RIGA TECHNICAL UNIVERSITY

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RATIONAL SYSTEM LATPOS

Summary of PhD Thesis

Riga 2012

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This work has been supported by the European Social Fund within the National Programme „Support for the carrying out doctoral study programm's and post-doctoral researches" Project „Support for the development of doctoral studies at Riga Technical University".

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GENERAL DESCRIPTION

Introduction - topicality

Coordination of information, objects in unified space is one of most topical processes due to creation of diverse information systems. It is particularly topical for coordination in the field and depiction on maps of environment objects and of objects created of humans. Unified coordinate reference system is necessary for this. This is prescribed also by data themes „Coordinate reference systems" of Annex I of European directive on globalization of space, establishment of unified reference space – INSPIRE directive, (14.03.2007 directive 2007/2/EK).

Coordinate reference system in the field is provided by geodetic networks that consist of geodetic survey markers on the Earth's surface. Survey markers are information carriers for a long period. In Latvia, survey markers have remained intact from 19th century. They provide historical link between today and former times.

Geodetic networks were built up technologically starting from overall networks of higher class up to local networks of lower class. This causes situation that networks of lower classes are not always mutually matched and coordinated.

At the end of twentieth century – in the late sixties, a global navigation satellite system was established, by which it is possible to determine coordinates in any location of the Earth – global positioning system.

In Latvia, global positioning was applied for renewal of geodetic networks and for establishing of Latvian coordinate system in Latvia – in the nineties of the twentieth century. By use of this technology, a new geodetic network was established, which provided higher accuracy of coordinates than networks left as heritage of Soviet Union. National Geodetic Network with 4 classes – 0, 1, 2, 3 – was established.

Up to now, measurements were carried out by tachymeters and at least two global positioning receivers, out of which at least one is placed on geodetic point with known coordinates. Each tool is operated by a geodesist. Total station measurements up to object and in object take much resources of time. Also determination of coordinates by two global positioning receivers is not operative enough, in order to carry out momentary demarcation of parcel boundaries in the field.

As applications of global positioning system developed and number of users increased, necessity to distribute base stations in the entire territory of the country arose in order to provide quicker and more accurate performance of works, which could provide quicker determination of coordinates in the entire territory of Latvia. Therefore solution was searched in order to enable the use of global positioning systems in Latvia, which give coordinates with accuracy of some centimeters momentarily.

The author of the doctoral theses carried out researches on the use of GPS in precise geodesy – world-wide and in the national level. Study was carried out on technologies enabling the performance of measurements with accuracy of centimeters in a large territory, e.g., in the territory of Latvian State. As literature and available information was investigated, it was decided to establish the national GPS base station system with data processing and distribution servers that provide coordinate determination with centimeters accuracy in the entire Latvia, providing homogeneous coordinate determination with post-processing – classically and also in real time, obtaining momentary result.

When GPS base station system is developed in the national level, for the entire territory of Latvian State, it is necessary to evaluate:

- selection of system type for circumstances of Latvia, specific character of the territory;
- develop the analytic model of the system;
- evaluation of circumstances of Latvia and establishment of the optimal system according to the territory of Latvia, available resources.

GPS base station system is body of receivers and data processing center that provides data processing, storing and delivery to a user. Data delivery takes place momentarily by use of wireless technologies.

Surveying results that are necessary in cadaster, construction, and mapping are obtained fast and qualitatively. As these technologies are developing, it is possible to obtain measurements of more and more high accuracy in any location. It is especially necessary in locations, where geodetic networks do not provide sufficient coverage.

A very important process for science is to carry out data storing in the long period and to carry out study of movements of the Earth’s crust and to enable forecast of movement of the Earth’s crust.

The objective

To establish rational geodetic support, information and communication system of the new generation by use of contemporary possibilities of Global Positioning, information and communication technologies – GPS base station system, by optimization of it for the specific character of the territory of Latvia, by realization of the configuration of system that is economically most favorable, in order to enable real time measurements, providing homogenous geodetic measurements in the entire territory of Latvia with accuracy 4 cm in the horizontal plane.

For the achievement of the objective, following **tasks** have been set for:

- to study trends of development of GPS base station networks in Europe and world-wide;
- to develop the analytic model of GPS base stations
- to optimize the analytic model of GPS base stations for circumstances of Latvia – number of stations, configuration of distribution and other parameters, taking into account of the specific geographic character and economic aspects;
- to establish the optimized GPS base station network in Latvia;
- study the results of the operation of the installed GPS base station network - coverage, stability of the operation and accuracy both inside the network and beyond the network. To clarify data of Latvian geodetic networks and of GPS base station network. To find proposals concerning the further development and improvement of GPS base station network.

Scientific novelty

- The analytic model of GPS base station network of Latvia was developed.
- The optimal solution for establishment of GPS base station network has been found.
- GPS base station network „LatPos" is established on the basis of the performed study.
- Study of operation of GPS base station network is carried out: continuity of the operation of the network, impact of external circumstances.

- Proposals for normative acts for the inclusion of “LatPos” into National Geodetic Network, regulations of use and recommendations are elaborated.

Practical value

- Optimal system “LatPos” for GPS measurements is developed, securing performance of geodetic measurements in the entire territory of Latvia, especially in locations, where the classical geodetic network is not available.
- Effective usage of GPS equipment for performance of geodetic measurements is established, as a result, duration of works is reduced four times in average.
- Study on reduction of costs of maintenance of the geodetic system is carried out.
- Methodology of geodetic measurements by use of network “LatPos” is elaborated and implemented. Training of users is carried out in the use of global positioning system and in use of system “LatPos”.

Theses submitted for final oral

1. System “LatPos” improves the homogeneity and accuracy of geodetic measurements in the territory of Latvia up to 4 cm.
2. With rational system “LatPos” the average productivity of geodetic measurements increases four times.
3. Quintuple reductions of costs of maintenance of geodetic support system is reached
4. System “LatPos” is tool for improvement of efficiency and economy of works of wide range of economic sectors

Structure and scope of the work

The thesis is unassisted scientific research and it consists of Introduction, 4 chapters, Conclusions and Bibliography. There are 169 pages, 118 figures, 9 tables, 6 annexes and reference list containing 91 references.

