigation equations. The difference is read by the Kalman filter. The filter knows the expected accuracy of the depth, and it knows the accuracy of its own estimates. The depth correction is weighted based on this knowledge, and the estimates of the filter are updated. New values for the position, velocity and attitude are sent to the navigation equations.

Position aid

The position aid in ***Figure 3*** is named ”dGPS + HiPAP”. The other alternatives for HAIN position aid is ”HiPAP” and ”LBL”, as explained later. HAIN Position Reference uses either “HiPAP” or “LBL”. In all cases, the latitude / longitude of the aiding position is subtracted from the latitude / longitude calculated by the navigation equations. The difference is processed by the Kalman filter, as explained in the example (for the depth) above.

The filter executes each time an external measurement is read. It updates its estimates based on the external measurement, and transfers the new position, velocity and attitude to the navigation equations. This transfer is often referred to as a ”reset”. Therefore the values calculated by the navigation equations and those estimated by the Kalman filter are very close to each other.

The graphs shown later in this document, use the same colours as the figure on page 19. These are:

Blue	is used for measurements
Magenta	is used for the navigation equations
Green	is used for the Kalman filter

The Kalman filter shown in the figure on page 12, is often referred to as the forward filter. It is executed in real time, and does not have any knowledge of the measurements ahead in time. When the measurements are post-processed with the NavLab, the forward filter is first executed. Then a backward filter is executed. It uses the measurements both back and forward in time. This gives a significant improvement in accuracy and stability. The result from the backward filter is displayed in red on the graphs.

Acoustics used as position aid

Complementary solution

The noise on acoustic positions is dominated by the white noise. There is almost no correlation between the noise on one measurement and the noise on the next measurement.

The noise on Inertial Navigation systems without position aid, is dominated by coloured noise, which is a position drift, as illustrated in the figure below.

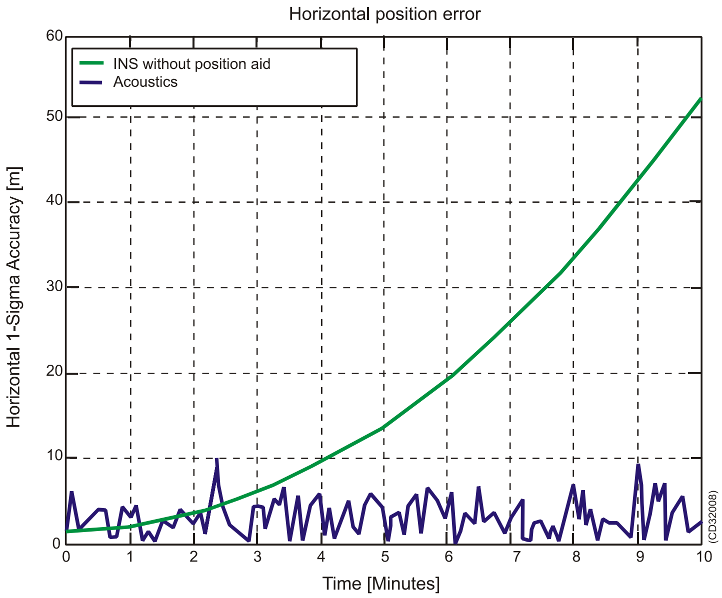


***Figure** 4* *Acoustic used as position aid*

The noise on inertial navigation without position aid and the noise on acoustic positions are complementary. Acoustic positions are therefore ideal as position aid for inertial navigation.

- The white noise of the acoustic positions is reduced because the inertial navigation has a small white noise.
- The coloured noise (the position drift), of the inertial navigation is strongly reduced by the acoustics, which has almost no coloured noise.

Position aid for HAIN position reference

- For **HAIN Position reference**, the depth is the depth of the reference point of the vessel.
  - The aiding position is the position of the vessel in latitude longitude. It is generated either by an SSBL measurement or by an LBL measurement. In both cases the position of the seabed transponder(s) must be known in latitude longitude. The SSBL transponder must have been boxed-in, and the LBL array must have been calibrated geographically. This must be done before the HAIN vessel positioning is started. After this, the HAIN vessel positioning is independent of the dGPS.

