Use of GPS in Seismic Tailbuoy Tracking Systems in the North and Barents Sea

Carl-Erik Mo, Håssein Ræsmasma, & Inge Bjart Torkildsen
Kongsberg Navigation

Biographies

Carl-Erik Mo graduated in 1965 from The Royal Norwegian Air Force Academy for Avionics as an Inertial Navigation Systems Officer, and spent 11 years working with avionics and inertial systems for the Norwegian Air Force.

In 1976 he was engaged as INS Test Manager at Kongsberg Våpenfabrikk, which participated in the joint NATO F16 Aircraft Production Program. Since 1990 he has been the General Manager of the Systems Division of Kongsberg Navigation.

Håssein Ræsmasma graduated in 1985 from The Iranian Technical University in Teheran as a M.Sc. in Electrical Engineering, and has spent more than 15 years working with computers, electronics and communications.

From 1985 to 1987 he worked for Bell Helicopter Co. as an avionic engineer and scientist. In 1988 and 1989 he did post graduate studies at the Norwegian Institute of Technology and worked for Notodden Elektronikk from 1989 to 1990.

Since 1990 he has been responsible for the Hardware Laboratory of the Systems Division of Kongsberg Navigation, and has specialised in further development of the DiffTrack Radio Link.

Inge Bjart Torkildsen graduated in 1975 from Oslo Maritime College as a Radio Officer, and worked as such until 1986. He started his engineering career in 1987 as a Project Engineer for Telox Engineering, and received his B.C.E. from Oslo Engineering College in 1988.

He worked for The Norwegian Geodetic Institute in 1990, and received a M.Sc. in Astronomy from the University of Oslo the same year. In 1991 he was engaged by the Systems Division, Kongsberg Navigation, to work on the software, testing and marketing of DiffTrack.

Abstract

Sponsored by Norske Shell, the Norwegian subsidiary of the Shell Group, Kongsberg Navigation in late 1989 started to look into the possibility of using GPS technology for high accuracy positioning of the tailbuoy, indicating the far end of the hydro acoustic cable used in seismic exploration surveys.

In April 1991 a complete tracking system named DiffTrack was put into ordinary operation both in the North Sea and the Barents Sea, as the first commercial available tailbuoy tracking system based on GPS.

Before this the system had been through extensive field and performance testing showing a dynamic positioning accuracy on the tailbuoy of 4 meters (2dRMS) relative to MicroFix.

The real challenging part in the development of the system was to overcome the problems in communication between the tailbuoy and the seismic vessel. The communication antenna on the tailbuoy was only 2.5 meters above sea level causing severe disturbance to the communication, particularly in heavy seas.

The project also revealed valuable information about how GPS performs in such a harsh environment.

By basing the tailbuoy tracking system on GPS technology it can be used worldwide without having to set up any kind of shore-based reference stations. Once the system is installed onboard it can be used wherever the vessel is located.

This paper describes the DiffTrack Tailbuoy Tracking System, the test results and experience gained during several months of operation in the North and Barents Sea.

1 Introduction

Kongsberg Navigation has for many years been working with navigation systems and services covering various requirements and applications. Recent involvement has been directed towards the oil exploration activity in the North Sea and in the rest of the Norwegian waters. GPS did not originally give these users the accuracy they needed, and KN therefore decided to develop a differential GPS system.

In the middle of 1983 KN had already developed its first generation GPS receiver. Based on this know-how, and with the support of several oil companies, a project was launched with the goal of having an operating differential system in 1986. The system was named DiffStar, and was after a set of acceptance tests ready for commercial use Summer 1986. Today seven reference stations cover the area from the Barents Sea in the north to the English Channel in the south. These stations are transmitting corrections in the 300-500 kHz and the 2 MHz band.

The DiffTrack history started in 1989 when LORAN C, Hyper-Fix and GPS were being considered for seismic streamer tailbuoy tracking applications. GPS technology was chosen as the best alternative for a high accuracy positioning of the tailbuoy, and a development contract was made with Norske Shell.