Approbation of the work and publications

Results of the thesis are reported and discussed in international conferences:

- 4 and 5 March 2002, 1st International conference Multifunctional GNSS base stations for Europe, Berlin,
- 10 and 11 June 2003, EUPOS ISC conference, Riga,
- 23 January 2004, Baltic Minister Committee Council of Geodesy, cartography and land reform conference, Carnikava,
- 10 February 2006, Latvian University 64th conference, Riga;
- 17 and 21 September 2007, EUPOS ISC conference, Vilnius,
- 12 October 2007, RTU 48th conference, Riga,
- October 2007, Vilnius Technical University 6th international conference, Vilnius,
- 31 October 2007, International Military Conference, Riga,
- 10 February 2008, Latvian University 66th scientific conference, Riga,
- 22 and 23 May 2008, Vilnius Technical University 7th international conference, Vilnius,
- 10 - 12 September 2008, Baltic – Swiss geodesy scientific conference, Tallinn,
- 24 - 26 September 2008, EUPOS ISC conference, Berlin,
- 13 October 2008, RTU 49th scientific conference, Riga,
- 12 February 2009, Latvian University 67th scientific conference, Riga,
- 28 and 29 April 2009, EUPOS ISC conference, Tallinn,
- May 2009, United Nations conference, Baku,
- 1 December 2009, GNSS international conference, Berlin;
- 19 February 2010, Latvian University 68th scientific conference, Riga,
- 16 – 22 May 2010, United Nations conference, Chişinău,
- 26 – 30 May 2010, EUPOS ISC conference, Novi Sad,
- 2 - 5 June 2010, EUREF international conference, Gävle,
- 25 – 28 October 2010, EUPOS ISC conference, Warsaw,
- 23 September – 2 October 2010, United Nations conference „GNSS Applications for Human Benefit and Development” and 61st International Astronautical Congress, Prague.

- 15 – 21 January 2011, United Nations/United Arab Emirates/USA/European Space Agency Workshop on Applications of Global Navigation Satellite Systems,
- 13 – 16 April 2011, EUPOS ISC conference, Budapest,
- 10 - 11 October 2011, International Symposium on GNSS, Space-Based and Ground-Based Augmentation Systems and Applications, Berlin,
- 12 – 13 October 2011, EUPOS ISC conference, Berlin,

The main results of the work are presented in 8 publications.

Work is carried out in the Department of Geomatics of Riga Technical University, in the State Land Service of Latvia, Latvian Geospatial Information Agency from 2001 until 2010.

CONTENTS OF THE WORK

Introduction. In the introduction of the thesis, traditional methods of geodetic measurements and directions of development of technologies are discussed. Taking into account the development of technologies and necessity to apply the latest technologies in geodetic measurements, in order to increase productivity of the work and accuracy of measurements, the objective of the thesis and tasks to be reached, its scientific and practical importance are formulated.

In the **Chapter One**, principles of activities of global positioning and factors having impact on accuracy of geodetic measurements are discussed:

- Delay of signal due to structure of satellite system,
- Inaccuracy of satellite clocks,
- Inaccuracies of satellite orbit,
- Errors of satellite antenna and wrong transmission,
- Part of Earth's atmosphere – Ionosphere,
- Part of Earth's atmosphere – Troposphere,
- Reflected GPS signals from ambient objects in the vicinity of antenna – „multipath",
- Errors caused by GPS receiver antenna,
- Accuracy of clock of receiver,

- Delay of receiver system parts.

Main problems are elimination or reduction of all undetermined errors, thus maximally undistorted signal is obtained. In Latvia, global positioning method – placing of the output base station on geodetic point and reduction of the above-mentioned errors – is used. Measurement of such type is carried out in Latvia already since the early nineties, when the use of global positioning system was started in the territory of Latvia both for establishment of geodetic network and for measurements of objects themselves.

Table 1

Sizes of error sources

Error source	Absolute impact
Satellite orbits	2 up to 50 meters
Satellite clock	2 up to 100 meters
Impact of ionosphere	0,5 up to 100 meters and more
Impact of troposphere	0,01 up to 0,5 meters
Effect of reflection of signal code	Impact in meters
Effect of reflection of signal phase	Impact in millimeters, centimeters
Errors of detection of antenna	Impact in millimeters, centimeters

In general, all errors comprise 5 up to 20 meters. So in the best circumstances, the accuracy of one receiver may be from 5 meters up to 20 meters.

When at least two global positioning system receivers are used, the error impact is reduced, however following problems are remaining and it is not possible to eliminate them by use of this up-to-date technology:

- At least two global positioning system receivers are necessary for work, it costs fairly expensive,
- Work shall be carried out by at least two people, one person stands at point to be measured, the second one at base station on national geodetic point,
- It is necessary to store measurement data and it is possible to carry out data processing only in the office – only by after-treatment,
- Measurements from a geodetic point are restricted – if the distance from base point is greater than 10 kilometers, the accuracy of the measurement declines and the necessary data quality is not secured,

- Session of the measurement depends on accuracy to be reached.

Calculation of the position from the corrected measurements may be as follows:

1) correction of codes (DGNSS)
2) correction of the carrier phase (RTK) – determination of unknown quantities.

For precise after-treatment calculations diverse additional data are used. They can contain ionosphere models, precise orbits for satellites, surface models and others.

Error sources in calculations:

Satellite clock error ϵ_S

Satellite orbit error ϵ_B

Ionosphere error ϵ_I

Troposphere error ϵ_T

Reflection, antenna and noice error $\epsilon_L = \epsilon_M + \epsilon_A + \epsilon_\Phi$

Receiver clock error Δt

The summary error will be described by a formula:

$$PR_{gem} = R_0 + \epsilon_S + \epsilon_B + \epsilon_I + \epsilon_T + \Delta t + \epsilon_L \quad (1.)$$

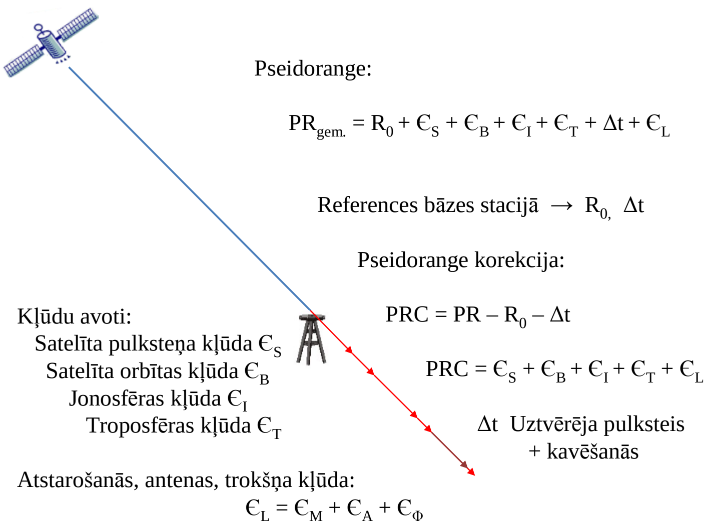


Fig. 1 Formation of the summary error

Positioning by one or several receivers can be carried out in several ways:

- use of corrections (code and carrier phase) in the receiver on the spot in the field, which are determined in the reference base station and through data transmission channel transmitted to receiver that is located in the point to be measured;

- baseline processing with input data (code and carrier phase), by use of data processing software.