The depth is processed as an external measurement.

HAIN POSITION REFERENCE

General

The HAIN system for vessel positioning is an aided Inertial Navigation System. The position drift that is inherent in the inertial navigation systems, is limited by the acoustic position measurements relative to transponder(s) on the seabed.

The system can be used with both Super Short Base Line (SSBL) and Long Base Line (LBL) position input.

The HAIN provides an improved position of the vessel that both has increased accuracy and higher update rate than the original position from the acoustic measurements. This extends operational water depth and reduced battery consumption. Position output during acoustic dropout will be maintained.

System description

The HAIN position reference system provides:

- **Improved acoustic position accuracy**
  - The HAIN system will typically improve the accuracy some 2-3 times.
    Example: If the ”ping to ping” deviation is 6 meters, the HAIN will reduce this to approximately 2 meters.
- **Higher position update rate**
  - The HAIN calculates a new position every 1 second regardless of water depth.
- **Extends operational depth capabilities**
  - Since both the accuracy and the position update rate are improved, the HAIN allows operation in deeper waters.
- **Longer transponder-battery lifetime**
  - The HAIN position update rate allows slowing down 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 though the acoustic position should fail to operate in periods of limited time.

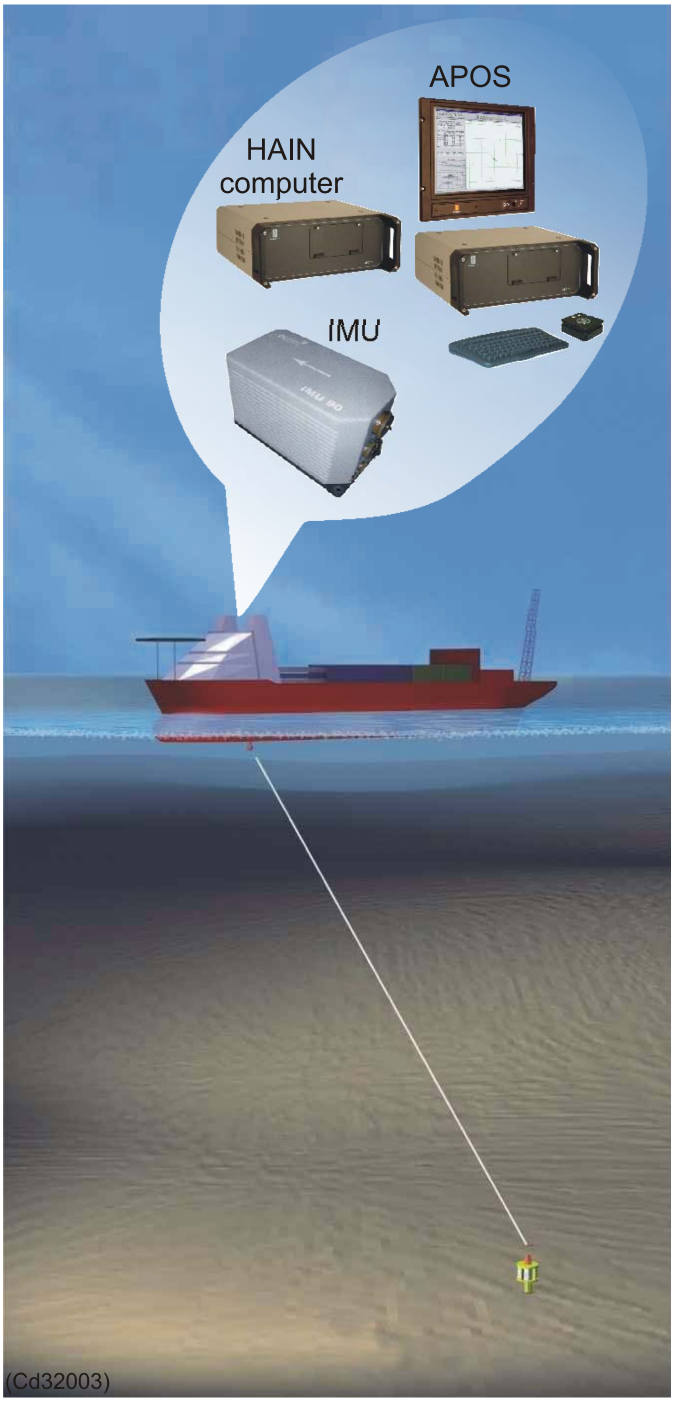


***Figure** 5   HAIN Position reference system*

The figure below shows the HAIN Position reference system used with a HiPAP system.

