En forundersøkelse av kombinert GPS, GLONASS og GALILEO for kinematisk presis punktbestemmelse (PPP)

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Jon Glenn Gjevestad et al.: A Pre-study of Combined GPS, GLONASS and GALILEO for Kinematic Precise Point Positioning (PPP)

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A pre-study of the impact of GLONASS and GALILEO on GPS-based Precise Point Positioning (PPP) has been conducted. The prestudy consists of a 24 hour simulated scenario of a vessel sailing through parts of the Sognefjord in Norway. The impact of GLONASS and GALILEO on GPS PPP is quantified in terms of satellite availability, geometry and reliability.

Key words: precise point positioning, simulated pre-study

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Introduction

At present Precise Point Positioning (PPP) provides sub-decimeter kinematic positioning accuracy, and together with simplified logistics, PPP represents a viable alternative for many applications, e.g. large scale surveys.

Due to biases present in both satellite and receiver hardware, the integer carrier phase ambiguities may currently not be reliably identified as integers. For this reason, the ambiguity parameters must be estimated as real numbers, a so-called float solution. This float solution will be highly accurate if there is sufficient convergence of the ambiguity parameters. Using GPS alone, the PPP convergence time will typically be 20-60 minutes if continuous carrier phase observations are provided from a sufficient number of well-distributed satellites.

In many applications these requirements can not be fully met, e.g. due to topographic constraints. The result is an increase in convergence time of the ambiguity parameters, or even failure to meet specified quality criteria. To compensate for increased convergence time in these situations, the PPP solution would benefit from an increased number of satellites provided by other satellite-based navigation systems such as GLONASS and GALILEO.

The integrity and reliability of the system is as important as rapid convergence. Integrity, the ability to detect and remove erroneous observations, is closely related to the redundancy of the system. Redundancy can be greatly improved by increasing the number of simultaneously observed satellites. The reliability of the system is a measure of the impact of undetectable errors in the observations, and is thus largely dependent on the integrity.

Future GALILEO and modernized GLONASS will have performance comparable to modernized GPS when fully operative and can therefore be expected to give a significant contribution under all conditions.

Simulation

The geometric scenario used in this prestudy is fully simulated based on a predefined trajectory of a vessel within a narrow and steep Norwegian fjord. Observation data were simulated using software developed inhouse (Kjørsvik et al. 2004). The topography of a fjord was simulated using a Digital Elevation Model (DEM) and the artificial hori-

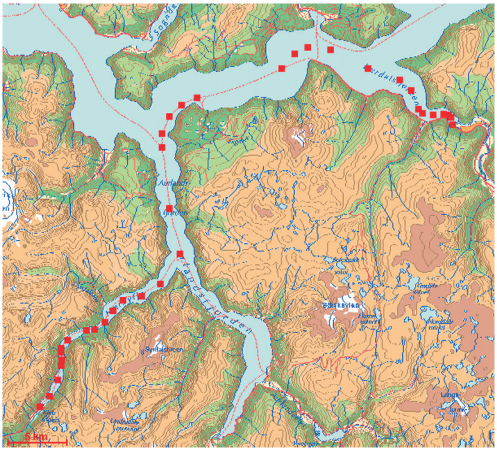

Figure 1 – Vessel trajectory through the Sognefjord

zon was applied to the simulated data to limit satellite availability.

The simulated scenario is based on the RINEX format for the observations and satellite clock corrections, and on the SP3 format for the satellite orbits. The stochastic model consists of *a priori* variances for observation noise and multipath, as well as stability of the satellite frequency standards as expressed by Allan variances.

Effects that normally must be considered in PPP include satellite antenna offsets and phase center variations, satellite hardware biases, phase windup and satellite yaw. These effects are mostly deterministic. Models or corrections are available and they may safely be ignored in a simulation. Ionospheric effects can be largely eliminated using dual-frequency observations and tropospheric effects can be handled using a combination of *a priori* models and estimation of residual effects. Signal propagation errors may thus be safely ignored in this context. Deterministic effects at the receiver side include phase center offsets and variations, receiver hardware delays, rotational deformation due to polar motion, solid earth tides and ocean loading tides, all of which may be safely ignored in this simulation.

We focus the investigation on the height component. Height is of primary importance in many marine survey applications and will usually be the most unreliable component due to the satellite-receiver geometry.

