Perspective of Galileo in Geophysical Monitoring: The Geolocalnet Project

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Abstract. Earth crust deformation continuous monitoring using Global Navigation Satellite System (GNSS) local geodetic networks demands suitable computational and informatics tools based on solid scientific background. This is particularly true if geophysical applications are concerned. Applications like seismic hazard mitigation, subsidence and landslides monitoring requires the highest accuracy in positioning with as short as possible measurements sessions length. The GEOLOCALNET project, co-funded by the Galileo Joint Undertaking (GJU) under the 6th Framework Program and managed by a consortium of Research Unit (RU) and Small and Medium Enterprises (SME), investigates the three carriers based Galileo Satellite System positioning capability developing and validating innovative algorithms, models and estimation procedure*s*.

The project addresses many and critical issues affecting precision and stability in GNSS processing strategies and promotes the usage of local geodetic networks for deformation evolution monitoring.

1 Introduction

GNSS has been used for many years for the deformation monitoring of manmade structures such as bridges, dams and buildings, as well as geophysical applications, including the measurement of crustal motion, and the monitoring of the ground subsidence and volcanic activity.

Modernized GNSS systems, such as GALILEO, based on three-carriers signal, offer the opportunity to address the NRT high precision positioning issue, and the GEOLOCALNET project objective is the utilization of GALILEO multiple frequencies to improve the accuracy in differential carrier-phase based positioning techniques and to promote the use of the local geodetic networks for Earth crust deformation monitoring.

The present work is organized as follow. In section 2 the whole project is briefly described, emphasizing the application background and the monitoring requirements in particular. Translation of requirements into algorithms is discussed in section 3, where the software prototype characteristics are presented and the implemented processing strategy discussed. After giving an insight into the established test plan for the GEOLOCALNET prototype validation in section 4, section 5 illustrates some preliminary numerical results. Conclusions are drawn in section 6.

2 Geolocalnet Project

2.1 Consortium Partners

GEOLOCALNET is a one-year project co-funded by the GJU aiming to fully exploit the new expected performances of GALILEO system.

Both RU and SME, belonging to the European Union, compose the Consortium involved in the GEOLOCALNET project. The Prime Contractor of the project is Galileian Plus S.r.l. (Italian SME). Other contractors are Space Engineering (Italian SME), Harpha Sea (Slovenian SME), University Ljubljana (Slovenian RU), University of Milan (Italian RU) and University of Jaen (Spanish RU).

Partners' background guarantees solid scientific knowledge, computational and informatics capability to properly address the GALILEO data processing issue in the frame of high accuracy positioning.

2.2 Application Background

The project main purpose is to develop and to validate innovative algorithms, models and procedures to improve the accuracy in differential positioning and to promote the use of local geodetic networks for Earth crust deformation monitoring. A local geodetic network can be considered a local element dedicated to high accuracy relative positioning measurements, through a set of GNSS receivers located in a limited area (typically $20*20\ km^2$). These networks are established to monitor the Earth crust deformations due to seismic motion, landslides and subsidence. The local deformation is measured by repeated estimations of baseline vectors between couples of fixed markers.

The accuracy in deformation determination strictly depends on the type of application, ranging from 1 cm order of magnitude for fast landslide monitoring [3] to millimetre level for active faults monitoring, which is the main application scenario of GEOLOCALNET project.

Among many geophysical events requiring high precise and fast update monitoring, seism is the most demanding one. Hereafter, discussion concerning accuracy will be focused on seismic monitoring, being aware that other deformation monitoring applications caused by other geophysical events (landslide, subsidence, etc.) will be by-product derived from this reference application.

Actually the currently available GNSS (GPS, GLONASS) applied to seismic monitoring allow high precise measurements indeed. Nevertheless the data amount required to obtain millimetre level precision is very large, thus preventing the possibility of NRT monitoring, as required, for example, during pre and post seismic events.

Deformation monitoring through GPS measurements, integrated with seismological studies and geophysical forward modelling, is becoming of paramount importance to discriminate areas prone to earthquake events with a given magnitude [1]. These results are obtained applying the so called intermediate-term middle-range earthquake prediction algorithms and the geophysical forward modelling, which translate surface strain fields obtained by GNSS data analysis in deep stress field at the level of the seismogenetic fault. The objective of geophysical forward modelling is to derive seismic hazard maps. A conceptual picture of the described approach is provided in Fig. 1. However, seismic hazard maps are associated to time and space uncertainties that, at present, are respectively of few years and of a few hundred kilometres. The order of magnitude of these uncertainties does not allow an effective early warning service to protect population.