All the processing strategies give similar results by carrying out the elimination of the known errors from measurement data.

All impacts were summarized and shown in table 2 depending on distance to base station.

Table 2

Error sizes

Error source	Absolute impact	Relative impact
Satellite orbit	2 to 50 meters	0,1 to 2 ppm
Satellite clock error	2 to 100 meters	0 ppm
Ionosphere impact	0,5 to 100 meters and more	1 to 50 ppm
Troposphere	0,001 to 0,5 metriem	0 to 3 ppm
Reflection impact code	meters	meters
Reflection phase impact	Millimeters, centimeters	Millimeters, centimeters
Antenna errors	Millimeters, centimeters	Millimeters, centimeters

Total sum of errors that are remained unsolved is 1 to 2 centimeters + 1...20 ppm. Improvement of error elimination can be achieved by use of GPS base station networks.

Along with development of technologies, already in the middle of nineties satellite technologies – Global Positioning Systems were used. In Latvia in 1992, measurements were made with post-processing, in order to coordinate points of class zero. In the post-processing measurements it is necessary to accumulate data for twenty minutes and to perform data post-processing at the office. It takes much time, it is impossible to obtain the accuracy of coordinate measurements.

In USA already in 1992, GPS base station network was established, which provides measurements in real time. The largest demand is control of farm machines, because fields are large and driver cannot perform even control of tractor. So the establishment of GPS base station system begins, which provides transmission of corrections directly to user.

Sending of corrections takes place by use of message of certain type – RTCM 3.1. Real Time Correction Message.

GPS base station system accumulates and processes data. In order to give possibility to the user to use the processed data, it is necessary to deliver them to the user in the field. Data transmission can be performed through radio waves, from transmitter or data transmission through Internet and mobile phone network

Reception of post-processing data is possible through Internet. This provides data accessibility at any time.

Transmissions of data of various types:

- Sea lighthouses – transmission through radio waves. Base stations along sea coast,
- System EGNOS – transmission through satellite systems, bases throughout the Europe,
- Local base station system – through mobile communications.

Interpolations of errors of various type and calculation methods:

- FKP – calculation of linear error for certain area,
- VRS – virtual base station data generation in the vicinity of point to be measured,
- MAC – main base station and auxiliary stations,
- SPR – overall correction parameter.

Considering the experience of other countries in precise geodesy, we can come to conclusion that placing of base station in the territory of Latvia is the most gainful option.

In the chapter two requirements of the system to be established and possibilities to meet them are discussed. In this chapter, requirements, which shall be met by the system to be established, are discussed on the base of spheres, where system will be applied.

Setting the same tasks to the system of next generation as to classic geodetic network, this system can be defined.

System of next generation shall provide 24 hours operation in the entire territory of Latvia, it shall have high degree of security – it shall be accurate and shall have the latest geodetic information, shall be accessible in the entire territory of Latvia. As it is planned that system will replace all geodetic networks and provide measurements in any territory of Latvia, accuracies provided by geodetic networks shall be taken into account. Approaches of the effective normative acts also shall be taken into account. One of them are Regulations of the Cabinet of Ministers No. 182 of 20 March, 2007 „Regulations on Determination of Real Estate Object". In the Annex 3 of these regulations, accuracies are prescribed, which shall be reached in the survey of objects and boundaries. Let us consider only the highest requirements, which shall be met by the system. It shall be taken into consideration that accuracy of measurements is defined in relation to some certain point of geodetic network or also to point of survey network. It means that parameter of accuracy in general space is much worse. Using GPS base station system accuracy of measurement can already be calculated in relation to geodetic network of higher class. Base station system will be regarded as geodetic network of class 1.

Table 3

Accuracy categories

Accuracy category	Location of land property	Negligible standard deviations along coordinate axes (m)		
		points of survey network	boundary points	edgy pronounced turnings of natural boundaries
1	Town	0.05	0.03	0.2
2	Village, build-up area for summer cottages or gardening	0.07	0.05	0.3
3	Rural area	0.15	0.10	0.5

According to Table 3 the highest accuracy is three centimeters. It means that GPS system in sites, where is good visibility of satellites, shall provide local network and polygonometry functions – enable determination of coordinates with two centimeters accuracy of measurements in any location of Latvia.

The operation of the system shall be provided at least 99% out of all time. We can take into account that the use of system in the dark time of the day is much smaller due to bothersome performance of measurements in the field.

Post-processing data shall be provided 100%. System shall be provided with uninterruptible power sources, which provide uninterruptible operation of base stations.

Additionally, when data are accumulated for longer time period, it is possible to perform research on coordinate changes in time, which is impossible for classical geodetic network. In order to determine coordinate changes in time for classical geodetic network, it is possible to perform repeated measurement of its coordinates. For system of the new generation it is possible instantly, because data are accumulated without interruption and for the whole period, which gives also possibility to make calculations for longer time period and to perform comparison

Taking into account research performed beforehand on GPS base stations and systems thereof, they comply with requirements of up-to-date geodetic systems, providing all imposed requirements.

Arrangement of base stations

For accurate calculation of correction distance between base stations is not greater than 70 kilometers, arrangement is even and base stations are placed at border. Such arrangement provides performance of measurements with accuracy up to 5 centimeters. Also measurements on the border would be made with high accuracy because base stations are placed not further than 30 kilometers from the border, which provides that base line is not greater than 30 kilometers and the maximally possible accuracy is reached outside the network boundaries.

Arrangement of base stations is essential for the homogeneity of the system so that it generates corrections evenly throughout the entire area covered by system operation, i.e., in the entire territory of Latvia. Even arrangement provides even interpolation between various base stations. By use of interpolation and other elimination of measurement inaccuracies caused by error sources, the necessary result is reached.