The DiffTrack Tailbuoy Tracking System [1] consists of two main units, the Vessel Unit and the Tracking Unit. The primary application is to track the position and provide identification of a seismic streamer tailbuoy.

Together with Norske Shell, trials were made at Haltenbanken in July - September 1990 in order to interface to the seismic system, gain experience with the power generator in the tailbuoy, as well as testing the radio link under operational conditions.

A static accuracy test [2] of 1 Vessel Unit and 2 Tracking Units was performed at Kongsberg in January 1991. The experienced accuracy was 3 m (2dRMS) over distances of 5 to 10 km.

In March 1991 the DiffTrack system was put into operation at Ekofisk in the North Sea. Damage to the communications antennas and problems with the power generator in the tailbuoy were experienced during this operation.

A dynamic accuracy test sponsored by Norske Shell was performed at NATO's Naval FORces Sensor and Weapons Accuracy Check Site (FORACS) [3] near Stavanger in April 1991. The dynamic accuracy achieved was 4 m (2dRMS) relative to

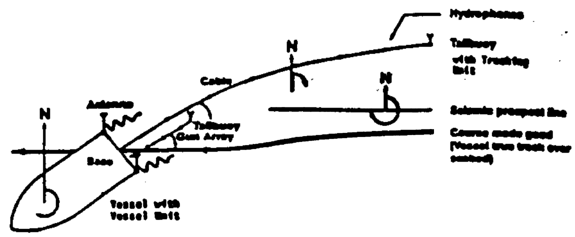

Figure 1: The DiffTrack Tailbuoy Tracking System Principle

MicroFix.

In the period May to July 1991 a two vessel 3D seismic survey operation took place in the Barents Sea. The operation was configured as two separate systems with 2 tailbuoys each on M/V GECO MY and M/V GECO SIGMA by using two radio links with different frequencies. The two vessels afterwards moved to Haltenbanken in the Norwegian Sea, where they are still operating.

At present we have six different systems in operation in the North Sea, Norwegian Sea, Oslofjord and Barents Sea. A more compact and ruggedised product (Mark I) is under development and will be put into operation this autumn.

2 System Descriptions and Characteristics

DiffTrack consists of two major parts, a Vessel Unit and one or more Tracking Units. DiffTrack used as a sensor for Seismic streamer tailbuoy tracking is shown in figure 1.

The system has also a potential of being used in other applications, such as:

- Positioning for VSP (Vertical Seismic Profiling).
- Positioning of Anchor Handling Vessel.
- Vessel Traffic Systems (VTS).

All these applications need to track the position and provide identification of a moving object. The system is therefore named DiffTrack to reflect this potential.

2.1 System component description

The DiffTrack System is divided into two major System Units - the Vessel Unit and the Tracking Unit:

1. **Vessel Unit**

   The Vessel Unit consists of 3 major modules:

   - The **VHF/UHF-link** is a receiver, transmitter and a asynchronous modem in the VHF/UHF band. The transmitter has 0.5 W output power, and is Frequency Shift Keying (FSK) modulated with a baudrate of 1200.
   - The **Computer** is an IBM PC/AT compatible, and includes an intelligent serial I/O-board for communication.
   - The **GPS Receiver** is currently an 8 channel single frequency C/A-code receiver, a Trimble 4000DL, but in principle other receivers can be used.

2. **Tracking Unit**

   The Tracking Unit is at present located in two main boxes. One box contains the GPS receiver, and a second box the VHF/UHF-link and computer. The final version is one integrated unit in a watertight box.

   - The **VHF/UHF-link** is, except the antenna, the same as for the Vessel Unit. The antenna for the Tracking Unit has no gain.
   - The **Computer** is based on a Single Board Computer (SBC). To increase the reliability and availability there is included a watchdog function to reset the computer in case of computer hangup and to monitor the power from the tailbuoy.
   - The **GPS receiver** is the same as for the Vessel Unit.