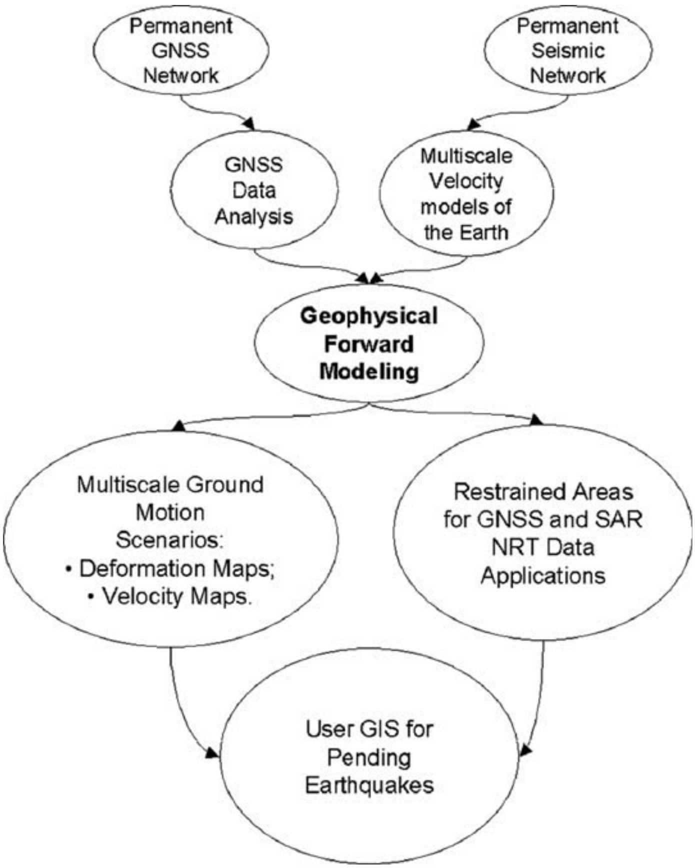

Fig. 1. Scheme of integration of geodetic information with seismic data analysis.

More refined monitoring of active faults, based on a NRT processing of data collected by local geodetic networks and on local seismicity analysis bridged together through geophysical forward modelling in the areas prone to earthquake events, is the current goal to further reduce time and space uncertainties in the prediction of the seismic events. Note that GNSS networks of permanent receivers play an important role also in the identification of the restrained areas where more refined monitoring is needed. A scheme of the NRT applications is depicted in Fig. 2.

The proposed scheme involves permanent GNSS network and analysis of seismicity to identify restrained areas for GNSS and SAR NRT monitoring (as better shown in Fig. 1), then, on a local basis, space geodetic data are analysed to provide NRT more refined information to geophysical forward modelling.

Concerning the space and time accuracy requirements, it is worth noticing that, in geodynamic monitoring of local networks, GPS accuracy is of the order of few millimetres using several hours of observations (at least three hours, with 30 seconds or higher sampling rate), while, as stated hereafter, the required accuracy is of the order of one millimetre in NRT.

What is really challenging is to explore the GALILEO capability for NRT high accuracy applications to provide a first step, in the overall approach depicted in Fig. 2, toward the provision of the essential contribution to reduce space and time uncertainties in the prevision of Earthquake events. This application is the frontier for a real support to Civil Protection in emergencies management.

2.3 Requirements for Seismic Hazard Assessment and Monitoring

Synergic use of GNSS and geophysical forward modelling complement the information gained from purely statistical analyses of earthquake historical records. In such a way the rules of seismic hazard estimate in terms of observational data and of sound physical methodologies are established. GNSS techniques, at the spatial

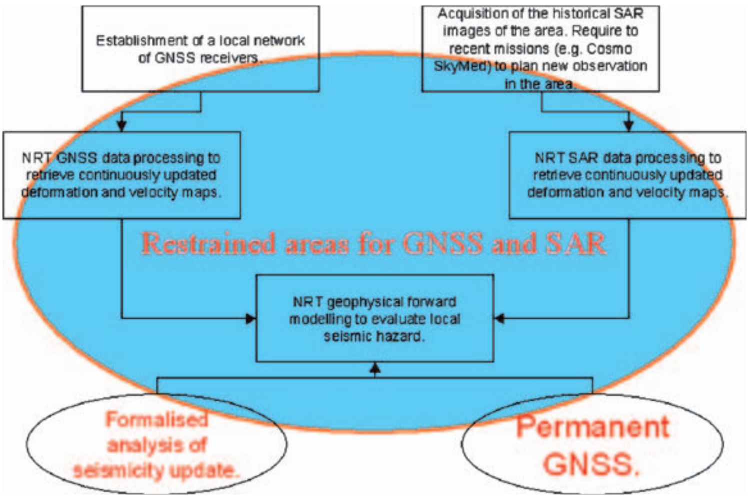

Fig. 2. Scheme of NRT applications.

scale of the seismogenic zones, coupled with expressly developed models for post-seismic, inter-seismic and pre-seismic phases within proper inversion and assimilation schemes based on GNSS data, can be used to retrieve the deformation style and stress evolution within the seismogenic zones, thus providing the tools for establishing earthquake warning criteria based on deterministic grounds.

