

On Analysis of LitPOS Stations Time Series and Velocities

V. Puškorius, E. Paršeliūnas, R. Baniulis, K. Galinauskas & S. Valotka
Vilnius Gediminas Technical University, Vilnius, Lithuania

ABSTRACT: LitPOS (Lithuanian Positioning System), the network of continuously operating GNSS (Global Navigation Satellite System) stations, became operational in July 2007. It provides data both for real-time and post-processing applications. LitPOS stations cover the whole territory of Lithuania. There are 31 of LitPOS GNSS stations in total network. Also LitPOS network includes 3 ASGEUPOS (Poland) and 6 LATPOS (Latvia) stations. LitPOS network data processing and analysis of station's velocities was done using Bernese 5.2, TSview and CATREF programs.

Results of analysis show that North/East velocities of the LitPOS stations are very homogeneous what leads to the conclusion that there are no any significant horizontal deformations of Earth's crust in the territory of Lithuania. Up components of LitPOS stations velocities fit very well to vertical movements of Earth's crust as described by the land uplift models of Fennoscandia.

1 INTRODUCTION

RTK (Real Time Kinematic) method for positioning is used in daily life by different consumers for many purposes. When there are so many measurements, it is essential to know where RTK measurements are concentrated and which stations are obligatory for LitPOS performance. LitPOS is a geodetic infrastructure for referencing spatial geoinformation, also it provides the direct linkage to the National Coordinate System and height datum.

LitPOS network data processing was done using Bernese 5.2 software. Software was slightly improved by editing scripts and writing procedures for RINEX files preparation, for downloading other necessary data, and for getting two processing solutions from single BPE (Bernese processing engine) process.

Two different calculation programs were used to analyze the time series of coordinates, while the data

received were displayed with the help of the GMT program.

2 LITPOS NETWORK STRUCTURE

Surface deformation in Europe can be studied at relatively large scales by modern GNSS geodesy if velocity data from a homogeneous and dense network of high quality stations is available for a sufficiently long lapse of time. LitPOS (Lithuanian Positioning System), is the global position determination system of permanent reference continuously operating GNSS stations, became operational in July 2007 (Baniulis et al., 2017). LitPOS combines a network of base GNSS stations with dedicated communication channels and appropriate hardware and software. Its main objective is to provide the 24/7/365 real time precise positioning service with national-wide coverage for

the geodetic, cartographic, cadastral and construction applications. This network is part of National Geodetic Foundation infrastructure. It allows users to evaluate their position by using RTK (Real-Time Kinematic), transmitting corrections through communication channels from points of geodetic basis. It uses VRS (Virtual Reference Station) and Ntrip (Networked Transport of RTCM via Internet Protocol) corrections methods. LitPOS provides to users a possibility to reach centimeter-level accuracy with single standard rover receiver at any point of Lithuanian territory. LitPOS network consists of 31 station, located evenly in country's territory, and regional management center. The stations are equipped with Trimble NetR9 GNSS receivers and Choke ring antennas. Overall running and management of LitPOS network is executed by Trimble Pivot Platform software.



Figure 1. LitPOS network map

Bigger part of GPS (Global positioning system) stations are installed in collaboration with Fire and Rescue Department under the Ministry of the Interior of the Republic of Lithuania. They are set up in fire towers. Average distance in between stations is around 50km. Additionally 9 stations from abroad are incorporated in LitPOS network (3 from Poland and 6 – Latvian).

LitPOS stations become very important geodetic points having the combined set of geodetic parameters:

- Coordinates to LitPOS stations are transferred from National Zero Order GPS Network and EPN (European permanent network) stations.
- Geopotential heights and normal heights of National First Order Vertical Network are used for data transfer to LitPOS stations.
- Gravity values of National Zero and First Order Gravimetric Network are used for data transfer to LitPOS stations.
- Height transfer from National Vertical First Order Network by precise levelling to GNSS station benchmark, and height transfer from it to antenna pier by trigonometric levelling (using total station).