2.2 Functional description

The DiffTrack Tailbuoy Tracking System computes the relative position between the vessel and the buoy(s). The Vessel Unit is the master in the system and can be connected to a total of 10 Tracking Units.

The "reference station" in this case is the GPS receiver in the Vessel Unit onboard the vessel. This GPS receiver is of course not static, but moves along with the ship. All of the GPS receivers in the DiffTrack system compute their own single solution position without any differential corrections.

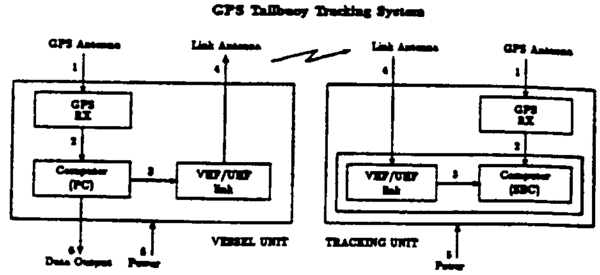

Figure 2: Block schematics for DiffTrack.

The computer onboard the vessel is reading positions from the onboard GPS receiver. The computer also sequentially asks for positions from each of the Tracking Units.

Based on the timetag of the position record from the Tracking Unit the corresponding position of the Vessel Unit is interpolated in the stored "backlog" of vessel positions. The delta latitude and delta longitude between the Vessel Unit and Tracking Unit is converted into a bearing (angle from true north clockwise to the tailbuoy) and a range (distance in meters from vessel to buoy).

It is very important to observe the following:

- The relative position method requires equal satellite constellations.
- The DiffTrack system computes a range and bearing from vessel to tailbuoy.
- The DiffTrack does not compute a differential GPS position for the tailbuoys relative to a fixed location ashore.

One of the main error sources when using GPS is Selective Availability (S/A). In DiffTrack this error source will be insignificant because the buoy position and the vessel position are calculated at the same time. Other error sources should also be negligible due to the short distance between the vessel and the buoy.

The position correction method used in DiffTrack requires that all GPS receivers are using the same satellites. To minimise the periods of unequal satellite constellations (time slips), the Vessel Unit is directing all Tracking Units which satellites to use. After being told to track a satellite, the Tracking Unit must lock on to the signals and collect ephemeris, in order to start navigating on the satellite.

Collection of ephemeris should normally not take more than 30 seconds, but the time may be prolonged due to bad signal conditions in the buoy (rolling antenna, unstable power supply etc...). Parity errors in the decoding of the satellite message (ephemeris) will give another 30 seconds delay before navigation can start.

The communication protocol for the radio link basically has two modes:

1. *BROADCAST mode.*

   The Vessel Unit (Master) sends a command to all the Tracking Units (Slaves). No response is expected.

2. *ADDRESSING mode.*

   The Master sends a command to a specified Slave. A response is expected for most of the commands. This mode can be divided into:

   - *Operational mode.*

     to get navigation data from the tailbuoy.

   - *Initial mode.*

     to initiate the SBC in the tailbuoy.

Data is sent as ASCII characters, with an End of Record (EOR) and redundancy for data transmission is provided by Cyclic Redundancy Check (CRC). No retransmission is performed when detecting an error in order to avoid a traffic jam in the communication.

The messages sent by the Tracking Units contain information on which satellites actually are being used in the position calculation, which makes it possible to discard all position data from different constellations. The Vessel Unit Computer continues to send a broadcast message containing the satellites to be used at a certain time interval as long as one or more of the Tracking Units are using a wrong satellite constellation. This is done because one or more of the Tracking Units could have lost sight of a satellite or missed a broadcast message.

The DiffTrack system is at present limited to a total of 10 tracking units. The SW could easily be updated for more units, but the link capacity will be the bottleneck when adding tracking units. In the communication system the Vessel Unit is continuously polling each Tracking Unit connected, and the time interval between updates for each Tracking Unit output will increase proportionally to the number of tailbuoys connected. The link transfer time for each Tracking Unit is currently 1.2 s.

