„ASG+": PROJECT FOR IMPROVING POLISH MULTIFUNCTIONAL PRECISE SATELLITE POSITIONING SYSTEM

M. Figurski[1)], J. Bogusz[1)], J. Bosy[2)], B. Kontny[2)], A. Krankowski[3)], P. Wielgosz[3)]

[1)]*Centre of Applied Geomatics, Military University of Technology*
[2)]*Institute of Geodesy and Geoinformatics,*
Wroclaw University of Environmental and Life Sciences, Poland
[3)]*Division of Astronomy and Geodynamics,*
University of Warmia and Mazury in Olsztyn, Poland

1. INTRODUCTION

The aim of the project which started in 2010 is to study the principles of Polish Active Geodetic Network (ASG-EUPOS) improvement. ASG-EUPOS is the multifunctional precise satellite positioning system established by the Head Office of Geodesy and Cartography in 2008. It consists of almost 75 Polish sites with GPS module, 14 Polish sites with GPS/GLONASS module and 20 foreign incorporated sites. The basic assumption of the project is to create the modules related to the system's functionality: module of network adjustment in quasi-real time, module of monitoring of the coordinates of reference sites, module of monitoring of the quality of ASG-EUPOS's services, modules of iono- and troposphere modelling with high time and space resolution, modules of iono- and troposphere's prediction, modules of supplying the system's services with the models of state of iono- and troposphere (the quasi-model and the prognosis), modules of ultrafast GNSS positioning in the postprocessing and kinematic mode, system of positioning using mobile phones and ASG-EUPOS services, integrated modules of vertical and horizontal litosphere's movements using GNSS data. The paper presents the general assumptions of the project and the frame of the ASG+ system as well. This interdisciplinary venture is financed by the Polish Ministry of Science and Higher Education.

2. ASG-EUPOS

Multifunctional precise satellite positioning system ASG-EUPOS established by the Head Office of Geodesy and Cartography in 2008 (Bosy et al., 2007). The system consists of three main elements: reference stations, management centre and users segment. One of the three main segments of the ASG-EUPOS system is the receiving segment (ground control). It's role is to collect observational data GNSS satellites and transfer them in real time into the Calculation Centre. The segment consists of GNSS reference stations evenly distributed over the area of Poland and neighbouring countries. One of the tasks of the Management Centre is the calculation of corrections for the respective real time services provided by the ASG-EUPOS system. The reference stations are sending observational data directly to the Centre.

On the basis of these data streams the corrections are being calculated and then sent to the system user. The whole process of calculations and delivering of corrections happens automatically. In this case the employees of the Calculation Centre are responsible for the continuity of satellite observations and for carrying out tests ensuring that the whole system is operating correctly. Directly from the Management Centre the user can download observational files from the respective reference stations of the ASG-EUPOS system (POZGEO D) or upload their own observational files in order to achieve a precise location of the measured terrain details (POZGEO). Besides providing services of positioning, the Calculating Centre serves the function related to conservation of the reference system. Weekly control of the system enable up-to-date control of coordinates' stability of points defining this system. Besides the reference stations and Management Centre, also users are part of the structure of the ASG-EUPOS system. The users of the system have the possibility to choose the measuring equipment from a wide range of devices available on the market. Particular services provided by the ASG-EUPOS system can be used both by single- and dual-frequency GPS receivers equipped with a communication module. The solutions accepted in the system give the possibility to benefit from it also by users not owning expensive measuring equipment, but equipped for example with a simple tourist GPS receiver. Thanks to the continuous availability on the whole area of Poland of the offered services, the user, who decides to benefit from the ASG-EUPOS system, has the possibility to precisely determine his position regardless of space and time (www.asgeupos.pl).

3. ASG+ MODULES

The main objective of the project is to create supporting modules for currently operating in ASG-EUPOS system services and creating new system services. Schematic design of the proposed in project modules is shown in figure 1.

