Using TerraPOS for efficient and accurate marine positioning

N. S. Kjørsvik and Even Brøste
TerraTec AS, PO. BOX 513, N-1327 Lysaker, Norway
March 24, 2009

Keywords. GNSS, PPP, Marine positioning

Abstract. Precise Point Positioning (PPP) is a technique where observations from a single Global Navigation Satellite System (GNSS) receiver are used. PPP does not use data from dedicated reference receivers, instead precise ephemerides and satellite clock corrections must be provided. PPP is thus logistically a very competitive alternative to differential GNSS methods.

For post-processing applications, precise ephemerides and satellite clock corrections can be freely downloaded from the Internet. No expensive real-time correction services are required.

This paper describes the fundamentals of PPP processing, and briefly discusses the TerraPOS implementation.

PPP performance in a marine environment is assessed through an extensive test, covering almost 40 days of 1 Hz GNSS data. This test demonstrates PPP accuracy in the range of 5 cm horizontal and 6 cm vertical at the 95% level.

Precise ellipsoidal heights in combination with Mean Sea Surface models may in some applications replace the tedious process of local tide measurements.

1 Introduction

Traditionally, hydrographic depth measurements have been related to the local tide. This implies that both the local tide and the vessel's heave motion have to be accurately measured. While heave motion usually effectively can be estimated by a Motion Reference Unit, accurate knowledge of the local tide can be difficult and tedious to obtain. In addition, the draft of the echo sounder may be in error due to e.g. variations in speed, fuel and water supplies, etc.

As an alternative, depths obtained from GNSS-based methods, referring to the ellipsoid, may be transformed to an appropriate reference level by using e.g. a Mean Sea Surface (MSS) model. This approach obsoletes the demanding task of local tide measurements, as well as heave and draft compensation. With the advent of increasingly more accurate MSS models, an improved transformation may be applied to the original time-invariant ellipsoidal heights in the database. This approach is very efficient, as long as the combined error of the GNSS heights and the MSS model meets the requirements.

Marine positioning with high accuracy requirements has historically posed some challenges logistically and economically. The GPS Standard Positioning Service (SPS) is globally and freely available, however too inaccurate for many purposes. Real-Time Kinematic GNSS with a local reference station is free of use once the equipment has been obtained, and has cm-level accuracy. Its operating range is however limited to some 10 km, making it unusable for many applications. In addition, deployment of local reference stations in coastal areas is both tedious, costly and possibly also risky during changing weather conditions. Real-time services with satellite-based corrections are accurate to a few dm, but can be quite expensive. Transmission of corrections is usually by geostationary satellites, which may pose reception problems at very high latitudes.

Precise Point Positioning (PPP) using GPS satellites was first developed for post-processing and static applications (e.g. Zumberge *et al.*, 1997). Later developments extended the use to both kinematic and real-time applications (e.g. Kouba and Heroux, 2001; Muellerschoen *et al.*, 2000).

PPP may be considered a refinement of the Standard Positioning Service. Major error sources in the SPS are satellite orbit and clock errors, ionospheric and tropospheric delays and code phase multipath. Replacing the broadcast ephemeris with precise ephemeris and high rate satellite clock corrections (e.g. from the International GNSS Service) reduces the corresponding contribution to ranging errors to the centimeter-level. Furthermore, employing dual-frequency carrier phase observations as the main observable eliminates ionospheric errors and alleviates the impact of code phase multipath errors. Tropospheric delay errors must be estimated together with other parameters, reducing residual range errors to the centimeter-level even for low-elevation satellites.

In order to obtain highly accurate ranges from undifferenced observations a great number of geophysical and hardware related effects requires careful modeling and compensation. Relevant effects include e.g. solid earth tide and ocean loading displacements, satellite and receiver hardware biases, satellite and receiver antenna effects, satellite attitude, etc.

Hardware biases in satellites and receivers make the identification of integer carrier phase ambiguities a very challenging task, and in the standard PPP model the ambiguities are not estimated as integers but real numbers (i.e. a so-called "float solution"). Observations for some tens of minutes, preferably a few hours, are required for proper convergence of a float-solution. In general, accuracy is increased with the length of the data set.

PPP algorithms may be employed in real-time or post-mission. In general, post-processing is nevertheless *always* statistically superior to real-time estimation. Figure 1 shows the general relation between precision of a real-time estimate vs. a post-processed estimate. From

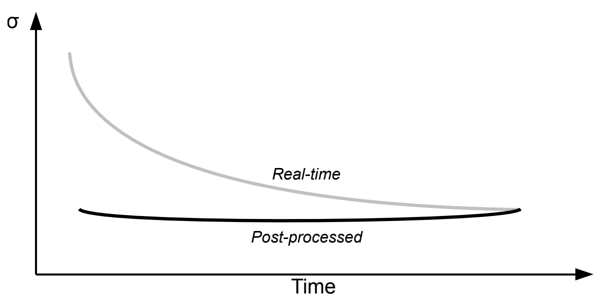

Fig. 1. Relation between precision of real-time and post-processed estimates.

this figure, it is also clear that the convergence period of a real-time solution (with steadily improving precision) is not present in post-processed solution, where homogeneous accuracy is available throughout the entire data set.