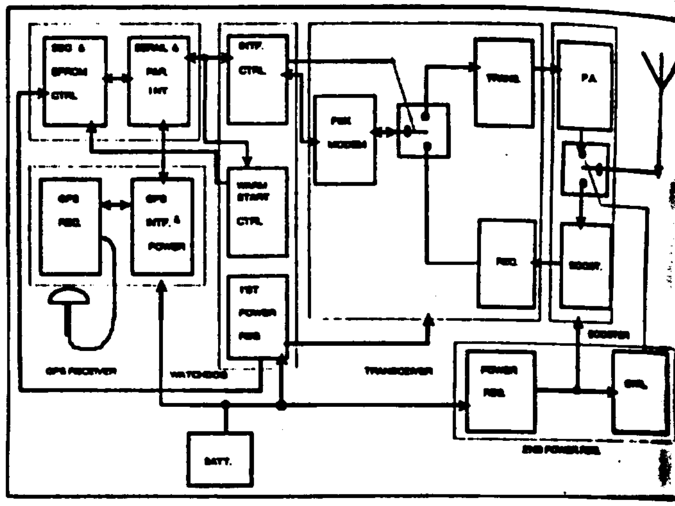

Figure 3: Block schematics for the Tracking Unit.

2.3 The Radio Link

The Radio Link is constructed to be flexible and compatible with different kinds of seismic tailbuoys. The link is stand alone to make the handling easier. The basic components in the Tracking Unit are shown in figure 3.

The link has 3 essential parts:

1. Radio.
2. Modem.
3. Watchdog and controller.

General specification for the present VHF Radio Link:

Frequency range	142 - 142.5 MHz
Operation temp.	-40 to +85 °C
Modulation type	FM
No. channels	1
Comm. baudrate	1200 bps
Channel sep.	25 kHz
Supply voltage	24 VDC (19-35 VDC)
Transm. power	+27 to +33 dBm
Autom. warm start	Watchdog control
Short circ. prot.	Power controlled
Antenna	Flexible fiberglass
Power consumption	18 - 42 W
Range	15 km (w/ booster) 5 km (no booster)

Other Technical Data:

1. **Radio.**

   The radio is a VHF transceiver which is designed for data transmission. It's specifications are:

Time turn-on TX	< 15 ms
Time turn-off TX	< 2 ms
Freq. stability	±2.0 kHz.
Output power	100-500 mW (20-27 dBm)
Harm. & spurious	< 2 nW
Time RX on	< 10 ms
Time RX off	< 3 ms
Sensitivity	> 12 dB at 0.5 μV EMF
Image rejection	> 80 dB
Adj. ch. rej.	> 70 dB
Inter. mod.	> 60 dB

   A booster is used when the distance between the vessel and tailbuoys exceeds 5 km. It makes it possible to amplify the output power by 10 dB and has selective amplification for both the receiver and transmitter. Supply voltage for the booster is 12 VDC and a power regulator with a short circuit protection facility has been constructed to isolate this part from the other components in the system.

   The communication antenna is at present a 1 m whip VHF antenna of flexible fiberglass to minimise the possibilty of breakage during launch and retrieval of the tailbuoys. It is installed on the tailbuoy about 2.5 m above sea level and is a major limitation to the range and quality of the link, especially in heavy seas.

2. **Modem**

   The modem is an internal RS232 CCITT and Bell compatible with a highest baudrate of 1200 bps. The modem is using two-tones FSK modulation for improved switching time.

3. **Watchdog and controller**

   The function of the watchdog card is to restart the system if something goes wrong. This happens if there is no connection in two minutes between the vessel and tailbuoy. This card has other functions like supplying different voltages for the link and making control signals for the modem and booster, which make the system switch at the right time with improved data security.