In general, co-seismic deformation is well understood, also in terms of GNSS data, as shown for example in [5] which makes it possible to provide a static description of the event, before and after the earthquake; post-seismic deformation also started to be understood and detected in the Mediterranean region, as first shown in [1]. Thanks to the expected performance of GALILEO, it is now possible to make a step ahead in the mathematical simulation of the fault behaviour during the pre-seismic phase, by inversion of the stress field within the fault gouge from accurate, high resolution GNSS data, collected at the Earth's surface in the seismogenic zone.

An essential requirement that the new earthquake warning scheme based on GALILEO data comes directly from the observation that during the post-seismic and inter-seismic phases, relative motions across typical Mediterranean faults is of the order of millimetres per year rather than centimetres per year, as for California's faults, for example, from which it is immediately possible to establish that in order to catch the expected pre-seismic signals at the Earth's surface of Mediterranean seismogenic faults it is necessary to go beyond the performances of actual GPS receivers, which already reached the following resolution during the most advanced studies of Mediterranean post-seismic phases, over baselines of few kilometres, namely:

- 1 mm/yr, in the horizontal component;
- 2–3 mm/yr, in the vertical component;

based on yearly sampled data.

In order to detect expected pre-seismic phase Earth's crust deformation and in particular possible acceleration in deformation rates at the Earth's surface over the fault zones during the final stage of the pre-seismic phase, as expected for strongly non-linear systems, it is thus necessary to detect Earth's surface deformation, over baselines ranging from few kilometres to tens of kilometres, with the following accuracy:

- 0.3 – 0.5 mm/yr, in the horizontal component;
- 0.5 – 1 mm/yr, in the vertical component.

Besides these "static" requirements of GNSS accuracy, it is necessary to establish time interval criteria over which that accuracy should be assured, in order to catch the expected acceleration of deformation rates during the pre-seismic phase: due to the strongly non-linear dynamics of the fault, it is required that such an accuracy could be reached at the weekly rate at the most.

2.4 Prototype Overview

The proposed research is focused on GALILEO NRT data analysis SW prototype development, aiming to reduce space and time uncertainties in the frame of Earth crust monitoring having in mind the accuracy requirements for seismic hazard mitigation and therefore to realize a preliminary step forward a faster and more refined updating of seismic hazard maps.

The goal shall not be only high accuracy relative positioning, but as fast as possible reaching of a precise and reliable solution, keeping unchanged the above accuracy requirement. This is the reason for having addressed what NRT means for the GEOLOCALNET processing technique. During requirement definition analysis it has been evidenced how GPS measurements campaign, in a short baselines scenario (few hundreds meters between receivers), allow to reach millimetre level accuracy with at least three hours of data, sampled at 15 sec. Similar experiments confirms this datum [2].

This project is focused on exploiting the three-carriers capability of GALILEO system and in particular for improving at least:

- ionosphere delay modeling/estimation;
- convergence time of phase ambiguity fixing.

The second feature essential for the application proposed, as indicated in Fig. 2, is the NRT response of the algorithm. To reach this goal a dedicated ambiguity fixing algorithm have been implemented and adapted to the three-carriers capabilities of the GALILEO system.

The algorithm approach is based on double differences (DD) building technique as usually applied in local networks data analysis. This technique does not completely eliminate the ionosphere and troposphere errors, which appear to be significant for baselines greater than few kilometres. Therefore, the development of ionosphere and troposphere models is essential to maintain the precision required for geodetic networks deformation monitoring and seismic risk mitigation.

The project does not include the procurement of new hardware or tools, but the reuse of existing facilities. Data processing will thus use the upgrade of a product developed by Galileian Plus, called Network Deformation Analysis (NDA) [4]. NDA has been developed from scratch and it is based on standard geodetic processing technique [13] designed for local network of GPS receivers. NDA is able to perform single baseline adjustment using L1 and L3 (ionosphere-free phases combination) double differenced data. The resulting prototype processing strategy is outlined in the next section.

As we do not have GALILEO data available yet, one of the main tasks of this project will be the generation of simulated data. This will be achieved by means of the Galileo System Simulation Facility (GSSF), an existing GALILEO simulator tool of ESA.

2.5 Progress Status

GEOLOCALNET activity started in the end of 2005 and it will last 12 months. At the time of writing this article the project entered the second half of its duration. The first six-months activity was mainly devoted to requirement definitions, GSSF simulator analysis and some preliminary implementation activities such as new RINEX 3.0 format data reader implementation, the upgrade of pre-existing cycle slips and outliers detection and removal algorithms and to focus on the processing strategy for baseline adjustment using the three-carriers GALILEO observations data.

After the mid-term review meeting occurred on late June 2006, the project entered into the validation phase, where both simulated GALILEO data and real and simulated GPS data will be generated and used to examine the performance of the developed prototype.

3 Algorithms and Processing Strategy

Upgrading NDA version from the dual frequencies GPS data processing to the prototype that allows baseline adjustment based on three-carriers signal of modernized GNSS has been the most time consuming part of GEOLOCALNET project. Algorithms implementation ended with the midterm review milestone when debugging and preliminary test activities started. In the following, phase linear combinations used in the processing strategy are introduced before outlining the whole processing strategy, from GALILEO data acquisition to baseline solution.

