Inertial navigation at high latitude: trials and test results

Yves Paturel, Jean-Baptiste Lacambre, Frédéric Patin
Navigation Systems Business Unit
iXBlue S.A.S
Saint-Germain-en-Laye, France
yves.paturel@ixblue.com

Christopher Moynagh
Support dept.
iXBlue S.A.S.
Aberdeen, UK
christopher.moynagh@ixblue.com

***Abstract*— Due to melting ice at the North Pole, navigation at high latitudes is increasing regularly. Therefore, navigation and survey at these high latitudes becomes more and more a key issue, especially for underwater operations where GNSS signals are not available. Navigation at high latitudes is a challenge for inertial navigation systems. Alignment of these systems with respect to North becomes more difficult when closer to the pole because the physical effect that is used becomes smaller and smaller when going to high latitudes. In order to evaluate heading accuracy and navigation performance of its inertial systems under these extreme conditions, iXBlue had the opportunity to test several of its navigation systems on a vessel up to 81 degrees of latitude during summer 2014. Thanks to the collaboration of the Norwegian Polar Institute, iXBlue has tested QUADRANS gyrocompass and PHINS navigation systems on the research Vessel Lance.**

The paper emphasizes on the potential difficulties encountered by inertial navigation systems at high latitudes. In a second part the paper presents and analyzes performance of all navigation systems and gyrocompasses under test in terms of heading accuracy and long term stability and navigation accuracy without GNSS aiding. The third part explains why we obtained extremely good results during this test campaign.

Keywords—inertial navigation; gyrocompass; north; high latitude; North Pole.

I. Introduction

Aircrafts have been navigating over the poles for decades. They are equipped with inertial systems that require good performance at these high latitudes. Ships or subsea vehicles using inertial systems should perform as well as these aircrafts. However, an important difference is that, in most cases, the aircrafts are aligned when they are on ground at rather low latitude and they just fly over the pole during the flight. Vessels will mostly be initialized and start at already high latitudes, which is, for the inertial system, a much more difficult task.

II. WHY SURFACE OR SUBSEA NAVIGATION CLOSE TO THE NORTH POLE?

Due to melting ice at the North Pole, it has become easier and easier to navigate at high latitudes. Therefore this type of navigation will not be restrained anymore to some scientific missions but will become open to more and more vessels. This phenomenon will of course be amplified for economic reasons. High latitude tourism may become fashionable in the future but more than that, there are some hidden treasures at and below the sea bottom near the North Pole.

According to USGS, the high latitude area is estimated to hold 13% of the world's undiscovered oil and up to 30% of its hidden natural gas reserves. This is a great interest for the oil and gas industry. But this is not all: there are deposits of zinc, diamond, silver and copper at the North Pole. Countries having borders close to this area have interest in expanding their Exclusive Economic Zone and for this purpose, they have a need for accurate mapping of the seabed. Therefore, navigation and survey at these high latitudes is becoming more and more of a key issue, especially for underwater operations where GNSS signals are not available.

The effects of climate change may someday even allow navigation through the North West Passage that would shorten travel from Europe to Asia and would avoid going through the Panama Canal. For these reasons, navigation at high latitudes will require more safety. Navigation is presently mainly ensured by gyrocompass and by inertial navigation systems for subsea navigation. It is known that gyrocompassing at high latitudes requires more accurate sensors and that algorithms have to be adapted so that they are not affected by the singularity of the North (or South) Pole; this is why it is important to check that all given inertial equipment is correctly designed.

III. WHY IS INERTIAL NAVIGATION MORE COMPLEX AT HIGH LATITUDES ?

Schematically, the principle of a gyrocompass consists in measuring the direction of the horizontal component of the Earth's rotation rate. When moving to higher and higher latitudes, this component becomes smaller and smaller (when at the pole, this component is zero because the horizontal plane is perpendicular to the Earth's rotation rate). An East bias error on gyro measurements creates an apparent parasitic change of the Earth's rotation rate that is converted into an error on heading as it can be seen on the drawing below.