Services and Products provided by LitPOS:

- Real-time services: RTK (Real-Time Kinematic) using VRS (Virtual Reference Station) technology; and real-time DGPS service;
- Post-processing products: RINEX data files for further processing.

Data streams are transferred in real time from GNSS stations to regional management center in separate data transfer lines. LitPOS network allows to determine position of a particular object in real time by providing corrections via communication channels from fixed points of the network. Users receive geodetic corrections via GSM and GPRS channels. LitPOS services are provided in RTK (+/-2cm accuracy), DGPS (+/-0.3m to +/-0.5m accuracy), and GPPS (up to 1mm accuracy) methods. Corrections to geodetic coordinates are transferred in RTCM 2.1, RTCM 2.3, RTCM 3.1, RTCM 3.2, CMR, CMR+, CMRx or DGPS RTCM 2.1, DGPS RTCM 2.3, DGPS RTCM 2.4 formats. In order to receive LitPOS corrections, users have to be registered in LitPOS website and receive username and password. LitPOS uses GPS and GLONASS satellite systems for network solution.

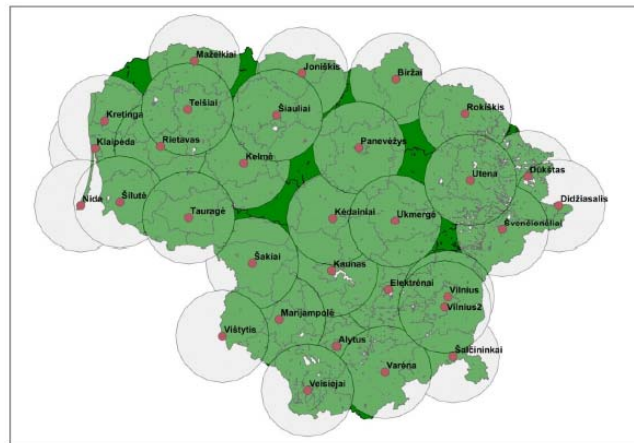


Figure 2. Coverage of LitPOS stations.

The station covers around 35 km radius around it (Fig. 2), thus the coverage of the whole country can be observable. Covered are by all LitPOS stations, situated in Lithuania. Not in the distant future, it is planned to install up to 5 more stations in the territory of Lithuania.

Main characteristics:

- Software: BSW5.2 update 2016 01 08
- Network: 30+6+3 LitPOS stations +10 IGS/EPN fiducial stations
- GNSS: GPS
- Antennas PCV: absolute and individual calibration
- Precise orbits, etc.: CODE
- Tropospheric refraction: VMF
- Ocean tide model model: FES2004
- Baselines processing strategy: OBS-MAX
- Ambiguities resolution strategy: QIF
- ITRF realisation: IGB08 (EPN_A_IGb08_C1845.SNX) (ITRF2014 -GPS week 1934 (29 January 2017)
- Cut-off angle: 3, 10, 25
- Period: 2008-2014; 2015-2017; 2017-
- Products: Daily and weekly SNX (NEQ + COV)

- Coordinates Time Series: analysis by TSview and KATREF

3 LITPOS DATA PROCESSING

LitPOS network data re-processing was done using Bernese (BSW5.2 update 2016 01 08) software and applying process control file NKG_R2Sall.PCF, which was set up using “Guidelines for NKG GNSS AC Re-processing No. 1”. Since July 2007, LitPOS provides data for real-time and post-processing applications. Data are stored to RINEX files from real-time streams using Trimble GPSNet software and TPP (Trimble Pivot Platform) at LitPOS permanent network servers. The format of LitPOS network stations data is RINEX 2.11. The hourly files with 1-second observations interval were stored. Before starting 2007–2018 re-processing of LitPOS network data, RINEX files are combined into one daily RINEX file (interval between observations was set to 30 seconds) using teqc.exe program and special batch file code. The combining of one-month data of 30 stations takes about 10 hours of computing time (Baniulis et al., 2017).