The HAIN Positioning reference system can be used on any vessel equipped with acoustic positioning system.

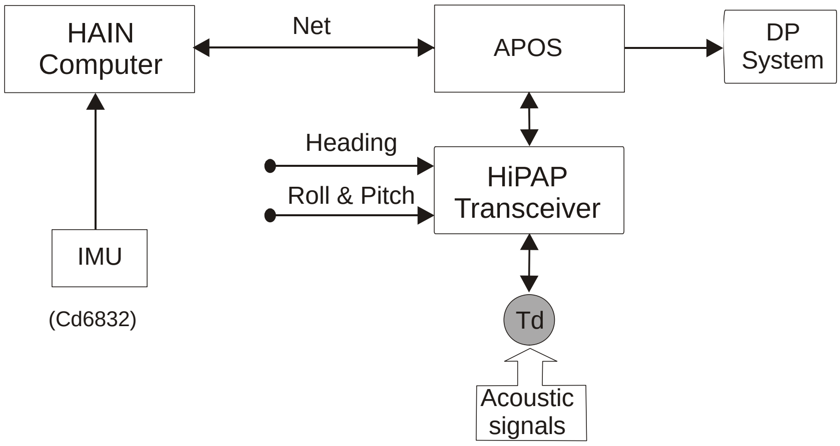


***Figure** 6* *HAIN Position reference - system diagram*

System units

HAIN computer

The HAIN computer executes the navigation algorithm, which consists of Strap-down navigation equations and a Kalman filter. The unit is interfaced to an IMU (Inertial Measurement Unit) and to the APOS (Acoustic Positioning Operator Station).

The HAIN computer receives the aiding positions (latitude / longitude) from the APOS, and it limits the position-drift that is inherent in inertial navigation systems. Vessel position, attitude, speed and expected accuracy, are sent back to the APOS at 1 Hz update.

Inertial Measurement Unit - IMU

The IMU consists of three accelerometers and three gyros, measuring the vessel’s accelerations and rotation in three axis very accurately.

Operator station - APOS

The HAIN system is operated from the APOS and has the following main functions:

- Controls the HAIN system.
- Displays position and sends position and status data.

The information received from the HAIN computer is displayed and sent to external computer(s). APOS can request status information in the HAIN computer to be displayed, which helps the operator to check the system in real-time.

Accuracy

HAIN combines the acoustic measurements and the readings from the IMU in an optimum way. The navigation equations update the vessel position, velocity, heading and attitude almost continuously based on the readings from the IMU. The Kalman filter corrects these values when new acoustic positions are available. This result in improved position accuracy compared to the acoustic measurements, as illustrated in ***Figure 7***.