When the user is situated nearer to the base station, it is possible to get more accurate measurements. However, it is not economically gainfully to locate indefinitely large amount of base stations in the country. It is necessary to choose the maximal distance between bases so that measurements are with the required accuracy. It means that in urban areas greater number of bases per unit of area is required than in rural areas.

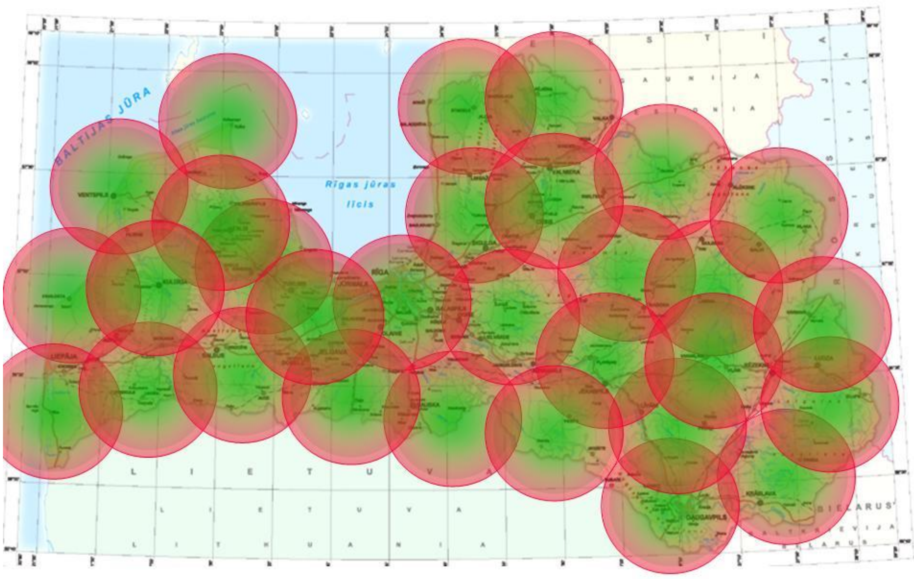


Fig. 2 Analytic arrangement of base stations

According to conditions of arrangement of GPS base stations the necessary distance between base stations is up to 70 kilometers. In some sites distance up to 100 kilometers is permissible.

Taking into account specific character of the territory of Latvia, distance between base stations 70 km, the following analytical arrangement is obtained in figure 2. However, other aspects having impact on arrangement of base stations shall be taken into account. So following conditions besides shall be considered in order to solve and establish system that:

-is economically most advantageous;

-has the minimal number of base stations, with which the required accuracy can be obtained;

Global positioning measurements depend on environment. It means that considering the experience of making of global positioning measurements in other countries and in world that is mentioned in the previous chapter it is necessary to make measurements in the circumstances of Latvia and to find conditions for making of most accurate measurements.

As it was mentioned above, accuracy of global positioning measurements depends on distance to base station, which accumulates data in already known point. It is demonstrated in figure 1.19 that with distance from base station composition of layers of atmosphere and troposphere changes. As Latvia is situated to the north from equator, it is necessary to make global positioning measurements for exact determination of this change. The maximal distances in the territory of Latvia, which can be reached, are from East up to West coast approximately 420 km and from North up to South 280 kilometers. In figure 3 it is demonstrated that already at the distance from base 28 kilometers fluctuations of data to be calculated reach up to 60 centimeters deviation.

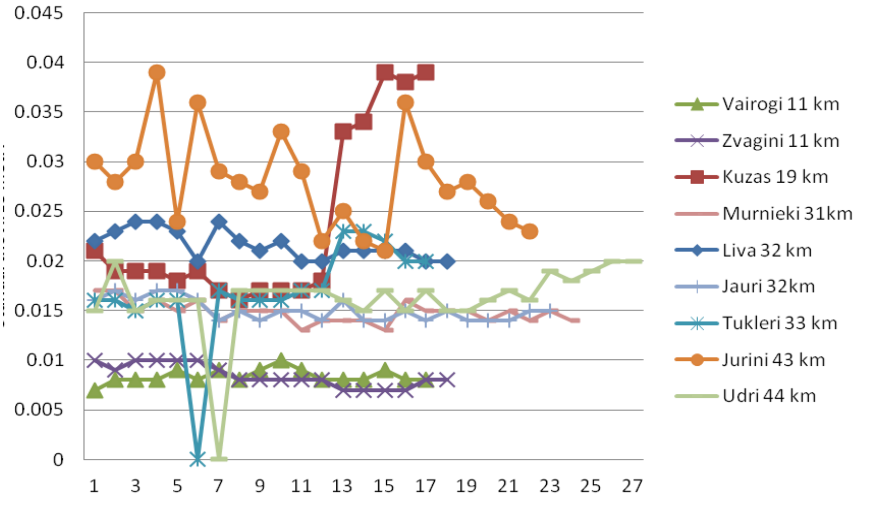


Fig. 3 Size of standard deviation depending on distance to base

For the testing in circumstances of Latvia experimental measurements were made in order to clarify, what is the accuracy in circumstances of Latvia. Measurements were made on State Geodetic points with established coordinates.

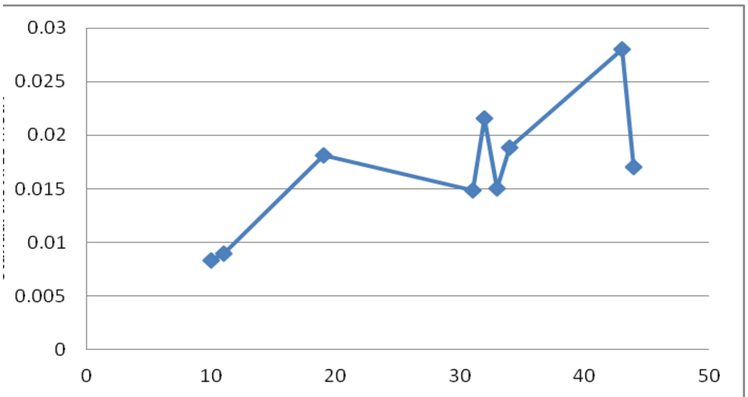


Fig. 4 Dependence of standard deviation on vector length

When dependence of size of standard deviation on distance to base station is depicted in the chart 3, it can be observed that it increases proportionally to the distance. However, an individual point has reached higher accuracy despite of increase of distance. In order to make analysis on this case, it is necessary to make study on different satellite situation and position. When increase of standard deviation is analyzed, it is possible to come to conclusion that after thirty five kilometers it increases fast. It proves also that with increase of distance from base station it is impossible to model changes of atmosphere, troposphere and ionosphere.