Post-processed PPP will in fact gain accuracy twice over real-time PPP services. At first, satellite ephemeris and satellite clock corrections are post-processed estimates, as opposed to real-time predictions. At last, the positioning of the user platform is also based on post-processing.

Many marine applications have only modest requirements for real-time accuracy. Real-time position is e.g. only used for navigation purposes and to verify completeness and coverage of the surveyed data, while an accurate final trajectory can be computed at some later time. Hence the SPS may often suffice for real-time navigation and data verification, making post-processed PPP an ideal complementary approach.

For other investigations of PPP in marine environments see e.g. Øvstedal *et al.* (2002) and Kjørsvik *et al.* (2006).

The remainder of this paper is dedicated to a description of the PPP software TerraPOS, culminating with results of an extensive performance study.

2 TerraPOS

TerraPOS is a software product from TerraTec AS, Norway, implementing PPP for post-processing. TerraPOS has been commercially available since 2006, following extensive testing by the Norwegian Hydrographic Service (NHS). The NHS has pioneered post-processed PPP for marine applications since the early 2000's (Øvstedal *et al.*, 2002), and currently relies solely on TerraPOS for hydrographic surveys.

The primary design goals for TerraPOS were accuracy, robustness, quality control of kinematic data and to provide a clean user interface. All data editing is fully automated, and ideally suited for batch-processing of large data-sets. The result is an unprecedented combination of state-of-the-art accuracy and overall ease of use. To allow the customer full flexibility, TerraPOS is supported on both MS Windows and GNU/Linux operating systems, with both command-line and graphical user interfaces.

TerraPOS uses internationally recognized and open file formats for all input, hence any geodetic grade GNSS receiver equipment may be used. Data can be processed in GPS or GPS/GLONASS mode, utilizing all available observables (code and carrier phases and Doppler).

TerraPOS is compatible with the latest IERS conventions (McCarthy and Pétit, 2004), as well as IGS recommendations. TerraPOS utilizes an optimal Kalman filter and smoother combination (e.g. Gelb, 1974).

In conclusion, TerraPOS offers capabilities previously only available in scientific software packages, combined with the robustness and ease of use required for demanding production lines.

Figure 2 depicts the general work-flow when using TerraPOS.

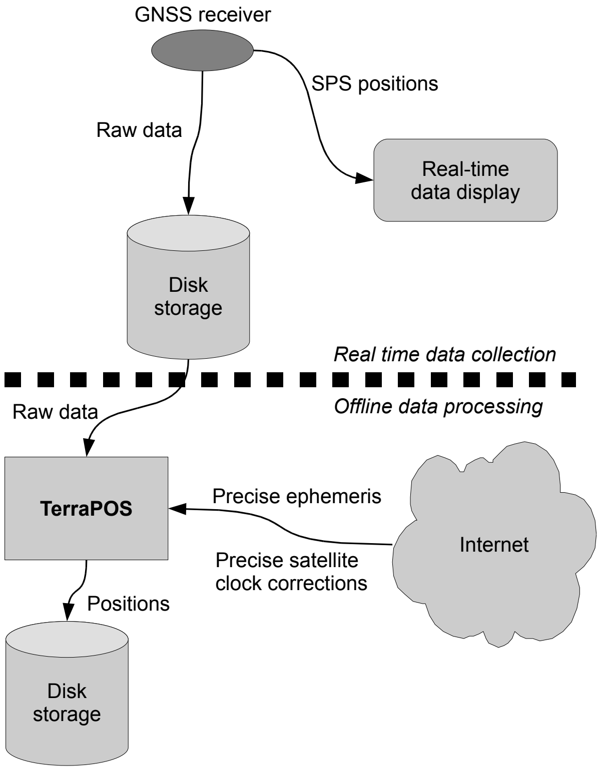

Fig. 2. TerraPOS work-flow.

3 Performance verification

3.1 Test data

In order to verify the performance of TerraPOS in a marine environment, the Norwegian Hydrographic Service conducted a large scale test during March to May 2006. Almost 40 days of 1 Hz GNSS observations were collected on the shuttle ferry traveling between Lauvvik and Oanes outside Stavanger, Norway. All data collection, processing and analysis were performed by NHS staff.

The ferry and the local reference station were equipped with Topcon Legacy GNSS receivers and identical geodetic antennas. The ferry route is approximately 1.5 km long, and repeated every half an hour. The terrain in the area is relatively flat giving very good satellite availability.

GLONASS observations have not been considered in any part of the analysis.

Figure 3 shows the ferry used to collect the data, with a map of the area shown in Figure 4.

Fig. 3. Shuttle ferry carrying the GNSS receiver.