Other data like a satellite clock file (*.CLK), Earth rotation parameter file (*.ERP), ionosphere file (*.ION), ephemeris file (*.EPH), Differential Code Biases corrections file (*.DCB), Vienna Mapping Function and RINEX files of fiducial stations necessary for reprocessing were obtained from ftp servers using batch file code and wget.exe program and were putted into appropriate directories. Downloading of RINEX files of 10 fiducial stations of one year takes about 4 hours, and other necessary files download takes about 2–3 hours of computing time.

Some batch files have been coded to gathered mandatory necessary files in automated way, using wget.exe program (Zurutuza et al., 2008). Also RINEX files preparation was carried out by using teqc.exe program and batch file code. During LitPOS operational period large amount of data was gathered what gives a possibility to construct reliable coordinates time series. Coordinates time series analysis is an important part of Geodesy and Geodynamics studies, especially when continuous GPS observations are used to explore very low rate deformations. In this domain, having precise and robust tools for processing and analyzing position time series is a prerequisite (Bruyninx et al., 2018). Having GNSS position long time series, it is possible to analyze them searching for discontinuities, velocity changes, and outliers. These are caused by various reasons and represented in time series like gaps and offsets (jumps). Especially in the Nordic countries, snow typically accumulates on the radomes during wintertime causing systematic outliers (snow peaks) in time series. The removal of the snow and other short and deviating periods were marked manually with the help of the Tsview tool (Herring, & McClusky, 2019) and cut off from the daily SNX solution before velocity. In Table 1 we showed how much epochs we should to rejected from calculations to get smooth time series and velocities.

Table 1. The difference between the number of epochs between the primary data and the processed data.

Station	Number of epochs	Epochs after cut off
ALYT	4009	3856
BIRZ	3898	3433
DIDZ	1693	1378
DKST	3770	3321
ELEK	3755	3627
JNSK	3907	3661
KAUN	4051	3868
KEDN	4026	3731
KELM	3963	3555
KLAI	1583	1526
KRTN	3981	3734
MAZK	3966	3650
MRJM	3233	2988
NIDA	1373	1266
PNVZ	4049	3790
RKSK	4056	3763
RTVS	4029	3813
SAKI	3709	3613
SAUL	3910	3729
SILT	3999	3764
SLCN	4013	3858
SVNL	3953	3906
TAUR	4064	3670
TELS	4032	3891
UKMG	1709	1630
UTEN	4035	3804
VARN	3782	3607
VEIS	3764	3422
VGTU	3810	3350
VLNS	3786	3397
VSTT	1460	1391

In GNSS observations data pre-processing may be required for metadata correction, time windowing, data splitting or combining and other filtering, perform quality checks prior to re-processing the data (Altamimi, Collilieux, Legrand, Garayt, & Boucher, 2007). The re-processing was executed with the following parameters:

- Cut-off angle: 3°, 10°, 25°;
- Tropospheric refraction: VMF;
- Precise orbits, etc.: CODE;
- GNSS: only GPS;
- Ambiguity resolution strategy: QIF;
- Baselines processing strategy: OBS-MAX;
- ITRF realization:
- EPN_A_IGb08_C1845.SNX; IGS14 from 1934 GPS week;
- Antennas PCV: absolute and individual calibration;
- Fiducial stations used in re-processing: BOR1, RIGA, ONSA, MDVJ, MAR6, WTZR, VLNS, SWKI, VIS0, SVTL.

Before starting 2007–2019 re-processing of LitPOS network data, RINEX files are combined into one daily RINEX file (interval between observations was set to 30 seconds) using teqc.exe program and special batch file code. The combining of one-month data of 30 stations takes about 10 hours of computing time. Other data like a satellite clock file (*.CLK), Earth rotation parameter file (*.ERP), ionosphere file (*.ION), ephemeris file (*.EPH), Differential Code Biases corrections file (*.DCB), Vienna Mapping Function and RINEX files of fiducial stations necessary for reprocessing were obtained from ftp

servers using batch file code and wget.exe program and were putted into appropriate directories (Lutz, & Brockmann, 2018). Downloading of RINEX files of 10 fiducial stations for a year takes about 4 hours, and other necessary files download takes about 2–3 hours of computing time.