3.1 Galileo Phase Linear Combinations

Wide-lane combinations, due to their large wavelength, play a prominent role in many of the GNSS ambiguity fixing procedures that have been proposed and published (see, for instance, [8]).

In this section we introduce the GALILEO wide-lanes, medium-lane and extra narrow-lane combinations and their corresponding ambiguities in the Open Service (OS) and Commercial Service (CS) frequencies scheme. In Table 1 the wavelengths of these combinations are shown.

Extra Wide-lane (EWL) linear combination is given by:

$$L_{EWL} = \lambda_{EWL}\left(\frac{L_2}{\lambda_2} - \frac{L_3}{\lambda_3}\right) \text{ with } \lambda_{EWL} = \frac{\lambda_2 \lambda_3}{\lambda_3 - \lambda_2}. \tag{1}$$

The observation equation for L_{EWL} reads:

$$\begin{aligned} L_{EWL}(t) &= R(t) + dR(t) + T(t) + c\,(dt(t) - d\tilde{t}(t-\tau)) \\ &\quad - \lambda_{EWL}\left(\frac{I_2(t)}{\lambda_2} - \frac{I_3(t)}{\lambda_3}\right) + \lambda_{EWL}(N_2 - N_3) + \varepsilon_{EWL}. \end{aligned}$$

where,
L_k is the phase observation on the k-th carrier frequency, in metres (k = 1,2,3);
λ_k is the wavelength of the k-th carrier frequency;

Table 1. Wavelength of some useful phase linear combination.

	EWL (m)	WL (m)	ML (m)	NL (m)
OS	9.768	0.814	0.751	0.125
CS	3.455	0.789	1.011	0.121

R is the geometric range between satellite and receiver (metres);
dR is the orbital error (metres);
I_i is the ionospheric delay (metres) on the i-th carrier;
T is the tropospheric delay (metres);
N_k is the phase ambiguity on the k-th carrier frequency;
ε_k is the noise of the observations;
$dt(t)$ and $d\tilde{t}(t-\tau)$ represent receiver and satellite clock offset at receiving and emission epoch (τ is the signal travelling time).

In the same way, the Wide Lane (WL) phase combination is

$$L_{WL} = \lambda_{WL}\left(\frac{L_1}{\lambda_1} - \frac{L_2}{\lambda_2}\right) \text{with } \lambda_{WL} = \frac{\lambda_1\lambda_2}{\lambda_2 - \lambda_1}. \quad (2)$$

and the corresponding WL observation equation is given by:

$$L_{WL}(t) = R(t) + dR(t) + T(t) + c\left(dt(t) - d\tilde{t}(t-\tau)\right) - \lambda_{WL}\left(\frac{I_1(t)}{\lambda_1} - \frac{I_2(t)}{\lambda_2}\right) + \lambda_{WL}(N_1 - N_2) + \varepsilon_{EWL}.$$

It is important to mention another important linear combination used in the ambiguity fixing procedure: the Extra Narrow-Lane (ENL):

$$L_{ENL} = \lambda_{ENL}\left(\frac{L_2}{\lambda_2} + \frac{L_3}{\lambda_3}\right) \text{with } \lambda_{ENL} = \frac{\lambda_2\lambda_3}{\lambda_3 + \lambda_2},$$

L_{ENL} observation equation is:

$$L_{ENL}(t) = R(t) + dR(t) + T(t) + c\left(dt(t) - d\tilde{t}(t-\tau)\right) - \lambda_{EWL}\left(\frac{I_2(t)}{\lambda_2} + \frac{I_3(t)}{\lambda_3}\right) + \lambda_{ENL}(N_2 + N_3) + \varepsilon_{EWL}.$$

Taking into account these linear combinations, the initial ambiguity N_1, N_2 and N_3 can be expressed in term of N_{EWL}, N_{WL} and N_{ENL} using the following relations:

$$\begin{cases} N_{EWL} = N_2 - N_3 \\ N_{WL} \;\; = N_1 - N_2 \\ N_{ENL} = N_2 + N_3 \end{cases} \Rightarrow \begin{cases} N_1 = N_{WL} + \frac{1}{2} N_{EWL} + \frac{1}{2} N_{ENL} \\ N_2 = \frac{1}{2}(N_{ENL} + N_{EWL}) \\ N_3 = \frac{1}{2}(N_{ENL} - N_{EWL}). \end{cases} \quad (3)$$

Relations in equation (3) will be used in baseline adjustment performed with the ionospheric-free (IF) three-carriers phases combination.

Since ionospheric effect is frequency dependent it is possible to exploit the full three-carrier capability of modernized GNSS for the first order ionospheric path error elimination. Among the many IF linear combinations, in this work it has been considered the triple frequency minimum noise combination.