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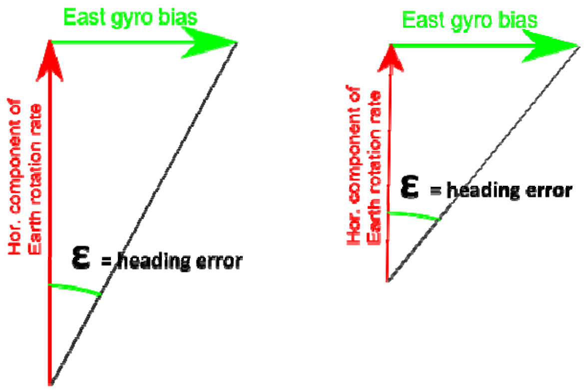


Fig. 1. Influence of latitude for a given East gyro bias on heading error

For a given East gyro bias, the heading error grows when horizontal component of the Earth's rotation rate becomes smaller, i.e. when latitude at which alignment is performed is higher; which can be easily seen by comparing the two drawings on Fig. 1.

In order to provide some orders of magnitude:

- At the equator, an East bias on gyro measurements of 0.05 degrees per hour creates a heading error of 0.19 degrees
- At 45 degrees of latitude, the same bias creates a heading error of 0.27 degrees
- At 80 degrees of latitude, the very same bias creates an error of 1.1 degrees.

This means that for a given heading accuracy, one would need a better gyro performance (bias repeatability) at higher latitude.

IV. TEST SETTING

From the above, it is obvious that navigation at high latitudes with inertial systems requires high-end inertial sensors. iXBue was keen to test its products at high latitudes other than by simulation and was looking for the opportunity for such real operation trials. This opportunity occurred thanks to the Norwegian Polar Institute who offered to host our inertial systems (and one iXBlue engineer) onboard one of their research vessels during one of their summer missions. The goal of this mission was to recover station moorings and deploy new ones at the section through the continental slope to the north-east of Svalbard.

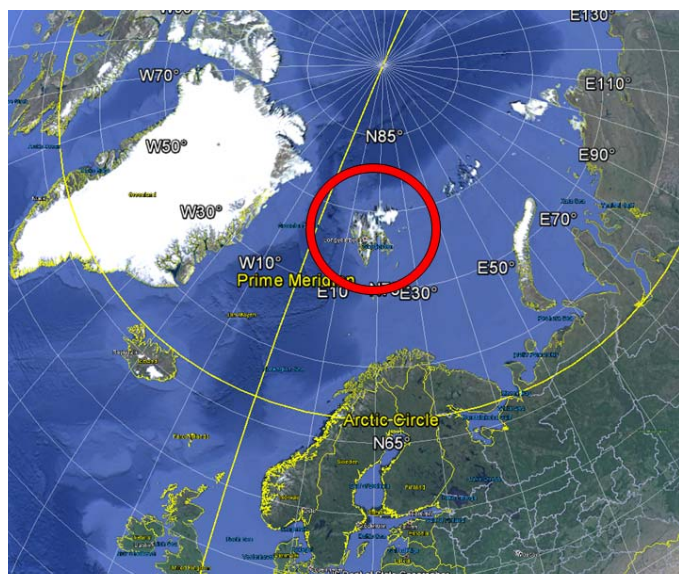
A. Vessel

Lance is a research and expedition vessel, used by the Norwegian Polar Institute and cooperating institutions. She operates primarily in the Arctic, but has also been used for Antarctic expeditions. Lance's home base is Tromsø, Norway. During the summer season, she normally operates out of Longyearbyen, Svalbard.

Fig. 2. Research Vessel Lance, on which the inertial products were tested

B. Test location

Trials took place during the mission that started and ended at Longyearbyen, in Svalbard. Svalbard (formerly known by its Dutch name "Spitsbergen") is a Norwegian archipelago in the Arctic Ocean. Situated north of mainland Europe, it is about midway between continental Norway and the North Pole. Longyearbyen is the administrative center of Svalbard. It is located at 78.22 degrees N. The mission was planned to travel up to 81.6 degrees of latitude. Unfortunately, due to the unusually high level of sea ice, the highest reached latitude was 80.83 degrees.



C. Inertial systems under test

iXBlue tested its new gyrocompass QUADRANS and the PHINS inertial navigation system. All equipment was mounted in the mast, with the gyros secured to the bracket on the wall. Both units were tested with and without GNSS aiding. Therefore the measured data from a GPS receiver was provided to the inertial systems through an Ethernet connection.