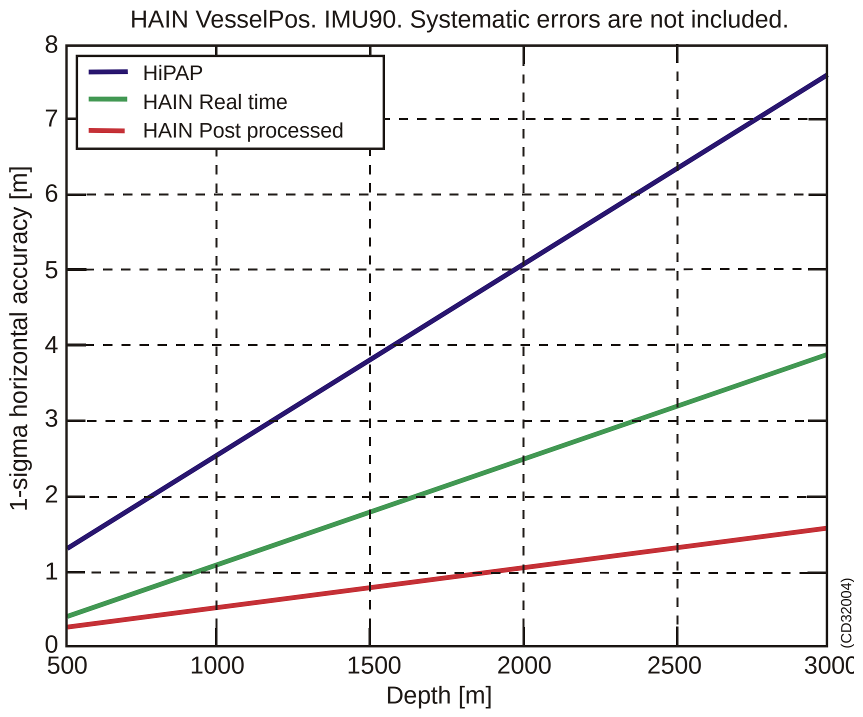


***Figure** 7 HAIN Position reference accuracy figures*

The simulations for the expected accuracy are based on the following accuracy figures:

• HiPAP angle accuracy	0.1° in x and y
• HiPAP's Motion Sensor white noise	0.02° in roll and pitch
• HiPAP's Motion Sensor coloured noise	0.1° in roll and pitch
• Accelerometers random walk	$15\,\text{mg}/\sqrt{Hz}$
• Accelerometers coloured noise	0.5 mg
• Gyro random walk	$0.0025°/\sqrt{h}$
• Gyro coloured noise	0.05°/h

Data Logging

Data logging can be done on two levels:

1 The HAIN computer is logging all measurements on its hard disk. These data can be post-processed.

2 The APOS can log measured and calculated vessel positions, attitude and velocity on its hard disk.

All measurements and positions in the log files are time-stamped. Be aware that the HAIN clock and the APOS clock may drift relative to each other.

Post processing software – NavLab

The HAIN computer logs all the sensor measurements to its hard disk. Then it is possible to calculate post-processed estimates of position, velocity and attitude. There are many situations where these estimates are of great interest after the mission is finished, for instance for map production and geo-referencing of objects.

- **NavLab is the HAIN post-processing tool**.
  - It can be used both for HAIN position reference and for HAIN subsea. It is, however, most relevant for HAIN subsea.
- **NavLab reads the measurements that are logged in real time by the HAIN computer**.
  - When calculating the position, it uses measurements both in the past and in the future, giving a better quality than can possibly be achieved in real time.

- **NavLab has functions to detect wild-points in the measurements, both automatically and with operator assistance.**
- It is easier to identify the wild-points in the post-processing than in real time, because also the future measurements are available. The wild-points are excluded from the calculation, giving a better accuracy and robustness.

- **The HAIN processing uses sensor parameters based on the sensor specifications.**
  - The actual sensor performance may differ from its specification, and in such cases the parameters should be based on empirical data. NavLab is a suitable tool to identify such cases, mainly due to its backward filter. It can post-process with new parameters, and the new parameters can be used in real time for the next missions.
  - Sometimes systematic errors are present in a sensor, typically due to imperfect calibration or misaligned mounting. NavLab is a suitable tool to detect and quantify such errors, mainly due to its backward filter. When the errors are known, they can be compensated for in the post-processing and in future missions.
- **NavLab exports the results to files for use by the survey SW.**
  - It exports one file with position and depth, and one file with attitude and heading. The values are time-stamped with the clock in the HAIN computer NavLab also generates many plots to visualize the parameters and the results. Many of the plots in this note are generated by NavLab.