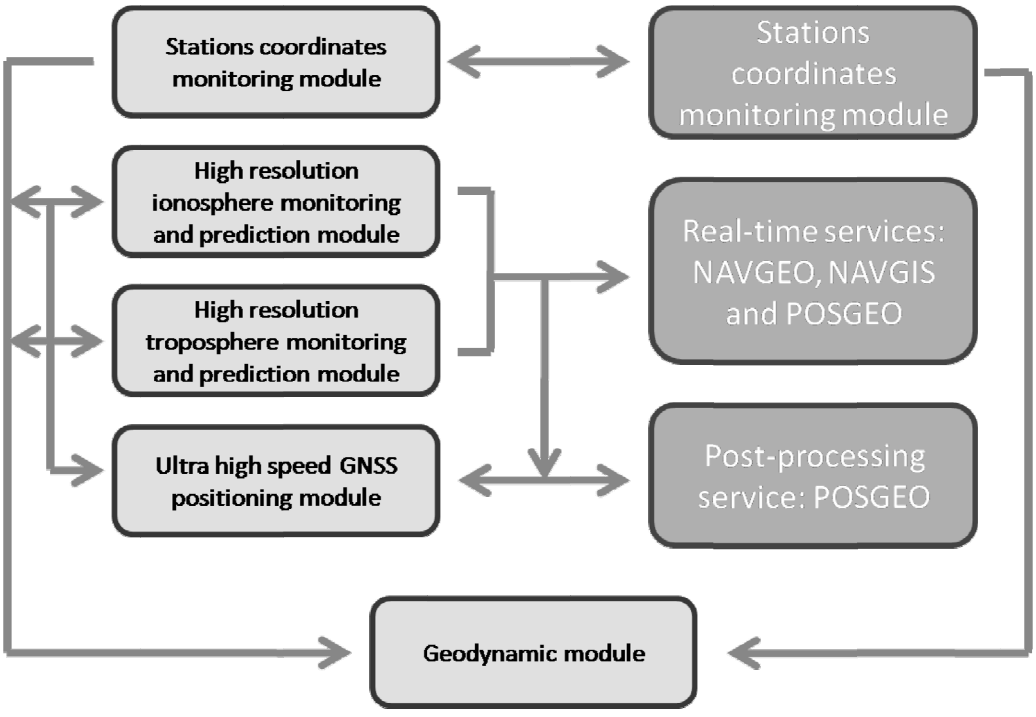

Fig. 1. Schematic diagram of the ASG-EUPOS supporting modules.

The proposed in ASG+ project modules need one hand to improve the quality of ASG-EUPOS positioning services. The new proposed services developed in the project should extend the application of ASG-EUPOS. A detailed description of each module is presented in the following chapters.

3.1. Data processing module

Within this module the development of ASG-EUPOS data processing in quasi-real time will be possible. This module is necessary for the rapid detection of any malfunction of the reference stations. Monitoring the ongoing operation of the stations can be done in three ways depending on the speed of obtaining processing results calculations using:

1. **"fast" ephemeris and rotation parameters, IGS (called Rapid IGS) and the observation of diurnal – delay – delay control results: max. 18 hours;**
2. **"ultra fast" ephemeris and rotation parameters, IGS (called Ultra Rapid IGS) and the observation of diurnal – delay control results: max. 3 hours;**
3. **"ultra fast" ephemeris and rotation parameters, IGS (called Ultra Rapid IGS) and the hour of observation – delay control results max. 20 minutes.**

In the case of this project launching a module for assessing the work station and to detect any abnormalities in max. 3 hours is planned. Besides that the precise data processing (using most precise products and Bernese 5.0 software) for geodynamical purposes will be done. Reference frame for ASG-EUPOS is ETRF2000 at epoch 2005.0 (Bruyninx et al., 2010) For proper operation the module needs IGS (International GNSS Service) products. The EPN (EUREF Permanent Network) strategy used by LACs (Local Analysis Centres) will be used in the data processing (Bruyninx, 2010).

3.2. Coordinate monitoring module

The module for monitoring network coordinates ASG-EUPOS is planned to be built. It would be a quasi real-time system based on 30 or 60 minutes of observations gathered at the reference stations. Computing system will be based on the strategy, which is currently used to process observations from EUREF Permanent Network. For the calculations the models of the troposphere and the ionosphere, which will be developed in this project are going to be used. The main assumption of utility module is user's access via the websites to the results of each hour of solution. The primary development tool utilized for this task will be Bernese GPS Software working in the mode of parallel computing. The system will compare the current coordinates of the reference and designated for each of the above mentioned time interval. Beyond calculation modules the system will be equipped with observation and verification of reliability of calculations subsystems. All calculations will be implemented on a multi-core computer cluster. The solutions of ASG-EUPOS network will be compared to the solutions obtained from EPN data processing made by Military University of Technology Local Analysis Centre (MUT LAC). Rapid ephemeris from ESA (European Space Agency), CODE (Centre for Orbit Determination in Europe), JPL (Jet Propulsion Laboratory) and SIO (Scripps Institution of Oceanography) will be taken. As the result time series characteristics will be obtained for recognizing possible time series abnormal course, seasonal oscillations, seasons-related variations (Bogusz et al., 2011). Preliminary results showed that many of the stations of the ASG-EUPOS do not maintain a sufficiently stable (Figurski et al., 2010).