The preliminary analysis of time series is made by Tsview. Tsview is a MatLab-script/program for analysis, editing, and velocity estimation of time series of daily position estimates from GAMIT/GLOBK. It provides a graphical user interphase and it is designed for manual interactive study of the time series. This program is calculating station velocities using station coordinate files (*.CRD) from re-processed SINEX files with Bernese software. For time series analysis with Tsview we set some parameters: *Outliers* (n-sigma) was set to 3 (an automatic outlier rejection criterion used in an iterative detrending); 3 more options: *RealSigma*, *+Semiannual* and *+Annual* was set; later *Detrend* function was used to estimate the velocities with current settings. If it is necessary, we used *Block* edit function to remove observations from certain period, for all coordinate components. Function *Break* is used to add discontinuities to the time series (Herring, & McCluncky, 2009). The *Save* button saves the results to the folder that is set in the Tsview shortcut properties. New files contains information of the data editing, breaks, station velocities in 3 axis and errors.

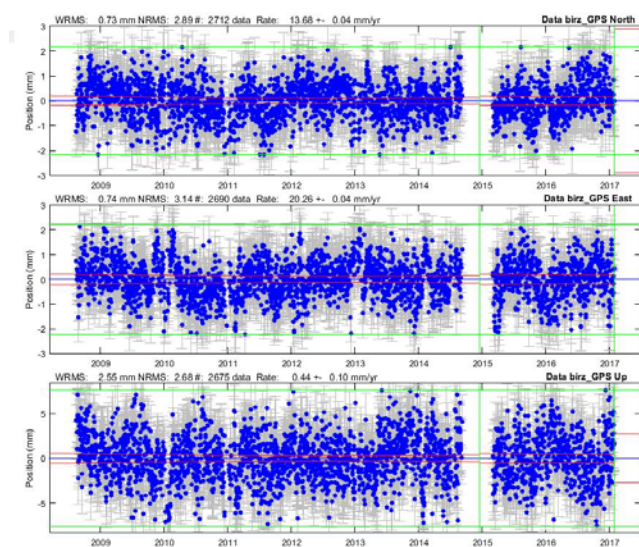


Figure 4. LitPOS network station coordinates change based on daytime measurements.

4 VELOCITIES ESTIMATION

The station velocities can be estimated by either combining the daily solutions (with full covariances) using least squares methods or estimating trends from the station position time series individually for each component. CATREF software has been originally designed for ITRF combinations and it is well adapted for time series combination. The combination model based on the seven parameter similarity transformation between the frames (Stanaway et al., 2015). CATREF consists of the main program combines

and several supportive programs for handling the SNXs

During LitPOS operational period large amount of data was gathered what gives a possibility to construct reliable coordinates time series. Coordinates time series analysis is an important part of Geodesy and Geodynamics studies, especially when continuous GPS observations are used to explore very low rate deformations. In this domain, having precise and robust tools for processing and analyzing position time series is a prerequisite. Having long time series of station coordinates, it is possible to analyze them searching for discontinuities, velocity changes, and outliers (Pospíšil, & Hefty, 2014). These are caused by various reasons and represented in time series like gaps and offsets (jumps). Main reasons for outliers and discontinuities are equipment change, environmental conditions like snow coverage or birds on antenna radome, earthquakes.