A general form for the triple frequency linear combination is given by the following expression:

$$L_{IF} = \alpha L_1 + \beta L_2 + \gamma L_3, \quad (4)$$

and the correspondent associated noise can be written as:

$$\sigma_{IF} = \sqrt{\alpha^2 + \beta^2 + \gamma^2}\,\sigma_0.$$

If parameters fulfil the following two relations:

$$\begin{cases} \alpha + \beta + \gamma = 1 \\ \alpha + \dfrac{\lambda_2^2}{\lambda_1^2}\beta + \dfrac{\lambda_3^2}{\lambda_1^2}\gamma = 0, \end{cases}$$

L_{IF} is a IF phase combination, and it is possible to obtain a single parameter depending expression for the noise σ_{IF}. Minimizing it, the three values for the parameters of the minimum noise IF three carriers combination results for CS and OS frequencies respectively:

$$\begin{cases} \bar{\alpha} \cong 2.380 \\ \bar{\beta} \cong -0.134 \\ \bar{\gamma} \cong -1.246 \end{cases} \quad \text{and} \quad \begin{cases} \bar{\alpha} \cong 2.315 \\ \bar{\beta} \cong -0.479 \\ \bar{\gamma} \cong -0.836. \end{cases}$$

Supposing phase measurements noise $\sigma_0 \cong 0.0030m$, double differenced L_{IF} combination of equation (4) associated noise is: $\sigma_{IF} \cong 0.0161m$ (CS frequencies) and $\sigma_{IF} \cong 0.0150m$ (OS frequencies).

ML is for the Medium Lane phase combination, given by:

$$L_{ML} = \lambda_{ML}\left(\frac{L_1}{\lambda_1} - \frac{L_3}{\lambda_3}\right) \text{with } \lambda_{ML} = \frac{\lambda_1 \lambda_3}{\lambda_3 - \lambda_1}.$$

3.2 Baseline Estimation Strategy

The upgraded version of NDA is able to manage and process GALILEO raw data to compute the estimated baseline coordinates. The baseline estimation procedure is carried out in two parts: pre-processing and processing. Both data flowcharts are introduced in order to give insight into the overall baseline estimation strategy and to give evidence of the mitigation models used in the computation.

NDA allows the user to choose between processing GPS or Galileo (OS or CS frequencies) and to set up some processing inputs, i.e.:

- To define the measurement session length to be processed;
- To import observation and ephemeris files;
- To import antenna phase centre file and phase centre variation table (if available);
- To choose the elevation mask (cut-off angle) for each station of the network;
- To choose the baselines to be processed, fixing the station to be considered as reference;
- To choose the appropriate model to handle the atmosphere (troposphere and ionosphere) effects;
- To activate the residual tropospheric zenith path delay estimation in baseline adjustment (i.e. using double differenced observations);
- To choose the observable to be processed in baseline adjustment, i.e. E1/L1 or IF.

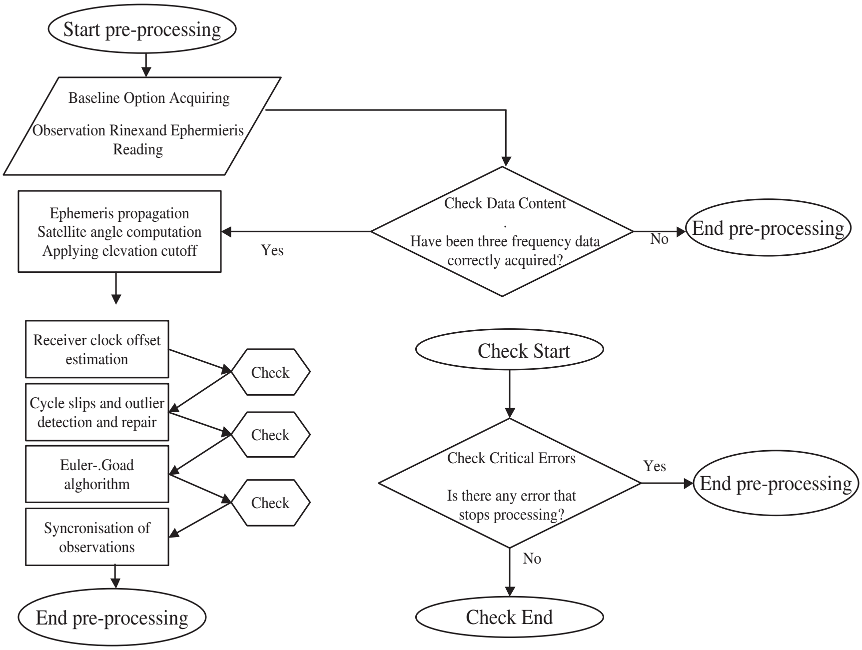

Fig. 3. Pre-processing flowchart.

After choosing operational set-up, single station data pre-processing, for every receiver that constitutes the baseline to be adjusted, can be started.

Pre-processing flowchart is shown in Fig. 3.