3.3. Module for monitoring the quality of services

The designation of a control system of DGPS and RTK corrections will be created. The system will be based on algorithms for data external RTCM identify and will return the coordinates of randomly selected points of the network. This solution is independent of the ASG-EUPOS network and based only on data recorded by stations. Direct connection to the control station will allow for immediate notification of any problems handling fixes network accessibility and quality. The proposed solution is characterized by an open architecture allowing for future expansion of additional control parameters. The proposed solution is crucial to improve the efficiency and credibility of the positions determination using ASG-EUPOS. As the result interactive validation map accessible via Internet will be created. This module will utilise satellite data collected by the system as well as real time services of the chosen sites.

3.4. Module for monitoring, modelling and prediction of the troposphere with high spatial resolution time

Global Navigation Satellite System is designed for positioning, navigation, amongst other possible applications it can also be used to derive information about the state of the atmosphere, what is now recognized as GNSS meteorology. Particularly GNSS meteorology is the remote sensing of the atmosphere from satellite platform (GNSS radio occultation meteorology) and ground permanent stations (ground based GNSS meteorology). The ground based GNSS meteorology is investigated by the research group of the Institute of Geodesy and Geoinformatics of Wroclaw University of Environmental and Life Sciences. The spatial structure and temporal behaviour of the troposphere (mainly water vapour in the troposphere) is modelled using the GNSS tomography method (Rohm and Bosy 2009, 2011). It is important product for GNSS positioning services (in post-processing and real time mode) and meteorological application (additional meteorological monitoring tool). Since 2008 in the territory of Poland a Ground Base Augmentation System GBAS) called ASG-EUPOS is working. This system gathers permanently the GNSS data from 130 stations and meteorological (temperature, pressure and relative humidity) data from 17 stations. The average distance between GNSS stations is 70 km. The GNSS and meteorological data from these sites and Numerical Weather Prediction (NWP) model outputs allow to develop a Near Real Time (NRT) troposphere model with unprecedented time-space resolution. The NRT troposphere model will be used for real time and post-processing ASG-EUPOS services. The model created from meteorological and GNSS data, could be competitive to NWP models, especially for nowcasting and establish in future new service of ASG-EUPOS system. As the input data the approximate coordinates, GNSS and meteorological data will be implemented together with the NRT products from IGS, CODE and EUREF. For calibration purposes data from synoptic stations and radiosoundings gathered by IMWM (Institute of Meteorology and Water Management) will be utilized together with the outputs from COAMPS (Coupled Ocean/Atmosphere Mesoscale Prediction System) weather prediction model provided by the Centre of Applied Geomatics MUT. The module will provide tropospheric parameters (Zenith Total Delay, Zenith Wet Delay or Slant Wet Delay) by means of precise tropospheric models for post-processing users and 15-minute prognosis for real-time users of ASG-EUPOS.

3.5. Module for monitoring, modelling and prediction of the ionosphere with high spatial resolution time

Total Electron Content (TEC) fluctuations and scintillations, due to large changes (in rapid succession) over the observation station may have a significant impact on the accuracy of the GPS position. They affect the increase in the number of lost cycles phase (cycle slips), and consequently on the quality of determined phase ambiguities. The standard ionosphere models (IGS/EPN) have a spatial resolution of the order of 200-300 km over the European continent and the temporal order of 1-2 hours. If such a resolution models allows their use to solute the long vectors (> 100 km) measured by GPS based on many hours of observations from the permanent stations, their usefulness in practice, to develop short observing sessions and kinematic measurements is insufficient. Therefore, the national systems of permanent stations, such as ASG-EUPOS, are a perfect complement to the IGS/EPN. While the average distance between stations amounts 70 km, data from these sites allow to develop a ionospheric model with unprecedented time-space resolution. This module will utilize information from Coordinate Monitoring Module to choose the most stable sites (30-40). The precise ionospheric model for post-processing users will be created together with the 3-hour prognosis for real-time users. Additionally the research on ionospheric scintillations using high-rate (100 HZ) GNSS receivers is going to be carried out.