Taking into account the stated aspects, solution was adopted to install GPS base stations in regional offices of the State Land Service, where data transmission network is already installed and available.

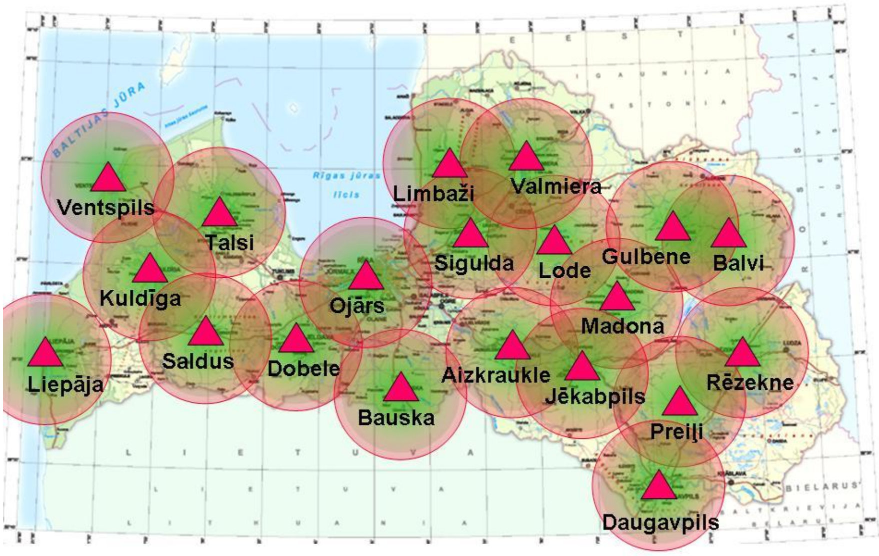


Fig. 5 Rational arrangement of base stations

As a result:

1. Arrangement of base stations is close to even coverage for entire territory of Latvia;
2. Buildings for installation are under management of supervisory authority, protected and safe – there are no additional expenses for rent of premises, server room and roofs;
3. The existing infrastructure is used: electricity, data transmission network, Internet connection;
4. As installation of the system is made by ourselves, installation charges are economized.

In the **chapter three** the installation of system LatPos and problems related to it and solutions found are disclosed.

After evaluation of conditions of arrangement of base stations and available resources, following solution is chosen:

-to use regional offices, which are at disposal of SLS – Following preconditions are obtained:

-there is no rent of premises. It is possible to install equipment in already existing premises;

-there is not necessary to establish data transmission lines. It is possible to use and check operation of equipment practically at once.

-there is no coordination with owners of building concerning installation of antenna on the roof. It is possible to make installation in short time;

However, if this solution is used, there are also shortcomings:

-if regional offices are used, arrangement of base stations is not ideal;

-there is no information, how inaccurate will be measurements beyond the system, because here and there base lines can be even 73 km long. Coverage is not provided at borderland of Latvia. It raises number of questions about the possible provision of accuracy of system in borderland. However, we can take into account that there are no settlements and towns, where accuracy of measurements is required up to 5 centimeters. Assuming that the system provides 2 centimeters within arrangement of base stations and up to 4 centimeters beyond the coverage of the system such type of installation will meet requirements for making of measurements in the entire territory of Latvia.

Installation of antennas

Fastenings of metallic pipes with diameter 60 mm were chosen and they were painted white in order to eliminate impact of sun light. Figure 6 Base station antenna in Madona.

Fig. 6 Mount of antenna in base station Madona

GPS receiver and power unit is placed in a metallic box. The power unit provides conversion of current from 220V to 12V and provides voltage also after disappearance of network voltage for forty-eight hours.

Fig. 7 Base station equipment

Box is made large enough so that GPS receiver and UPS can be placed there freely. In sites, where cable is not used in full length, it is placed in the box. Large box enables easy maintenance of the placed equipment. Antenna cable is especially thick and does not bend, therefore sufficient space shall be provided in order to place roll. It is not recommended to change the length of cable so that is equal in all GPS base stations. Correction calculation depends on it.

Server system

Data distribution server provides fulfillment of three functions – WEB server that by Internet browser software is accessible and can be used comfortably by users, FTP server that is used in automated systems, which can search and receive data automatically in order to use them in calculations. Customer himself has no need to perform data search and download, software can perform it automatically, only surveyor field data shall be uploaded. And RTK server that distributes real time data for tools that are situated in the field and are connected to server by use of wireless data transmission technologies.

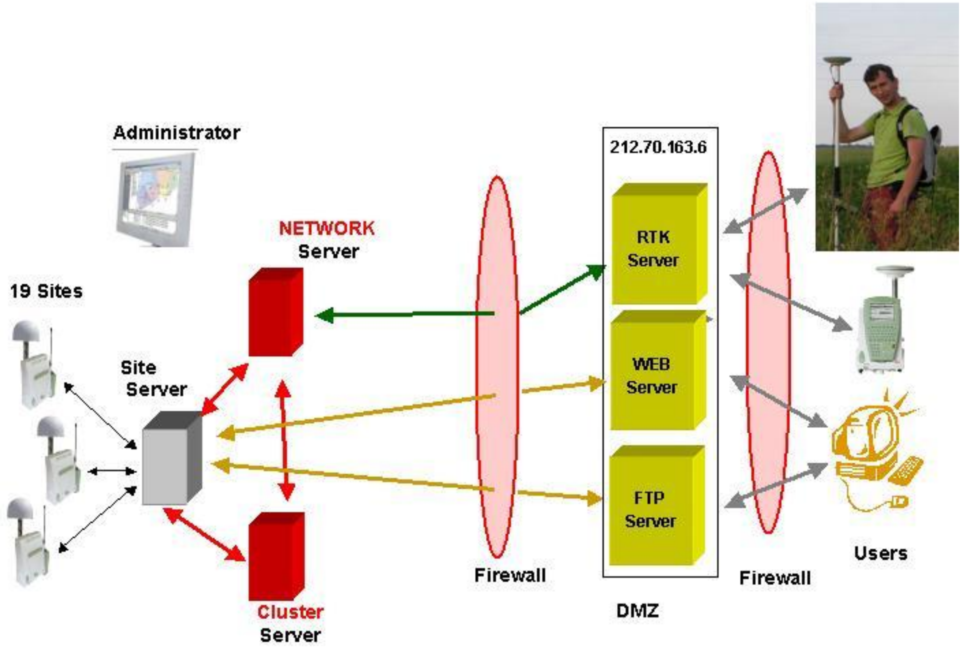


Fig. 8 GPS base station system scheme

System consists of 19 base stations, servers, data transmission network. Further each component is discussed individually. In 2011, already 23 base stations are operating, geometry of the arrangement is improved.