Fig. 3. Inertial systems mounted on the wall

D. Heading and Position reference

In order to have a reference for both heading and position, a dual antenna GPS receiver was installed on the vessel. The GPS receiver was Septentrio AsteRx2eH PRO GNSS heading system and we used two Septentrio PolaNt*_MC GNSS antennas.

Antennas for the GPS were mounted on the aft end of the helideck. Antennas were on the top of two tripods that were secured with straps to the edge of the deck or the helicopter tie down points.

Fig. 4. Double antenna GNSS as reference

With the lever arm of between the antennas, the expected accuracy for heading was 0.03 degree RMS.

V. TRIAL RESULTS

A. PHINS navigation system

PHINS is a navigation system that can be aided with GNSS position. It is able to align and navigate without GNSS position aiding, however heading and position accuracies are improved by GNSS position aiding. We have therefore tested both modes of operation.

1) Heading performance when aided with GPS

In this test, PHINS was aided with GPS position. Only position from the GPS was provided to PHINS. Dual antenna GPS receiver heading was never input in PHINS but only used as a reference for comparison.

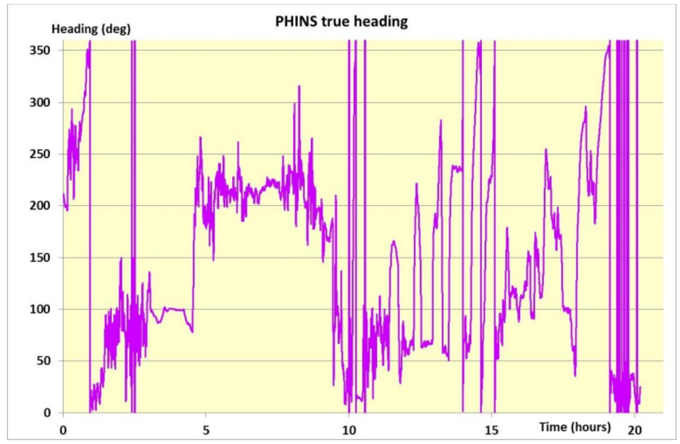


Fig. 5. PHINS heading during 20 hours

Fig. 5 shows how heading varied over the 20 hours during which data was logged. It can be seen that heading varies quite a lot.

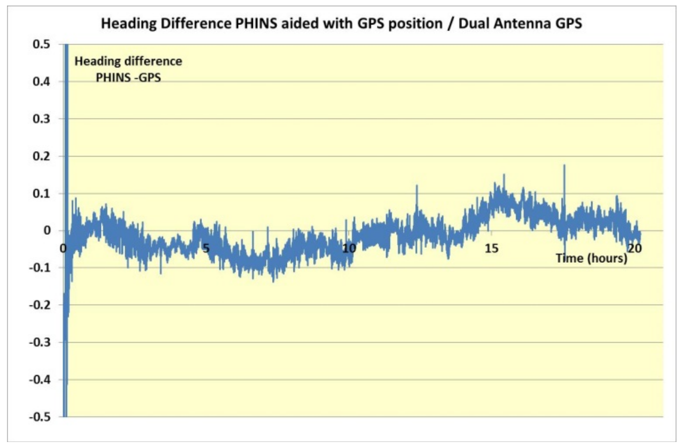


Fig. 6. PHINS heading error while aided with GPS position

Fig. 6 shows the difference between the heading reference provided by the dual antenna GPS receiver and PHINS. It can be seen that during the first minutes, PHINS is in the alignment phase (where difference can be greater than 0.5 degrees) and then PHINS heading converges toward the true heading. Once this alignment phase is performed, the difference between reference and PHINS heading remains quite small. The RMS of the heading difference is 0.04 degrees while the specified RMS performance of the dual antenna GPS receiver is 0.03 degrees. Therefore it is difficult to provide a reliable figure of the actual PHINS heading accuracy since reference heading accuracy is very similar to the one from PHINS. All that can be said is that PHINS and the reference system have the same order of magnitude for heading accuracy.

2) Heading performance in pure inertial mode

A second test on PHINS was performed after 6 hours of GPS aiding: during the 12 following hours, absolutely no external data was provided to PHINS. PHINS was during this time in pure inertial mode (no position and no velocity aiding). The test was performed on the same trajectory as shown in Fig.