Operations performed in this phase include single station data acquisition, managing cycle slips and outliers, the noisy data and data under the cut-off mask editing, computing quantities such as geometrical variables, satellite coordinates at emission epoch, etc., and estimating the receiver clock offset, the dispersive and non-dispersive epoch-by-epoch path delay and the initial float ambiguity.

During each pre-processing step, controls are active to check every computational operation, verifying their reliability, and preventing the prototype collapse in presence of critical errors. Euler-Goad algorithm refers to the originally proposed algorithm [7] for single station epoch-by-epoch estimation of the dispersive, non-dispersive path delay together with the initial (float) ambiguity. The original algorithm has been upgraded for managing three-carriers GALILEO signal, as well as modernised GPS.

The purpose of this computational block is to prepare the observation data batch to processing block, i.e. to the baseline adjustment of synchronised data.

Processing allows to obtain the final baseline coordinates by keeping fixed the reference receiver coordinates to their a-priori values and applying the estimated corrections to the rover receiver coordinates only. Data processing flowchart is shown in Fig. 4.

NDA approach to be chosen (E1/L1 or IF) depends on the baseline length. If the baseline length is less than 5 km, it is suggested the E1/L1 processing, since ionospheric

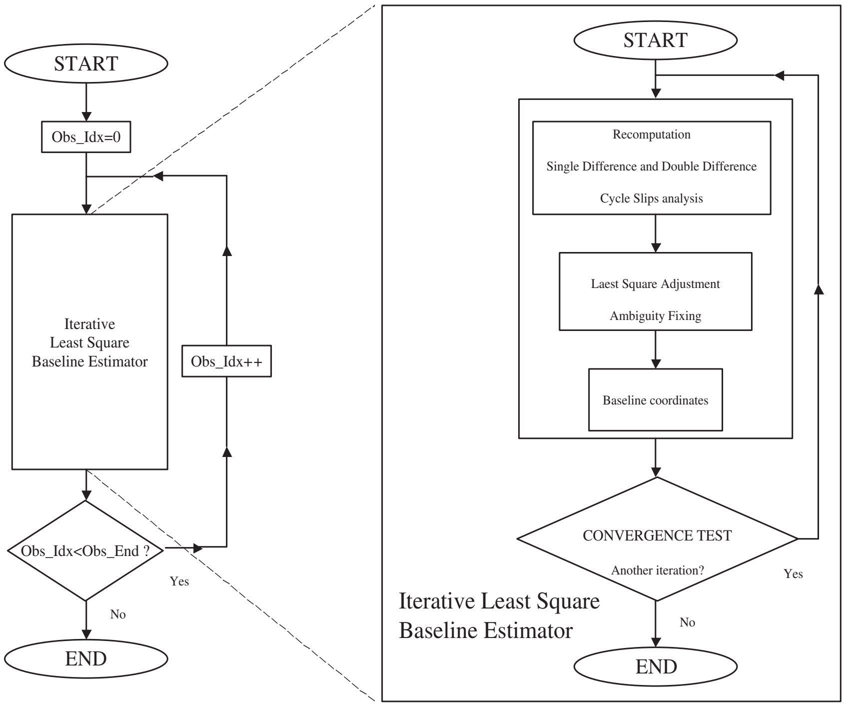

Fig. 4. Processing flowchart.

effect is common to both stations and it is mainly removed in DD procedure. When baseline length is greater than 5 km it is recommended to use the IF observable.

Data processing module mainly performs an iterative batch least squares (LS) adjustment following these steps:

- Recomputation: once coordinates corrections have been estimated, they are applied to compute satellite coordinates, geometric distance between satellite and receiver and tropospheric path delay. This step is obviously omitted in the first iteration;
- Single difference construction;
- DD construction;
- Cycle slips and outliers analysis on DD;
- LS approach: a weighted least square batch estimator is performed to estimate the corrections to (float) baseline coordinates, float ambiguities and, eventually, residual tropospheric zenith path delay, based on Saastamoinen slant model [11] or projecting the dry and wet zenith delay using the corresponding Niell mapping function [10];
- Ambiguity fixing by using LAMBDA method [12];
- Integer Least Square approach to obtain the fixed solution;
- Convergence test, if it fails another iteration starts;

- Storing the solution: baseline coordinates, ambiguities, and the estimated correction to the tropospheric zenith path delay are stored in the observation matrix for post-processing purposes.