2.4 System operation

The DiffTrack Tailbuoy Tracking System [5] is mainly used as a sensor connected to the integrated Navigation System onboard the vessel. The Tracking Unit is controlled completely from the Vessel Unit's keyboard. The display enables the user to monitor relevant data from the system.

- **Controlling the Tracking Unit**

  The operator is able to control each specific Tracking Unit.

  The control extends to:

  - Positioning mode.
  - Receiver sync. time.
  - PDOP limit.
  - Elevation mask.
  - Height setting.
    This is important for navigating on 3 satellites with fixed height.
  - Init position.
    Initiate GPS receiver position is done if the GPS receiver is out of position due to an internal error.
  - Reset SBC.
    If there is a serious error in the SBC, the operator is able to reset the computer.
  - Connect/disconnect a tailbuoy.
    The operator is able to connect and disconnect a tailbuoy in the system.

- **Controlling the Vessel Unit**

  On the GPS receiver the operator is able to control:

  - Positioning mode.
  - Sync. time.
  - PDOP limit.
  - Elevation mask.
  - Height setting.
  - Enable/disable satellites.

- **Output to Integrated Navigation System**

  Using a menu, the operator can control which type of data the DiffTrack system outputs to external computers. There is also a function for setting the data transmission parameters.

- **Logging of data**

  In some cases there is a need for logging of tracking data. This is selected by the operator through the displayed menu. Using a floppy disk with a capacity of 1.44 Mbyte gives 1 hour of recording for a system with 5 Tracking Units and logging of all data.

- **Display output**

  The DiffTrack display gives information about all Tracking Units connected. The data displayed are as follows:

  - Identification
  - Status
  - PDOP
  - Age of data
  - Range and bearing
  - Height difference
  - Satellite selection

  In addition to these data the operator is able to select one Tracking Unit for more detailed information.

3 Dynamic Test

The following requirements were used when the dynamic test site [3] was selected:

- Availability of an accurate position reference system.
- Easy access to the test range in order to minimise the transport of heavy test equipment.
- The GPS antennas should not be shaded by houses, terrain or any other obstructions.
- Free line of sight from the Vessel Unit to the Tracking Units in order to ensure good radio communication.
- No or minimal radio interference.
- The test should be performed at a time of day with good 3D satellite geometry and a few periods with 2D coverage to check the performance during fixed height periods.
- The distance between the Vessel Unit and the fixed and moving Tracking Unit should be about 3 to 5 and 0 to 10 km respectively.

The NATO FORACS test range was chosen as it seemed to fulfill the specified requirements in a better way than any other ranges considered. FORACS near Stavanger is instrumented with MicroFix and theodolites, and designed to measure the bearing and range accuracies of the weapon systems and navigation sensors installed in surface ships, submarines and helicopters.

The coordinates of the geodetic points, where the MicroFix transponders and theodolites are placed at the test range, are given in a local coordinate system with a defined transformation to ED50 and WGS84.

An ordinary DiffTrack system comprising one Vessel Unit and two Tracking Units was used during the test. The Vessel Unit and one Tracking Unit were placed at surveyed points. The other Tracking Unit was installed onboard a naval vessel. Range and bearing were computed by the system and logged on the Vessel Unit's floppy drive.

The FORACS MicroFix equipment performed well and provided us with the proper reference. The time-tagging of the MicroFix data was done by setting the clock of the FORACS computer manually to the GPS receiver time.

3.1 Processing method

A computer program system for post-processing has been developed by KN and used to process the test measurements and perform the quality control.

The data were processed by various programs in the following ways:

- Transformed all the MicroFix derived positions into WGS84.
- Calculated the true range and bearing between the geodetic points based on the known coordinates, as well as the true Delta Northing and Delta Easting for comparison with our measurements.
- Found the time slips due to differences in satellite constellations and ephemeris observed by the various units in the system. A time slip is defined as a period above 40 seconds, when the system is unable to update results for a Tracking Unit.
- Calculated the differences (DiffTrack minus MicroFix, ΔNorth & ΔEast) in positions given by the DiffTrack and MicroFix systems. The differences were also converted into an Along-Track / Across-Track coordinate system.