5. The 6 first hours are operated with GPS position aiding and the 12 following hours are pure inertial mode.

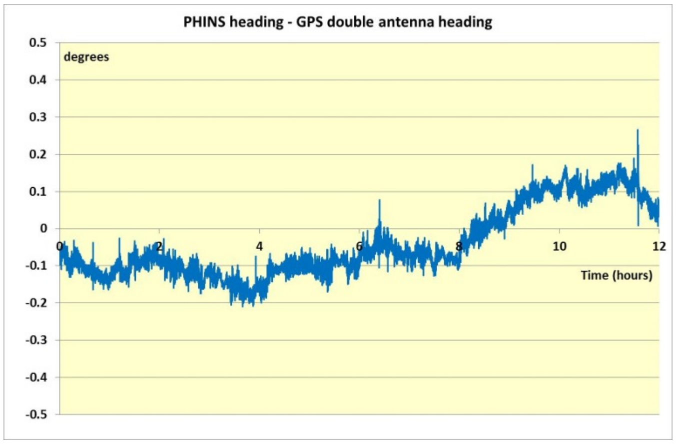


Fig. 7. Difference between PHINS heading (pure inertial mode) and reference heading

Fig. 7 shows difference between reference heading and PHINS heading during the 12 hours during which PHINS is not aided. RMS value of this difference is 0.09 degrees, while PHINS specification under these conditions at this latitude is 0.12 degrees. Part of the RMS error is due to the noise of the reference and also synchronization between PHINS time and reference time.

3) Navigation performance

When PHINS is not aided, position accuracy also has to be checked since position drift in pure inertial mode could be very large if sensors are not high performance. We can see on Fig. 8 the trajectory of the vessel during the 12 hours without any aiding.

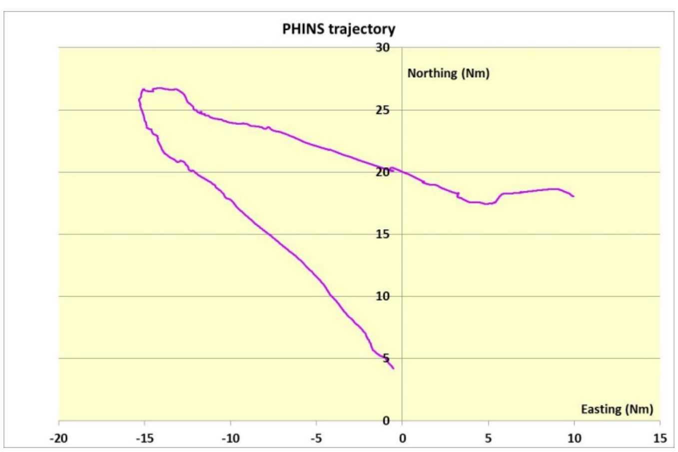


Fig. 8. Vessel trajectory over 12 hours

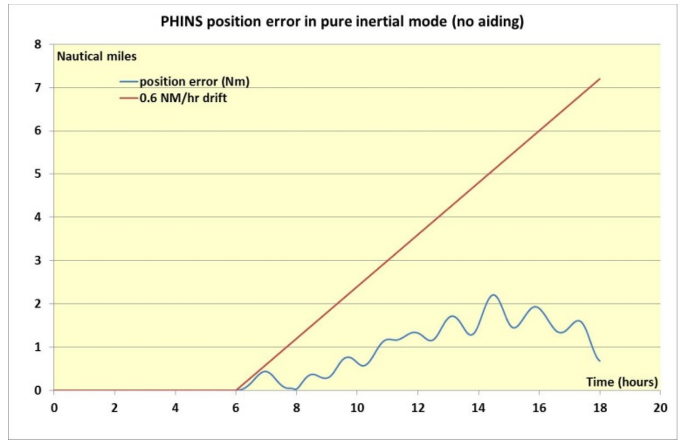


Fig. 9. Navigation error over 12 hours (pure inertial mode)

The blue curve on Fig. 9 shows PHINS position error. The red curve shows the RMS specification of PHINS position drift. Maximum error over 12 hours is 2.2 nautical miles while PHINS specification is position of 0.6 nautical miles per hour at CEP50, which means 7.2 nautical miles over 12 hours. The computed TCEP 50 (Time CEP 50) is 1 nautical mile. PHINS meets its specification by a factor of 7.