This iteration procedure is used if single frequency (E1 / L1) DD observables are processed. If ionospheric-free DD are considered, a loop (that in Fig. 4 is represented as a loop over ObsIdx variable) over three different phase combinations starts. Phase combinations are considered in this order: EWL, WL (due to their decreasing wavelength) and IF DD. In case of IF approach, the iteration is carried out as following:

1. DD of EWL and WL combinations of equation (1) and equation (2) respectively, are considered to estimate float EWL and WL ambiguities in an LS approach. In this case the ionospheric effect is reduced by Klobuchar model [9] (with broadcast coefficients or coefficients estimated by the CODE centre - http://www.aiub.unibe.ch/ionosphere - improving the mitigation of the ionospheric effect), or the technique explained in [6]. Alternatively, float EWL ambiguities, due to their long wavelength and being the mismodeled residuals well below this value, could be obtained from the Euler-Goad algorithm extension applied to the DD of observations.
2. LAMBDA method is used to estimate integer EWL and WL ambiguities $DD\check{N}_{EWL}$, $DD\check{N}_{WL}$.
3. $DD\check{N}_{ENL}$, $DD\check{N}_{WL}$ enter as known parameters in the minimum noise ionospheric combination written in terms of DDN_{EWL}, DDN_{WL}, DDN_{ENL}, as equation (3) states. The LS approach is used to estimate a float solution (coordinates, tropospheric residual on DD, and ENL ambiguity) and LAMBDA method is used again to solve the ENL ambiguities. It is worth noticing that ENL ambiguity has an associated wavelength of 12 cm order, while the intrinsic noise of the combination is at one-tenth level. Furthermore, parity bound link between EWL fixed ambiguities and the ENL ones is used, with the effect of doubling the associated ENL wavelength.
4. $DD\check{N}_{EWL}$, $DD\check{N}_{WL}$, $DD\check{N}_{ENL}$ enter as known parameters in the minimum noise ionospheric combination. Fixed solution is obtained from an LS approach.

The iteration loop on EWL or WL observables stops when the corresponding ambiguities are all fixed, or ambiguity validation fails. In case of IF observations are processed, the iteration stops if the LS estimator reaches convergence, i.e. if the new coordinate estimated corrections do not produce any relevant change on residual variance.

4 Test Plan and Validation

The validation of the developed prototype starts at time of writing this article and it is performed through the usage of pre-existing GPS networks data (real) and the corresponding GPS and GALILEO simulated data with GSFF. Tests will make use of real and simulated GPS data to verify the consistency of the simulation environment. Simulated GALILEO data will be used to verify the capability of the developed prototype to produce baselines estimates with the millimetre level accuracy using progressively shorter time span. Furthermore NRT data analysis on GPS and GALILEO simulated data shall provide a test bed for evaluating expected improvement of GALILEO with respect to GPS system.

This approach will also have an added value, being test cases built on the basis of real existing GPS networks, thus demonstrating the capability of the developed prototype to properly address the target monitoring needs. Two test methodologies will be adopted.

Repeatability Test: using four different baselines lengths (zero, up to a Km, less than 10 Km, ≈ 30 Km) and different data session length (from one solution with 24 hours data, to 24 daily solution with one hour batch data), three different data batch will be collected and processed, namely: simulated GALILEO data, simulated GPS data and real GPS data extending over 10 consecutive days at 15 s sampling rate. With the estimated coordinates, the standard deviation of the samplings will be computed for addressing NRT performance issue, since the estimated time series repeatability shall assume the meaning of nominal accuracy for different measurement sessions. In this sense, repeatability datum represents the smallest detectable receiver displacement that the prototype will be able to detect in the considered time span.

NRT Capability Test: it shall start from the repeatability results obtained from the above-depicted analysis. Simulating GALILEO data needs to know the a-priori coordinates of the two receivers. As a consequence the only way to compare a GPS measurement with a GALILEO measurements without using a-priori coordinates estimated with the GPS itself is a system allowing knowing the baseline components of the two receivers system at a given epoch with an independent measurement equipment.

For this reason NRT capability test shall use a GPS antenna mover mechanism. It will be powered by a stepper motor and steered by software to generate linear

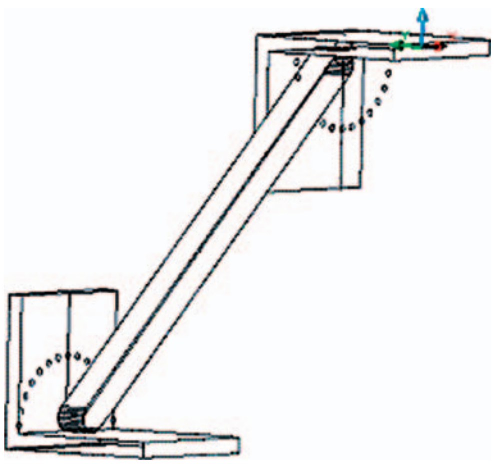

Fig. 5. Antenna mover mechanism schema.

velocities in the range of interest (a few mm/h). The accuracy of the position of the mobile equipment is less than one millimetre. The concept is shown in the schematic diagram in Fig. 5.

Different test will be performed with the aim of putting in evidence the time resolution of the a-priori known moving position of the mobile antenna, and comparing the obtained results with monitoring requirements.

5 Preliminary Numerical Results

For prototype debugging purpose two hours observations data for the GALILEO constellation and for two receivers PRO1 and PRO2 have been simulated using the GSSF. Observation are sampled at 15 s rate and they have not been corrupted by receiver noise or multipath, i.e. observations have been simulated in as best environmental condition as possible.