Table 1 – GNSS orbit description

YUMA	GPS	GLONASS	GALILEO
Almanac	Real	Simulated	Simulated
Number of Satellites	29	24	27
Orbital Planes	6	3	3
Eccentricity	-	0	0
Orbital Inclination(deg)	55	64.8	56
Right Ascen at Week(deg)	-	60, 180, 300	0, 120, 240
Altitude (km)	20200	19100	23222
Week	1371	1371	1371

The simulator is prototyped in MATLAB and consists of several subroutines covering the various steps in the simulation process. The simulator steps are summarized below.

Main Simulator Steps

1. YUMA almanac (GPS, GLONASS, GALILEO)
   GPS: Real almanac week 1371 (29 satellites)
   GLO: Synthetic almanac (24 satellites)
   GAL: Synthetic almanac (29 satellites)
2. Convert from YUMA to tabulated coordinates in SP3 format
3. Interpolate SP3 orbits
4. Generate satellite coordinates and biases
5. Generate synthetic trajectory
6. Generate synthetic observations (RINEX)

Results

The performance parameters emphasized in this simulation study are: satellite availability, geometry and reliability. All three systems involved are processed in all possible combinations.

Quality Control Criteria

The quality control criteria for this simulation are defined as:

- No Solution
  PDOP > 100
  # Satellites < 4

- Rejection Limits
  Precision: σ_{hor}=0.10m, σ_{vert}=0.15m
  Reliability: r_{hor}=0.30m, r_{vert}=0.45m

where σ denotes computed standard deviation of coordinates and r denotes computed reliability of coordinates.

If any of these criteria are exceeded, the solution will be rejected in the quality control.

Single System

The single system performance is fairly similar under all three systems. The satellite availability varies from a minimum of 4 satellites to a maximum of approximately 12 satellites. The satellite geometry expressed as PDOP shows many large spikes indicating long periods with severe degradation of the satellite geometry. The height reliability measure is highly correlated with the PDOP and reaches far beyond the 4m level in many epochs.

The results for GPS, GLONASS and GALILEO respectively are given below.

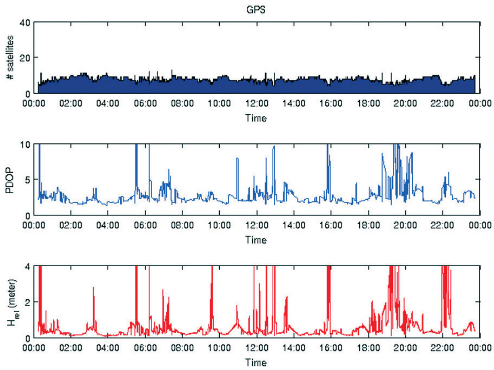

Figure 2 – Availability, dilution of precision and height reliability for GPS

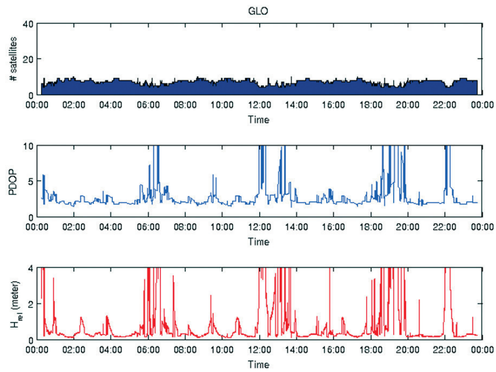

Figure 3 – Availability, dilution of precision and height reliability for GLONASS

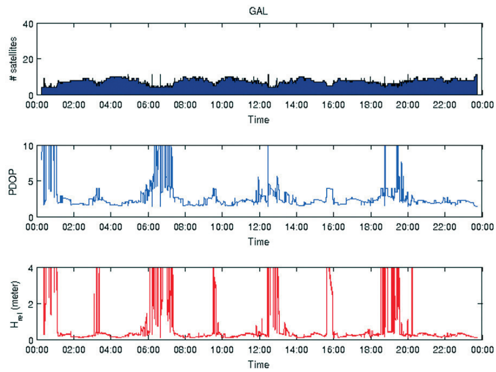

Figure 4 – Availability, dilution of precision and height reliability for GALILEO

A cumulative plot of the distribution of height reliability in the single system scenario shows rather poor performance. Approximately 20% of the solutions exceed 1m reliability in height. Note also that none of the single systems are able to provide solutions for all epochs.