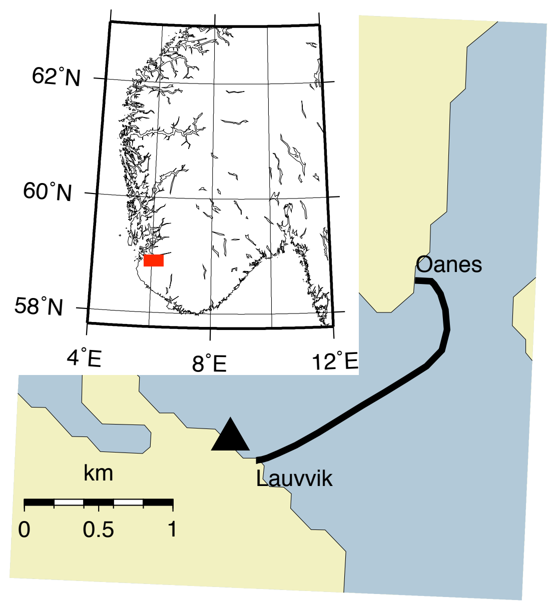

Fig. 4. Map showing the test area. The triangle denotes the local reference station.

3.2 Reference trajectory

A reference trajectory was computed post-mission using a local (< 2 km) reference station with fixed double-differenced ambiguities. To ensure high confidence, a total of 6 different software packages for differential GPS were employed. Using an iterated weighting scheme, the final weighted average constitutes the reference trajectory.

3.3 Data processing

TerraPOS was run in 26 h batches, exporting the central 24 h for each run. The concatenated results were used for further analysis. Approximately 3.3 million epochs were analyzed. A TerraPOS solution was available for 99.98% of the epochs investigated. Comparison with the reference trajectory yields the results presented in Tables 1–2. Note that these statistics also include errors due to reference frame transformations and errors in the local reference station coordinates.

Table 1. Horizontal accuracy statistics.

	95%	**99%**	**Max**	**Mean**
Lat	0.040 m	0.052 m	0.173 m	-0.010 m
Lon	0.040 m	0.052 m	0.096 m	0.010 m
2D	0.050 m	0.062 m	0.173 m	0.026 m

Table 2. Vertical accuracy statistics.

Std dev	**95%**	**99%**	**Max**	**Mean**
0.030 m	0.061 m	0.086 m	0.329 m	0.003 m

Independent tests using Inertial Navigation Systems (not included here) have shown that TerraPOS velocities are accurate to approximately 5 cm/s (3D RMS).

4 Summary and conclusion

Precise Point Positioning constitutes a logistically very attractive alternative to differential approaches. Post-processed PPP is highly competitive compared to real-time services in terms of both cost and accuracy.

TerraPOS performance in a marine environment has been verified by an extensive test conducted by the Norwegian Hydrographic Service. Position accuracy was found to be 5 cm horizontally and 6 cm vertically at the 95% level.

Height accuracies as documented here implies that in many applications a production based on ellipsoidal heights from GNSS can indeed be feasible.

TerraPOS is currently successfully applied in a wide range of applications. In addition to hydrography, it has proven to be a very reliable means for accurate positioning in applications ranging from Antarctic snowcat expeditions to helicopter-based laser ranging (LIDAR) missions.

Acknowledgements The authors greatly acknowledge the International GNSS Service (Dow *et al.*, 2005) for its continuing efforts. The ferry test was conducted and processed by Lars K. Nesheim and Arne E. Ofstad of the Norwegian Hydrographic Service.

References

Dow, J. M., Neilan, R. E. and Gendt, G. (2005). The International GPS Service (IGS): Celebrating the 10th Anniversary and Looking to the Next Decade. *Advances in Space Research*, **36**(3), pp. 320–326.

Gelb, A. (editor) (1974). *Applied Optimal Estimation*. The M.I.T. Press. ISBN 0262570483.

Kjørsvik, N., Gjevestad, J. G. and Øvstedal, O. (2006). Handling of the troposheric delay in kinematic Precise Point Positioning. In *Proceedings of ION GNSS 2006*, Fort Worth, TX. Institute of Navigation.

Kouba, J. and Heroux, P. (2001). GPS Precise Point Positioning Using IGS Orbit Products. *GPS Solutions*, **5**(2), pp. 12–28.

McCarthy, D. D. and Pétit, G. (editors) (2004). *IERS Conventions (2003)*. Verlag des Bundesamtes für Kartographie und Geodäsie, Frankfurt am Main. IERS Tecnical Note No. 32.

Muellerschoen, R. J., Bertiger, W. I., Lough, M., Stowers, D. and Dong, D. (2000). An Internet-Based Global Differential GPS System, Initial Results. In *Proceedings of the ION National Techinical Meeting*, Anaheim, CA. Institute of Navigation.

Øvstedal, O., Ofstad, A., Haustveit, K. and Kristiansen, O. (2002). An empirical comparison between absolute satellite positioning methods and differential methods in a maritime environment. In *Proceedings of ION GPS 2002*, Portland, OR. Institute of Navigation.

Zumberge, J. F., Heflin, M. B., Jefferson, D. C. and Watkins, M. M. (1997). Precise point positioning for the efficient and robust analysis of GPS data from large networks. *Journal of Geophysical Research*, **102**(B3), pp. 5005–5017.