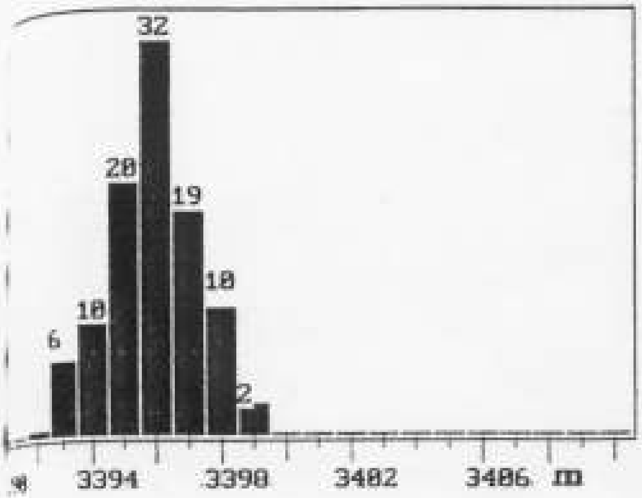

Figure 6: Histograms of starboard tailbuoy for a typical line run on M/V GECO MY.

There is an increase in DiffTrack radio link fault transmissions during two boat operations due to crosstalk between the two links. The link is almost perfect when no interference and impedance problems are present, with a fault rate of less than 1 %. The major problem is power failure in the tailbuoy itself, caused by debris in the propeller of the power generator.

DiffTrack was out for a few minutes due to poor satellite coverage twice during the day/night in the Barents Sea this summer. The elevation mask was 8 degrees in order to decrease periods of poor satellite coverage. Normally a 10 degrees elevation mask is used in order to avoid multipath and bad signal conditions. However, the client's demand for continuous positioning is the decisive factor in an offshore situation.

DiffTrack is slightly affected by heavy seas, but has proved to work even in storms and wave heights up to 10 meters.

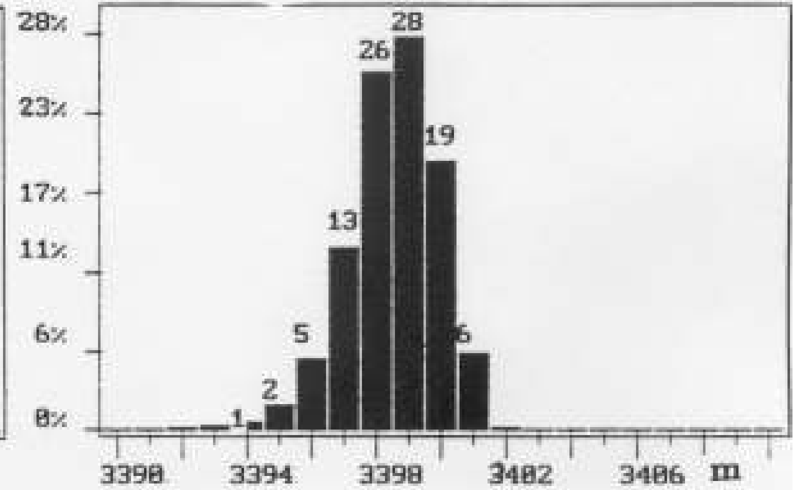

Figure 7: Histograms of port tailbuoy for a typical line run on M/V GECO MY.