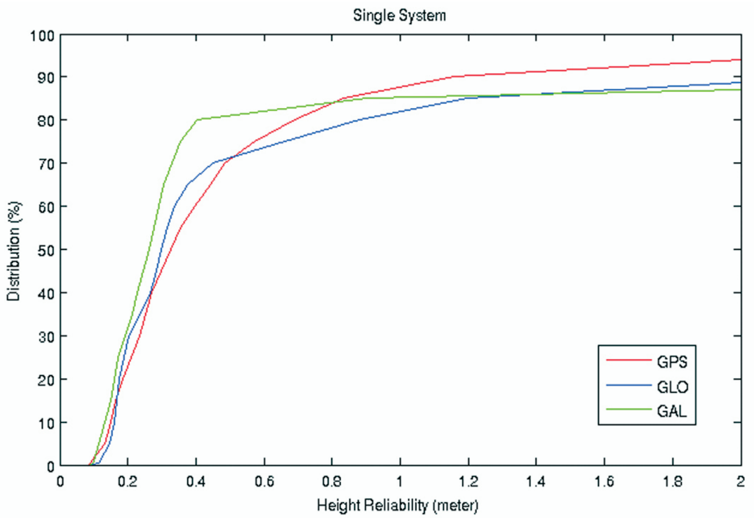

Figure 5 – Distribution of height reliability for single system

System	No Solution	Rejected
GPS	0h 0m 20.0s (0.02%)	8h 0m 31.0s (34.1%)
GLO	0h 11m 7.0s (0.78%)	6h 59m 30.0s (30.0%)
GAL	0h 32m 37.0s (2.31%)	5h 0m 41.0s (21.8%)

Table 2 – Quality control for single system

Dual System

With a combination of two systems the situation greatly improves and a valid solution is available at every epoch. Approximately 98% of the solutions meet the specified quality criteria.

Results for the various dual combinations of GPS, GLONASS and GALILEO are shown below.

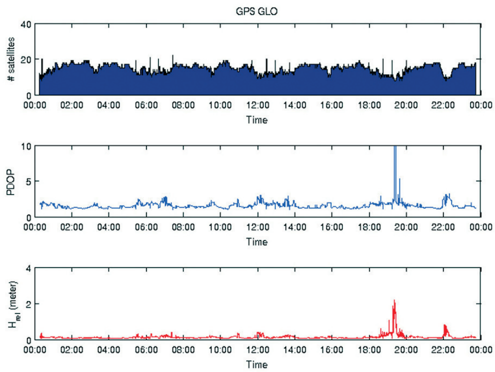

Figure 6 – Availability, dilution of precision and height reliability for GPS/GLONASS

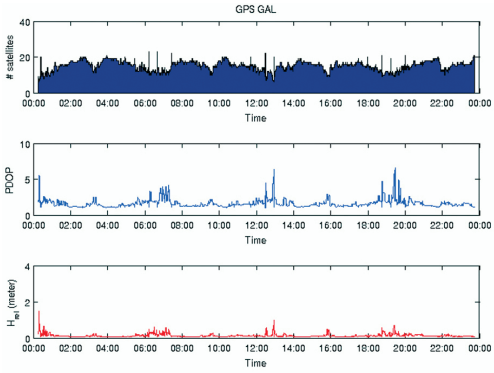

Figure 7 – Availability, dilution of precision and height reliability for GPS / GALILEO

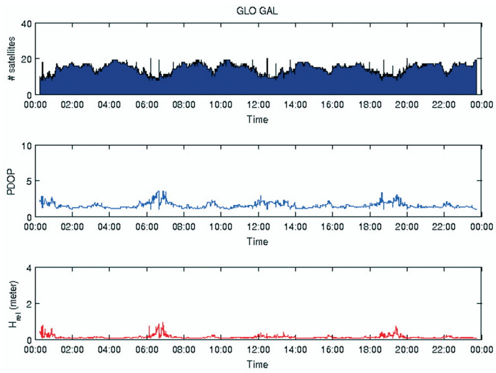

Figure 8 – Availability, dilution of precision and height reliability for GLONASS / GALILEO

The cumulative plot for the distribution of height reliability in the dual system combination is greatly improved compared to the single system scenario. The rejected solutions account for approximately 20–30 minutes in sum.