3.6. Postprocessing module (POZGEO 2)

The basic problem in this task is to develop methods for rapid determination of the phase ambiguities and verification of their value based on a small number of observations. Currently, an automated service of static precision positioning system used in the ASG-EUPOS requires a minimum of 15 minutes dual frequency GPS observations. However, the tests show that satisfactory results are obtained only from the development of one-hour observing sessions. It is anticipated that the planned ultra-fast positioning module will provide accurate and reliable position after 5 minutes of observation of GNSS satellites. One of the principles for a fast resolution of phase determination is to provide atmospheric corrections (ionospheric and tropospheric) and their appropriate weighting in the least squares adjustment (Wielgosz, 2010; Wielgosz et al., 2011). Due to the fact that the ASG-EUPOS network consists of a large number of stations, it is possible to use most of them to generate the corrections and the opportunity to test advanced interpolation techniques. The project is expected to conduct theoretical and practical studies aimed at assessing the suitability of the new modernized GPS (L2C, L5) and Galileo signals. It is anticipated that these signals, with higher precision and the number should significantly increase the speed and reliability of the determination of position with geodetic accuracy (2 cm in horizon and 4 cm in height).

3.7. Kinematic processing module (NAWGEO p)

Currently, ASG-EUPOS does not provide an automatic system to develop measurements of kinematic post-processing mode. However, such a service would be very useful because it enables the determination of kinematic position postprocessing mode observations collected by the mobile receiver, where the measurements performed during the absence of communication with real-time sites.

It also allows the development of kinematic data, even if one do not have a receiver that allows to receive observations and services in real time via the Internet (currently most of the receivers used by the surveying companies has no built-in GSM modem).

3.8. Mobile phones module

The novelty introduced by the described project will enable the use of real-time network services of ASG-EUPOS for mobile phones users. The following records: NMEA (data), GGA (position) and GSA (satellites) will be utilised for self-written software able to run on mobile phones for correcting the single point position determined by the built-in GPS receivers.

3.9. Geodynamical module

The results derived from this module will be the vertical and horizontal recent movements of the Earth's crust based on ASG-EUPOS network. This module will provide a system of geodynamic parameters (deformation rates) for the Polish territory based on the analysis of time of coordinates determined in the Data Processing Module. This module includes implementation of a comprehensive evaluation of a network of permanent geodetic stations for its suitability to study the dynamics of Earth's surface. Among the points of the network will be designated the ones that meet the strict criteria for accuracy from Coordinate Monitoring Module. The task is to demonstrate that with the help of advanced mathematical methods of analysis of antennas displacements, one can get reliable geodynamic information. Planned geomechanical numerical modelling would be to check the consistency of the results of calculations based on geodetic measurements from geophysical database of contemporary tectonic stress in the upper crust and the pool of geological data on the structure and tectonic movements on Polish territory (Jarosinski et. al. 2006; Zuchiewicz et al., 2007). As a result, there will be demonstrated that using large amounts of data from ASG-EUPOS variety of deformation fields of tectonic origin in Poland can be characterized. This task can significantly broaden the base of measurement data characterizing the surface deformation of the lithosphere in Poland. This module is divided into two parts:

- **horizontal movements;**
- **vertical movements.**

As the result the integrated geodynamical module will be created. Additionally the compute-analytical module will perform the following functions:

- **verification of data from the modules of horizontal and vertical movements of the lithosphere in terms of their suitability for geodynamic interpretation,**
- **detection of episodic and nonlinear spikes in the time series of coordinates of reference ASG-EUPOS stations and their space-time correlation of earthquakes recorded in the national, European and global services on-line seismic data (eg, IRIS Data Management Center, EarthScope, the European-Mediterranean Seismological Centre, GEOFON Earthquake Information Service, Institute of Geophysics - Seismic Monitoring Programme),**
- **modelling the field of crustal deformation on the Polish territory (updated current models),**
- **detection of discontinuity models of deformation fields on the basis of residua distribution analysis,**
- **evaluation of tectonic activity of the main geological structures on Polish territory to identify areas of potential tectonics risks.**

For comparative purposes the geophysical data from Institute of Geophysics of the Polish Academy of Sciences and geological data from the Polish Geological Institute will be used. Information on antennas' position changes will be presented in the form of map of movement rates of geodynamical character.

4. SUMMARY

The project has started in November 2010, the research related to the sophisticated data processing, iono- and troposphere modelling, mobile phones applications and geodynamics are in progress. Other modules will be launched soon. Project completion is scheduled for October 2013.

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