Data obtaining from GPS receivers – sensors.

Data are satellite signal measurements in GPS antenna. It is measured every second, how long is time, in which code has come from satellite. It is done by GPS receiver. Measurements are calculated and results are prepared in digital form. All data are accumulated in the internal GPS memory. In the case of outage of electric power supply, UPS provides uninterrupted operation for forty-eight hours. In the case of outage of data transmission line, the internal memory of GPS receiver provides data accumulation for seven days. Data are sent to station server that receives data from all base stations.

Data arrangement

Originally all data from GPS base stations are stored in one folder. Further data are divided for processing for real time flow and for distribution for post-processing. Post-processing data are sent to distribution server. Data of two types are sent to distribution server: in data format Leica MDB and format RINEX. Format

MDB is used for WEB interface software and by it RINEX data in time chosen by user are generated. Data format RINEX is placed on FTP data distribution server.

Data processing for RTK distribution

Stations' server sends data to real time server. Data of all base stations, in data format MDB. Real time server, by use of information sent by users on location prepares correction flow, calculating individual correction. In order to do it there is area defined, where general correction is calculated, which is used as base for calculation of individual correction.

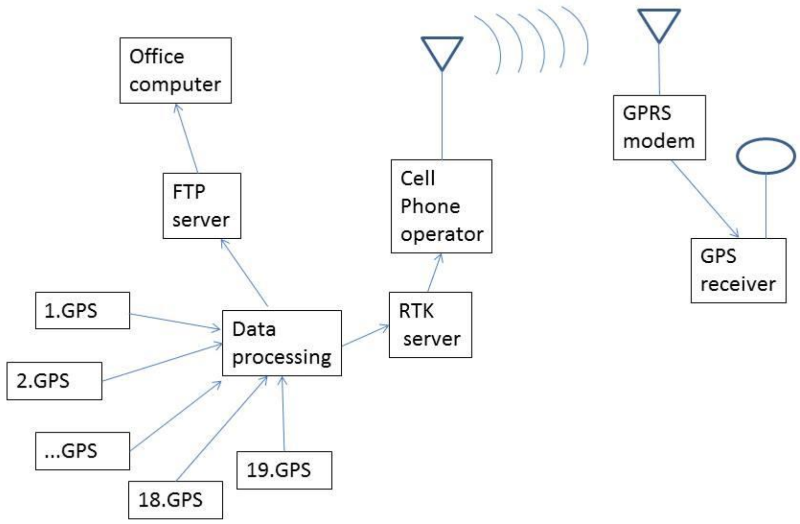


Fig. 9 Data transmission to user

For provision of system operation in the territory of Latvian state and in order to secure that it gives the same results of geodetic measurements as making measurements from the national network, it is necessary to connect system to the National Geodetic Network of Latvia by calculating coordinates of base stations.

In order to calculate coordinates of base station system homogeneously, points shall be chosen in the entire territory of the state. Geodetic points of class zero Rīga, Kangari, Indra and Arājs. They are located in the territory of Latvia and it is possible to perform coordination of 19 base stations. Vectors are used in measurement – from every starting-point to nearest base station. Reciprocally between bases also one vector forming homogeneous triangles

To perform determination of coordinates from points of class 0, which are located throughout Latvia. Determination of coordinates from geodetic points of lower class, which are nearer, will not form homogeneous calculations. When individual points, which are nearer, are taken, homogeneity of the whole network will not be achieved, because already points of class 1 and points of lower class are surveyed by areas and alignment of them is made. Measurement from nearer geodetic networks would include better every GPS base station in local networks – small areas. It would be possible to use shorter sessions, but then it is necessary to perform them for each of 19 base stations. Base station system would form inhomogeneous and would not provide measurements of equal accuracy in the entire territory of Latvia.