- Input data – daily sinex files (10 degree cut off angle) with NEQ (Normal equation) obtained from BERNESE using NKG guidelines.
- Time span of reprocessing 2007-2018.
- Velocities were calculated using CATREF software package and Tsview program.
- Objective: To estimate LitPOS network station's coordinates horizontal and vertical velocities in ITRF 2014 reference frame;

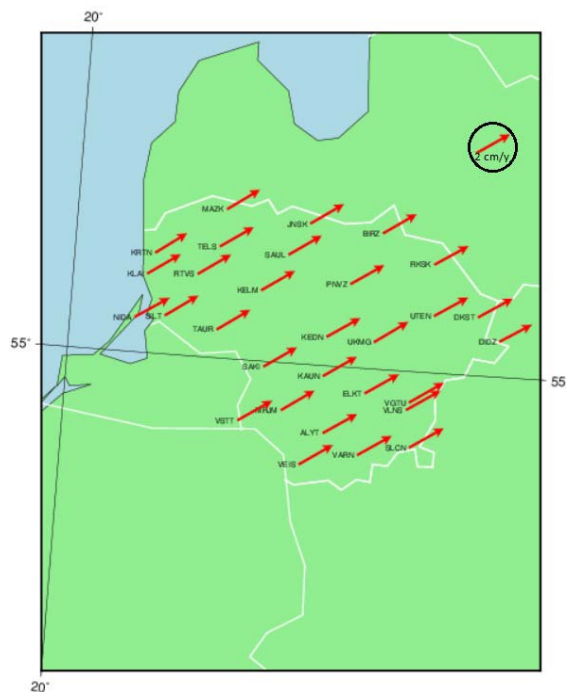


Figure 5. North/East velocities calculated with CATREF

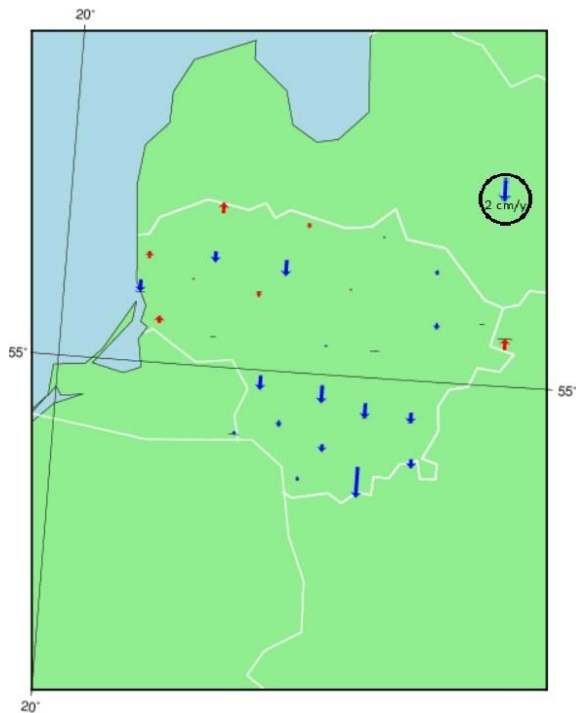


Figure 6. Up component velocities calculated with CATREF

5 DISCUSSION AND CONCLUSIONS

The inconsistencies of different types were detected and removed from the LitPOS data to process the final solutions of LitPOS network based on stations absolute antenna models, 3°, 10° and 25° cut-off angles by Bernese 5.2 software and applying the initial parameters from NKG (The Nordic Geodetic Commission) guidelines.

We used the CATREF software for the cumulative combination. The combination model is based on seven parameters similarity transformation, and each of the daily solution is transformed to the combined solution at the fixed epoch. The results obtained were compared against the results of neighboring countries obtained by international organizations (Kenyeres, 2018; Lutz, 2018; Zurutuza et al, 2019; Lahtinen et al, 2018, 2019). It could be stated that North/East velocities of the LitPOS stations are very homogeneous what leads to the conclusion that there are no any significant horizontal deformations of Earth's crust in the territory of Lithuania. Up components of LitPOS stations velocities fit very well to vertical movements of Earth's crust as described by the land uplift models of Fennoscandia (Vestøl 2006; 2018).

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