Table 2: Vessels in operation and days DiffTrack has been operative:

M/V	Period	Days
BASTØY	September	
GECO ECHO	Mar. - Aug.	>120
GECO GAMMA	May. - Aug.	> 80
GECO MY	Apr. - Aug.	>100
GECO SIGMA	Apr. - Aug.	>100
MASTER TOR	July - Aug.	> 40
Total	Mar. - Aug.	>440

Table 3: Range in meters and bearings in degrees for the tailbuoys during a typical line run on M/V GECO MY:

Buoy	Range		Angle		No.
	Mean	Sd	Mean	Sd	Samples
Port	3396.3	1.3	268.2	1.5	2378
Stbd	3399.0	1.7	269.8	1.5	2162

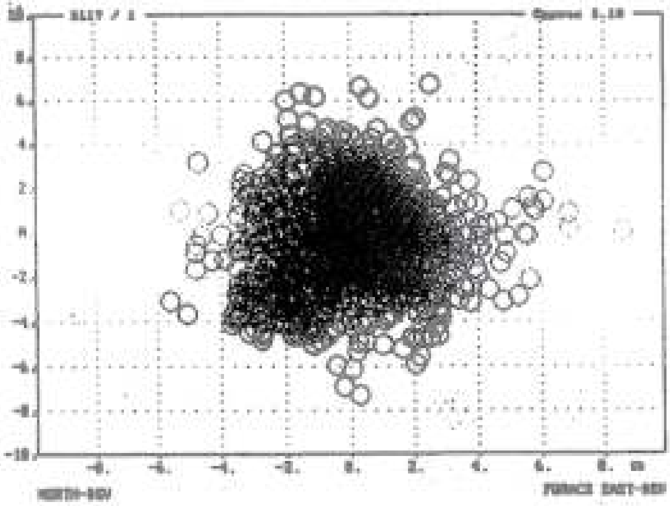

Figure 4: Scatter plot of DNORTH and DEAST for the moving TU at FORACS

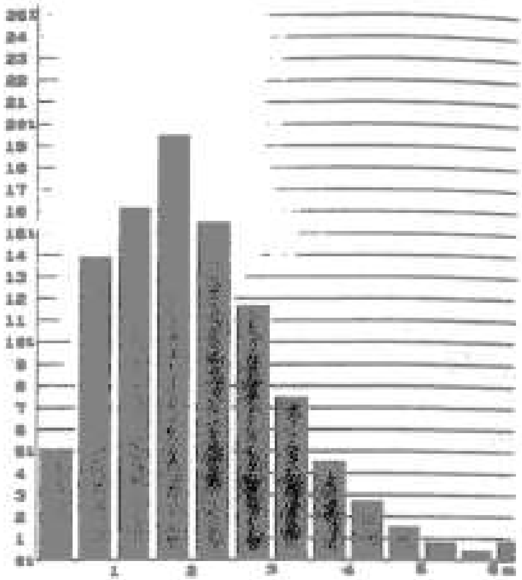

Figure 5: Total Deviation histogram for the moving TU at FORACS

Table 1: Deviation (m) from ground truth for the fixed Tracking Unit, and difference (m) between DiffTrack and MicroFix for the moving Tracking Unit at FORACS:

	Delta Northing		Delta Easting		Samples	
Unit	Mean	Sd	Mean	Sd	OK	Rej.
Fix.	0.4	1.3	-0.1	0.8	3201	2
Mov.	-0.1	1.8	0.2	1.9	2117	1

- A residual time synchronisation error between MicroFix and DiffTrack was estimated to -1.22 seconds based on minimising the Along-Track mean deviation for the whole period. All time-tags were adjusted accordingly for the final processing.

3.2 Results

The results from the test are given in table 1. Fig. 4 shows a scatter plot of DNORTH and DEAST for the moving Tracking Unit, and fig. 5 a histogram showing the distribution of the deviations from the MicroFix reference system.

The results of the test show that:

- The static accuracy of DiffTrack is 3 meter (2dRMS).
- The dynamic accuracy of DiffTrack relative to MicroFix is 4 meter (2dRMS).
- The tests have shown that the use of fixed height has no influence on the accuracy, when the satellite geometry is good, but that it is important to use a good estimate when fixing the height in periods of poor satellite geometry.
- Different synchronisation times of the GPS receivers does not influence the accuracy of the system.