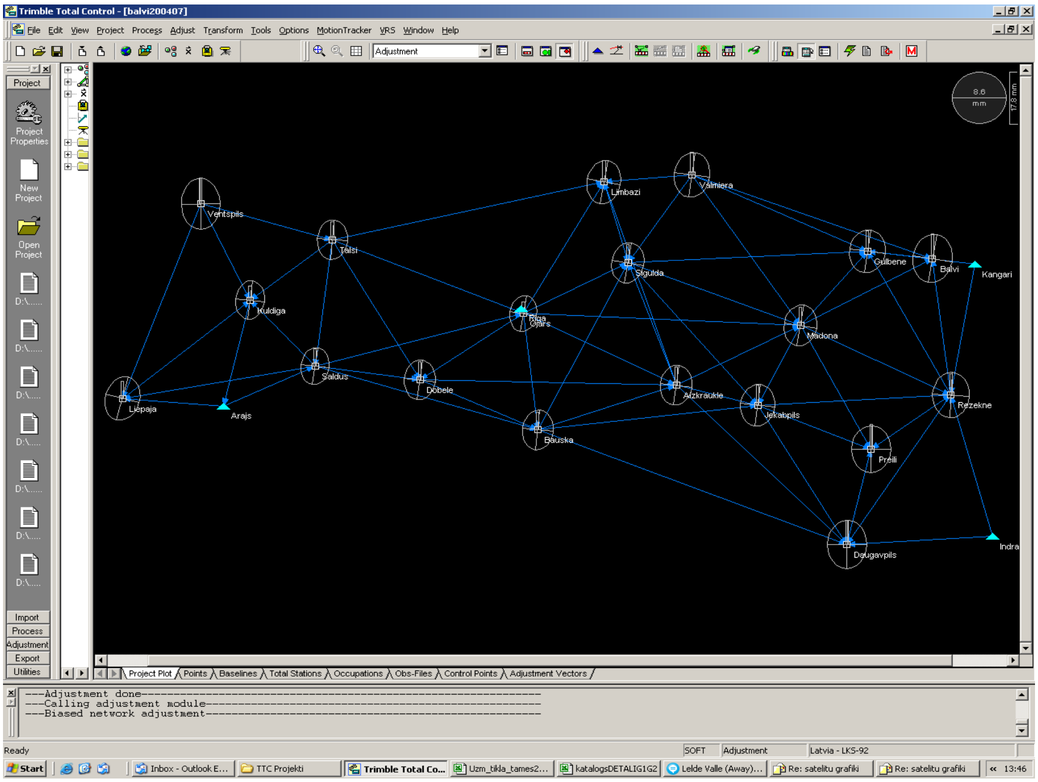


Fig. 10 Vector scheme in base station calculations

To establish length of session six hours. In order to obtain accuracy of coordinate determination below 1 centimeter, the necessary minimum is three hours. In order to give opportunity to select most qualitative signals and most accurate measurements, length of session is rums is established six hours. Study of correlation of session length and accuracy was made by Atis Vallis.

Double base lines are not formed between points to be surveyed. It means that base lines in network are formed so that regular triangles are formed and all base stations are mutually connected.

Table 4

Results of coordinate calculations

Point	Northing	σ	Easting	σ	Height	Elevation	σ
Aizkraukle	273457.1265m	6.7mm	576759.4890m	5.2mm	117.5483m	95.9563m	12.5mm
Arajs	263208.7690m	0.0mm	363511.1810m	0.0mm	208.6030m	184.1449m	0.0mm
Balvi	336401.4863m	8.0mm	697627.2696m	6.3mm	145.7069m	125.6213m	17.2mm
Bauska	251271.2262m	6.6mm	511487.3134m	4.9mm	69.3985m	46.9068m	12.2mm
Daugavpils	194449.9228m	8.1mm	657323.5202m	6.3mm	132.9071m	110.9864m	16.8mm
Dobele	276183.1479m	6.6mm	455883.7608m	5.0mm	85.0888m	62.1123m	12.9mm
Gulbene	339945.4965m	7.2mm	666868.7838m	5.7mm	162.4557m	141.9610m	14.3mm
Indra	198519.9470m	0.0mm	725865.8500m	0.0mm	213.6250m	192.7628m	0.0mm
Jekabpils	263562.7602m	7.0mm	615239.6088m	5.5mm	117.2090m	95.8896m	14.0mm
Kangari	333650.3330m	0.0mm	717694.6970m	0.0mm	163.8540m	144.1525m	0.0mm
Kuldiga	315769.9635m	6.4mm	375951.7161m	4.6mm	70.8313m	48.3396m	9.9mm
Liepaja	266927.7606m	7.3mm	315796.8324m	5.6mm	51.3565m	27.1156m	12.2mm
Limbazi	374452.0675m	7.2mm	542746.1623m	5.4mm	115.3948m	95.7979m	14.8mm
Madona	303239.9304m	6.8mm	635457.4344m	5.4mm	174.2183m	152.8118m	12.9mm
Ojars	309093.6011m	6.0mm	504631.3138m	4.4mm	41.9308m	20.8775m	8.2mm
Preili	241689.6296m	8.0mm	668648.8307m	6.2mm	159.2105m	138.0503m	17.2mm
Rezekne	268589.7334m	7.6mm	706252.0780m	5.9mm	170.5142m	150.3126m	14.6mm
Riga	311650.4800m	0.0mm	503564.5890m	0.0mm	29.3370m	8.3554m	0.0mm
Saldus	282873.4865m	6.2mm	406505.0873m	4.6mm	144.7918m	121.4166m	12.0mm
Sigulda	334306.0144m	6.8mm	554012.1597m	5.2mm	133.9112m	113.4122m	12.7mm
Talsi	345708.1728m	6.7mm	414728.4504m	4.8mm	115.0609m	93.5890m	12.6mm
Valmiera	377914.4982m	7.5mm	584166.3671m	5.7mm	75.6571m	55.6146m	15.6mm
Ventspils	363589.6645m	8.6mm	352632.0117m	6.2mm	39.3560m	18.0017m	17.8mm

If attachments of all four geodetic points are used in comparison with calculations from attachment to one geodetic point, coordinates of base stations can differ even by three centimeters. It can be explained by the circumstance that if attachment is made only to one geodetic point, coordinates of further points are calculated summarily from very long base lines. The most successful solution is to use all geodetic points of class zero. When attachment of base stations of system LatPos to geodetic network was made, all four geodetic points of class zero were used.

For calculations of high accuracy it is necessary to use data of good quality. „Of good quality" for the purposes of GPS are uninterrupted data. Consequently, when base line calculations are made, uninterrupted data are selected. Data continuity is depicted in figure 14.

Data continuity is selected visually, by excluding data of time periods, when signal transmitted by satellite was covered or satellite was low and behind obstruct. Practically such continuity of signals was not observed in base stations. Point surrounded by highest trees is Arājs. Therefore, when this point is used, the used data shall be chosen carefully. Practically, visibility of satellites is limited up to angle of 15 degrees.

In order to cream off the accumulated information and data, it is possible to exclude unnecessary data manually. It provides the use uninterrupted data flows in calculations. If interrupted data are left, software cannot calculate uninterrupted signal cycles. It is necessary to use full signal code cycles in data calculations, which provide accuracy of calculations.

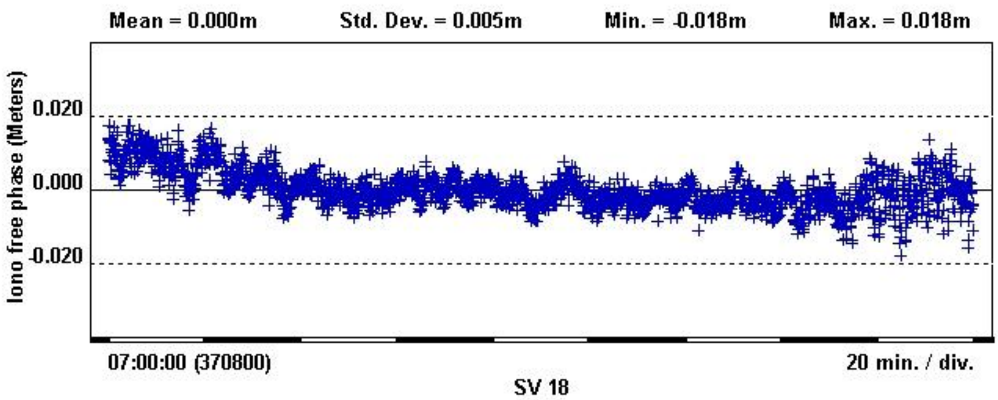


Fig. 11 Fluctuations of measurements in one component for one satellite

Continuing the analysis of accumulated data study of fluctuations of individual measurements from one satellite takes place. Perfect example is shown in figure 11, where good data from satellite 18 can be seen. Data of low quality can be seen from another satellite in this measurement session, figure 12 shows data, according to which evaluating it is possible to exclude certain part of bad data, which exceed dispersion of one centimeter.