FIELD RESULTS POSITION REFERENCE

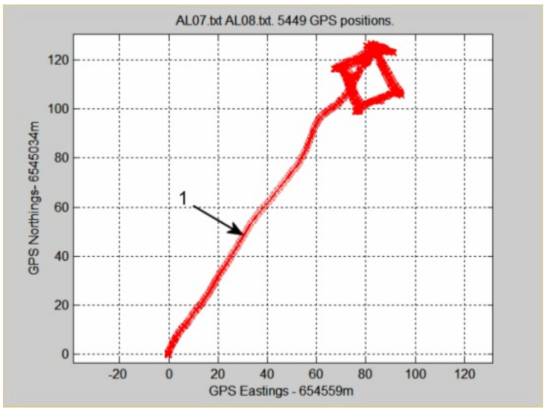
Introduction

Kongsberg Maritime has performed several sea-trials with the HAIN Position reference system on our own vessel, the Simrad Echo. The trials are done for debugging purposes, evaluation of IMUs and accuracy analysis.

A short trial on an offshore DP vessel has also been carried out.

Scatter-plots

The two plots below are from the offshore trial.



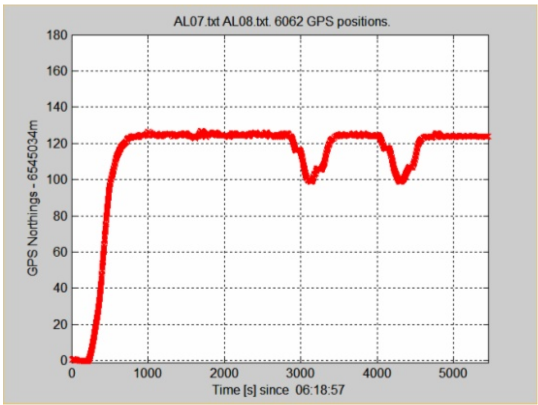


Figure 8 Scatter-plots offshore test

The scatter-plots above show the vessel position during the test, as logged by the dGPS.

1 Sails backwards 150 m with HiPAP update rate 20 s.

2 Stationary with HiPAP update rate 10s and then 20 s.

3 Changes heading first CCW 40° and then CW 70°, with HiPAP update rate 20 s.

4 Sails a square with HiPAP update rate 20 s.

5 Sails a square with HiPAP update rate 5 s.

6 Removes the HiPAP position aid from the HAIN for 10 ½ minute.

DP used HAIN as the reference during operations 1 to 5. DP used dGPS as reference during operation 6, and just logged the drift in HAIN.

Time-plots

The two plots below are from the offshore trial.

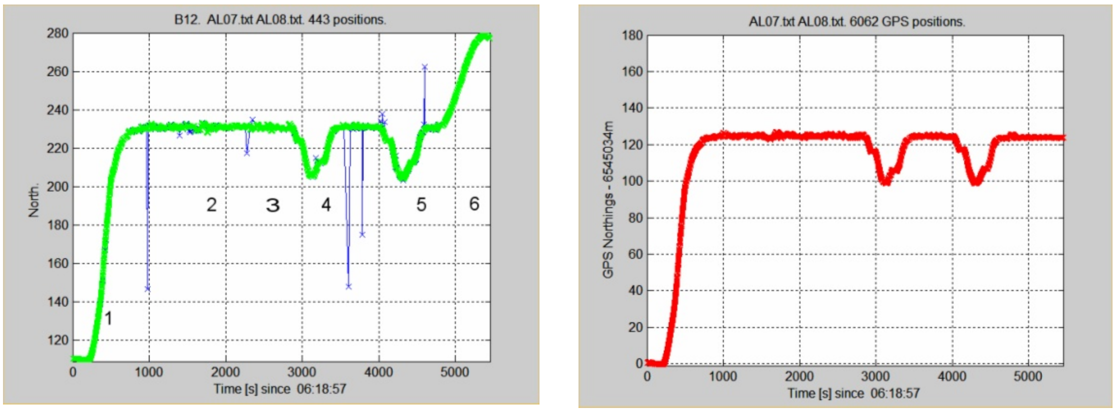


***Figure** 9   Time-plots - offset test*

The time-plot to the right shows the dGPS North co-ordinate from the scatter-plots on the previous page.

The time-plot to the left shows the HAIN position in green and the HiPAP positions in blue.

The update rate of the HiPAP positions varies between 20 s and 5 s. In the last 10 ½ minutes there is no HiPAP positions. The update rate of the HAIN positions is 1 s.