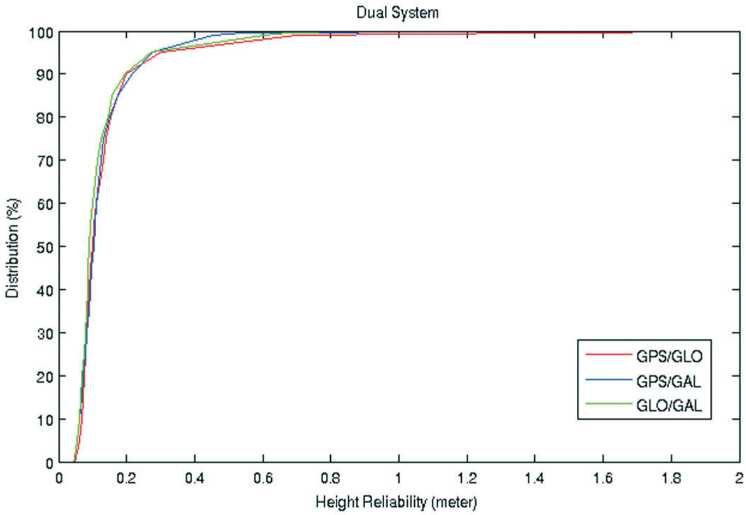

Figure 9 – Distribution of height reliability for dual system

System	Accepted	Rejected
GPS/GLO	23h 7m 17.0s (98.4%)	0h 22m 43.0s (1.6%)
GPS/GAL	23h 9m 41.0s (98.6%)	0h 20m 19.0s (1.4%)
GLO/GAL	23h 0m 17.0s (97.9%)	0h 29m 43.0s (2.1%)

Table 3 – Quality control for dual system

Triple System

With a combination of all systems the height reliability is at the decimeter level and is available at a remarkable 99.7%, even under the extreme topography in this simulation.

The results for the triple combination of GPS, GLONASS and GALILEO is shown below.

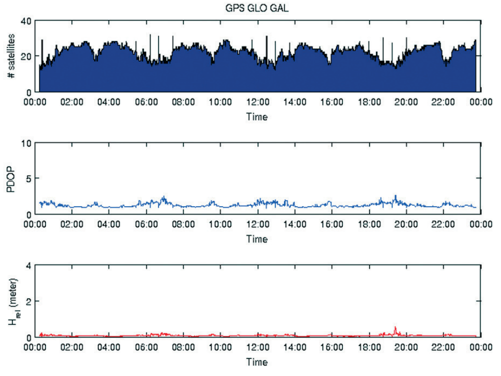

Figure 10 – Availability, dilution of precision and height reliability for GPS / GLONASS / GALILEO

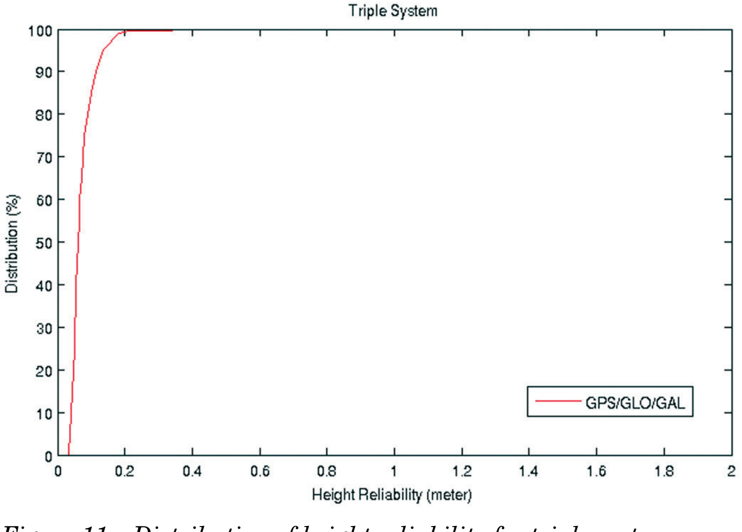

Figure 11 – Distribution of height reliability for triple system

System	Accepted	Rejected
GPS/GLO/GAL	23h 26m 24.0s (99.7%)	0h 3m 36.0s (0.3%)

Table 4 – Quality control for triple system

Conclusion

This investigation demonstrates the contribution of GLONASS and GALILEO to kinematic GPS PPP in an extreme marine environment. The contribution from GLONASS and GALILEO is simulated based on nominal constellations. Synthetic orbits are realized in the SP3 format.

There are three main observations to be made from the simulation:

- **No** single system provides solutions for all epochs
- **All** of the dual system combinations provide reliability measures at the meter level (r_{vert}<1.5m, 99%).
- **Only** the triple system combination provides reliability measures at the decimeter level (r_{vert}<21cm, 99%).

References

N. S. Kjørsvik, K. Radzeviciute, J. G. G. Svendsen and O. Øvstedal (2005) A software-based GNSS simulator for research and education. KART OG PLAN, Vol 65, pp. 84-86.