In Table 2, receivers coordinates, used for generating simulated RINEX 3.0 observables files, and "true" baseline components are shown.

Ephemerides have been generated in .sp3 'c' data format (the new International GNSS Service format for precise ephemeris).

Processing options used are:

- IF observable is used;
- Estimation of tropospheric zenith residual delay during baseline adjustment over both receivers;
- Integer ambiguity determination required;
- Ionospheric delay modelled with Klobuchar model with CODE estimated coefficients;
- Tropospheric delay modelled with Saastamoinen zenith model and Niell mapping function.

Figure 6 shows the NDA interface messaging during processing.

Estimated coordinates have an associated errors below the 10^{-4} and this is mainly due to the optimal simulated environmental conditions.

Results are summarized in Table 3, while in Table 4 differences between "true" and estimated baseline components and module are shown.

Table 2. GALILEO receivers' coordinates and PRO2–PRO1 baseline components and module (ITRF 2000) used to simulate the RINEX 3.0 data.

	X (m)	Y (m)	Z (m)	Module (m)
PRO1	4562839.3221	1040349.2812	4320428.0735	–
PRO2	4556822.0410	1070672.8784	4320758.4559	–
Baseline	–6017.2811	30323.5972	330.3824	30916.6196

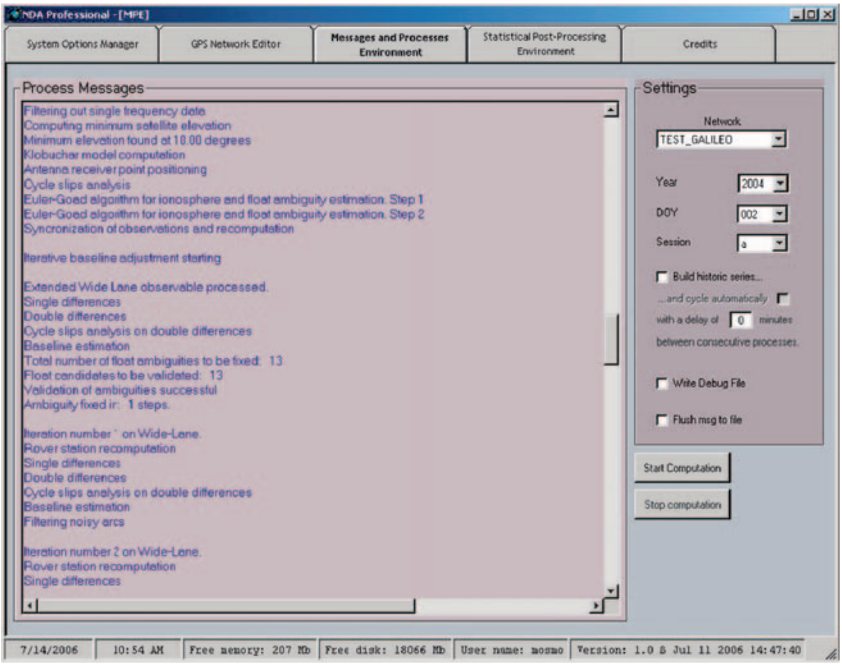

Fig. 6. NDA processes enviroment.

Table 3. Baseline adjustment results. In last column amount of data batch used in processing is shown.

Mod. (m)	X (m)	Y (m)	Z (m)	Data amount
30916.62085	−6017.2798	30323.5986	330.3841	1 hour
30916.62068	−6017.2800	30323.5984	330.3838	2 hours

Table 4. Differences between "true" values and estimated values.

Δ Mod. (m)	Δ X (m)	Δ Y (m)	Δ Z (m)	Data amount
0.0011784	0.0012440	0.0014350	0.0016793	1 hour
0.0010074	0.0010882	0.0012324	0.0014434	2 hours

6 Conclusions

GELOCALNET is a one-year long project co-funded by the GJU under the 6th Framework Program realised by a consortium of European RUs and SMEs aiming to address the high accuracy NRT monitoring issue using modernised GNSS such as GALILEO.

The project is based on upgrading an existing software module for dual frequencies GPS baseline adjustment, called NDA, to explore the GALILEO capability to provide a first step toward the essential contribution to reduce space and time uncertainties in the prevision of Earthquake events. This application is the frontier for a real support to Civil Protection in emergencies management.

GEOLOCALNET thus represents a step forward the synergic use of a solid underlying computational tool and interfacing capability for establishing warning criteria based on deterministic grounds, since future perspectives shall give the opportunity, with an integrated approach of GNSS and geophysical modelling results and methodologies, to achieve the two-fold objective of cross-validating the GALILEO performances and calibrating the geophysical models proposed for the spatial scale of the seismogenic faults, targeted towards the detection and comprehension of the dynamics of the earthquake pre-seismic phase.

At time of writing this article, the project entered the prototype validation and testing phase. This phase is devoted to test the performance of the prototype in reaching the objective of millimetre level accuracy in baseline estimation using few hours of GALILEO observations.

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