The north axis in the HAIN plot has the transponder position as the origin. The north axis in the dGPS plot is in UTM. (If more questions about the axes, tell that UTM north is not the same as geographical north, and that an UTM meter is not exactly one meter.)

We can observe:

- There are some wild-points in the HiPAP measurements. The position QA test in the HAIN has rejected these positions in real-time.
- There is a good correlation between the plots, except during the 10 ½ minute interval (6) without position aid. In this interval the vessel is stationary, as shown on the dGPS plot. The HAIN position drifts 50 m in the North direction.

HAIN OPERATOR CHECKLIST

Check list to verify HAIN operator settings and performance on HAIN DP-reference.

Task	Comment	OK
1. HAIN Acoustic Aid Setup	SSBL / (Mu)-LBL Setup to be done before HAIN start.	
2. Acoustic Aid Origin	Verify Northing /Easting in APOS	
3. Acoustic Aid QA Check	Verify Position St. Dev on DP	
4. Select HAIN Input Source		
5. Set HAIN Vessel Positioning		
6. Set UTM Position Values		
7. Select HAIN Input Properties: All	Pos, Heading, Roll/Pitch, Depth	
8. Select Logging: All	Sens. Data, Nav. Data, Nav. Estim.	
9. Verify No Mission Name Entered	Data logged as “Unnamed”	
10. Set HAIN Update Rate: 1 Sec.		
11. Set Output As “HAIN”	Telegram to DP	
12. Set Vehicle Max Speed: 1 m./sec.		
13. Set Position Accuracy Factor: 1		
14. Set # LBL Measurements: Max - 2	xyz for each Tp + Depth: # LBL for 4 Tp: 13 – 2 = 11	
15. Set Median Limit Accuracy: 3		
16. Set Median Limit Signal Str.: 3		
17. Set SSBL Median Depth: 3 m Dev.	Disabled if LBL as Aid	

Task	**Comment**	**OK**
18. Start HAIN: Check Status View	Only DVL should be missing (red)	
19. Verify Stability Value	Should Fail (N) if > 3	
20. Verify CPU Load	Should be < 5 (Average)	
21. Verify Remaining Disk Space	Should be > 5000 (Mega Byte)	
22. Enable HAIN as DP Reference	Verify HAIN St. Dev. On DP	

TECHNICAL SPECIFICATIONS

HAIN computer

Material	anodized aluminium
Length x width x height	(425 x 445 x 185) mm
Weight	17 Kg
Waterproof	IP 66

Power

Power Requirements (50-60 Hz)	(180-264 / 90-132) Vac
Nominal	80 W

Environmental specifications

Temperature:

Storage	-20 to + 65^{o} C
Operational	+10^{o} to +40^{o} C

Humidity:

Storage	90 % Relative
Operational	80 % Relative

Degree of protection	IP 21

The unit must be kept in an operational environment with the room temperature and humidity within the specified limits, and in a corrosive, salt and dust -free atmosphere.

IMU - Position Reference Unit

General

Material	anodized aluminium
Length x width x height	(182 x 182 x 300) mm
Weight	9.8 Kg
Waterproof	to 3000 m depth

Power

Requirements	220 volt ac
Consumptions	35 W

Accuracy

Heading	0.169 Deg
Roll/Pitch	0.028 Deg

Environmental

Operational life	> 19000 hours
Random Vibration	4.13 grms
Shock	30 G 11ms half sine pulse
Temperature	-40 to +60^{o} C

Interfaces

The HAIN system supports the following interfaces:

- **To the HAIN computer**
  - IMU measurements, RS-232 up to 115 200 baud
    - RDI PD0 protocol.
  - IMU heading and attitude, RS-232 up to 57 600 baud
    - Octans standard format or Simrad EM 1000 protocol.
- **Between the HAIN computer and APOS**
  - 10 / 100 Mbit, Ethernet TCP / IP.
- **Output of position headings and attitude**
  - Ethernet TCP / IP or RS-232 / RS-422
    - Standard APOS protocol, NMEA or binary.