B. QUADRANS gyrocompass

QUADRANS is the new small gyrocompass developped by iXBlue. As any IMO certified gyrocompass, it must be able to provide heading without position aiding. The only aiding allowed is velocity since it must compensate for the North velocity. QUADRANS was therefore tested in a mode when it was aided by a velocity equivalent to the one provided by an electro-magnetic log. No GPS position was provided to QUADRANS, even if QUADRANS is able to use such aiding when available.

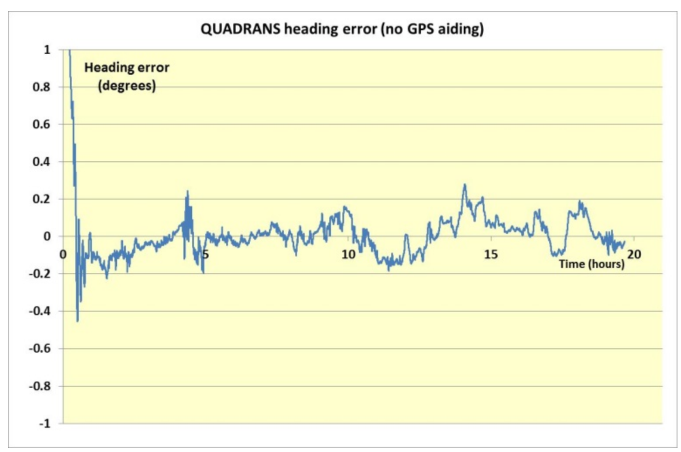


Fig. 10. QUADRANS heading error over 20 hours

Fig. 10 shows the difference between QUADRANS heading and reference heading. It can be seen that after the alignment phase that lasts about 30 minutes at this latitude, the heading error remains always below 0.22 degrees. The RMS value of the error is 0.09 degrees. Let’s keep in mind that QUADRANS specification at this latitude is 1.3 degrees RMS.

C. Performance summary

TABLE I. PHINS HEADING RESULTS

PHINS heading results summary			
	RMS spec	***RMS***	***95%***
PHINS heading error aided by GPS (degrees)	***0.06***	***0.04***	***0.07***
PHINS heading error in pure inertial mode (degrees)	***0.12***	***0.09***	***0.13***

TABLE II. NAVIGATION RESULTS

PHINS navigation results summary				
	CEP50 spec	***TCEP50***	***TRMS***	***TCEP95***
PHINS navigation unaided 12 hours (nautical miles)	***7.2***	***1***	***0.7***	***1.9***

TABLE III. QUADRANS RESULTS

QUADRANS results summary			
	RMS spec	***RMS***	***95%***
QUADRANS heading error (not aided by GPS) (degrees)	***1.3***	***0.09***	***0.15***

VI. PERFORMANCE EXPLANATION

Performance that was obtained during these trials is extremely good for both PHINS and QUADRANS products. This can be explained by three main reasons:

- iXBlue products use Fiber Optic Gyro (FOG) sensors. FOG sensor parameters are very repeatable over the life time of the products. Once they have been calibrated in factory, they remain very stable over the ON/OFF cycles , the temperature variation while system is OFF, vibrations during operation, vibrations when non-operating, …

- Algorithms in the products are such that they take advantage of any aiding (position and/or velocity over ground or velocity relative to water) to estimate the small variations of the sensors parameters. The sensors are therefore calibrated while running and the estimated parameters are used for in-run compensation.

- For FOG sensors, the in-run stability of these parameters is extremely good, so that the value estimated when aiding is available remains valid for a long period of time. This is well illustrated by the PHINS position performance over 12 hours showing a maximum error of 2.2 Nm.

VII. CONCLUSION

Navigation safety at high latitude will probably require different means of navigation. GNSS receivers will be one them, but they will not be the only ones: GNSS signals are very sensitive to solar storms and arctic regions undergo frequent solar storms. Other technologies will be essential for maintaining navigation capability. Inertial technology will be, as it has always be so far in other parts of the world, a key technology for maintaining autonomy, self-containance, and independence from infrastructures. But inertial technology will require high-end sensors for enough performance at high latitudes. iXBlue products have been proven to be ready for such challenge.

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