4 Operational Experience

At present, we have 6 systems (table 2) in operation on 4 GECO PRAKLA and 1 Master Seismic vessels in the North Sea, Norwegian Sea and Barents Sea plus a ferry going between the cities of Horten and Moss in the Oslofjord. The reports from our operators prove that the system lives up to it's specifications. Norske Shell has expressed that they could not have done the 3D seismic surveys in the Barents Sea without our system, and other companies have followed their example.

Table 3 and figs. 6 & 7 shows a typical example of one line run and the estimated standard deviations of the range given in a dynamic situation with the drift caused by wind and sea currents included. The results are taken from an operation onboard *M/V GECO MY* this summer.

5 Conclusion

- DiffTrack is more than acceptable for offshore operation, but a quicker update rate and elimination of time slips is necessary for harbour traffic management and aviation.
- Low elevation satellites tend to cause periods when DiffTrack is unable to update the position of a Tracking Unit. These socalled time slips are due to the relative position difference method, which requires equal satellite constellations in all units to be able to present a correct solution.
- Test results and operational experience clearly shows that counter measures should be taken to reduce the size and frequency of time slips.
- Static accuracy 3.0 m (2dRMS).
- Dynamic accuracy 4.0 m (2dRMS).
- Radio link crosstalk during two boat operations can be avoided by using UHF with greater separation in frequency between the two links, or a mix of VHF and UHF.

These conclusions are based upon the field operations of 5 seismic exploration vessels and one ferry since March 1991, as well as the results achieved in the dynamic test performed on the 25th of April 1991.

The delta pseudo range solution for DiffTrack is being implemented to avoid time slips and ensure a more continuous update of positions. This will be done by reading raw pseudo range data from the GPS receiver on the Tracking Unit and transfer them on the radio link to the Vessel Unit where the necessary calculations will be performed.

A future prospect is the integration of the KN differential GPS system, DiffStar, and DiffTrack in order to save a GPS receiver onboard the vessel and also to improve the efficiency of the operation.

A more ruggedised version of the tailbuoy Tracking Unit is under development to handle rougher conditions offshore. Data compression is also being tested to increase the actual transfer rate of data, and the UHF band is used to decrease the bit error rate and increase the baudrate.

The rapid development of microelectronics will certainly affect our future choice of components for the radio link and micro computers and thus bringing down the size of the system, and the total polling sequence time.

Acknowledgements

We would like to thank the following persons and companies:

Mr. Kolbjørn Sæther, *Head of Topographical Services, Exploration and Production, Norske Shell, who has been our main source of inspiration and application information.*

Mr. Paul Edge, *Head of Group Topographical Services, Exploration and Production, representing Shell International, in supporting the project.*

Capt. Helge W. Norberg *and his officers and crew at FORACS for providing us access to their test range and assisting us with a proper reference for the dynamic accuracy of DiffTrack.*

Saga Petroleum and Norsk Hydro *for implementing DiffTrack in their present seismic surveys.*

QPS *for providing the histograms in figs. 6 & 7 based on their real-time quality control of DiffTrack during the operation onboard* **M/V GECO MY.**

GECO PRAKLA *and the assistance of their navigators, seismic personnel, crew and officers during operations, in particular providing the tailbuoy.*

References

[1] Kongsberg Navigation. *DIFFTRACK. System Description.* Systems Division, Kongsberg Navigation (February 1991).

[2] Eivind Wist. *DIFFTRACK STATIC TEST.* Kongsberg Navigation (February 1991).

[3] Torbjørn Hals, Inge Bjart Torkildsen & Eivind Wist. *DIFFTRACK DYNAMIC TEST at FORACS 25.04.91.* Kongsberg Navigation (June 1991).

[4] Håssein Ræsmasma. *DIFFTRACK RADIO LINK TESTS.* Systems Division, Kongsberg Navigation (May 1991).

[5] Kongsberg Navigation. *DIFFTRACK. Operators Manual.* Systems Division, Kongsberg Navigation (February 1991).