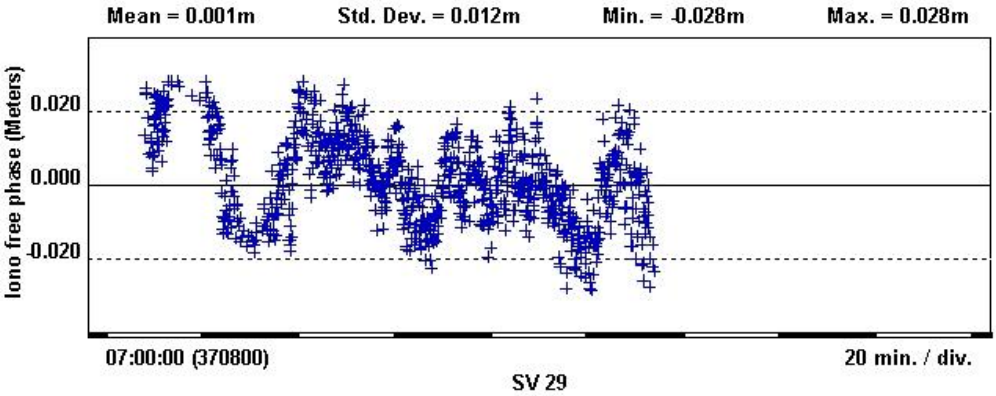


Fig. 12 Data received from satellite 29 during the session

Figure 12 shows not only the bad quality of data – large dispersion around the assumed possible calculable value, but indicates that satellite signals are not detected in the whole time of session. Data dispersion reaches even two centimeters. It is not recommended to use data of such quality in calculations of high accuracy.

In the chapter four results of control of system operation and the secured performance are discussed.

For control of results of system operation geodetic measurements by GPS receivers were made. The main principles for achievement of results were chosen in accordance with basic laws of geodesy and basic principles of GPS measurements.

When control of system operation is performed, it is necessary to establish:

- Results given by the system, standard deviations of measurements, if the classical geodetic network is used, making measurements on National Geodetic Networks;
- Differences of coordinates from coordinates of National Geodetic Network points, how consequent they are, homogeneity and orientation of deviations;
- Stability of measurement accuracy, as GPS base station system is electronic system and performs calculations and it depends also on configuration of satellites and received data;
- When measurements are made, consider additional circumstances influencing the accuracy of measurements – encumbered circumstances, impact of Sun light, measurements in longer period of time.

- Comparison of results between two systems, LatPos and EUPOS-Rīga.

For the control of system operation tools of diverse manufacturers were used, in order to eliminate trend of one manufacturer proving that tools of any manufacturer give equal results.

For stable measurements tools of Leica, Trimble and Topcon were used. In experiments operation of tools of Sokkia was not controlled, because tool was not available.

When we are examining measurements, which are made in system LatPos, difference can be observed in the system. For LatPos measurements, 70% measurements fall within one centimeter. Such information points at higher accuracy of the system. And, if we are considering 2 centimeters, it can be statistically maintain that for measurements of network LatPos in 90% cases error of measurement will not exceed two centimeters. It shows the degree of credibility of measurements in every system.

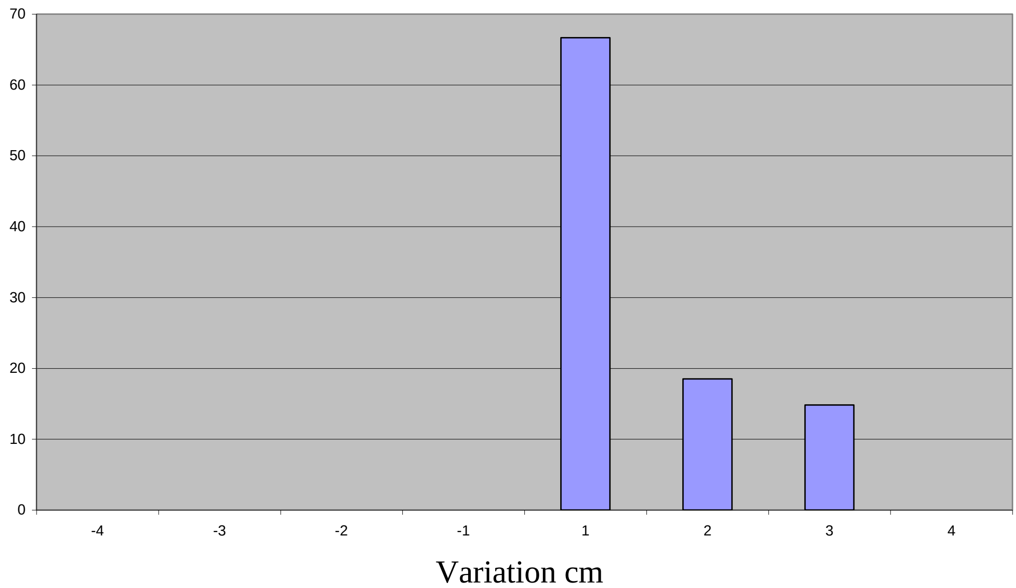


Figure 13 Distribution according to deviations in LatPos network

For provision of real time, data flow from all GPS receivers – base stations is transmitted every second. Data flow shall be uninterrupted and it shall not be late, because data already processed shall be delivered to the user not later than one second after data detection. Therefore data delay from base stations is not admissible greater than half of second or 500 milliseconds. Data volume that is sent within one second is not greater than 3 kilobits. Software Spider Site Server follows uninterruptedness of data flow and delay of signal.

Software of Leica Spider Site Server regards discontinuity that is greater than 500 milliseconds as data flow interruption and depicts in performance chart Figure 14. System administrator can observe visually data flow interruption and react correspondently in order to avert failure in data transmission.

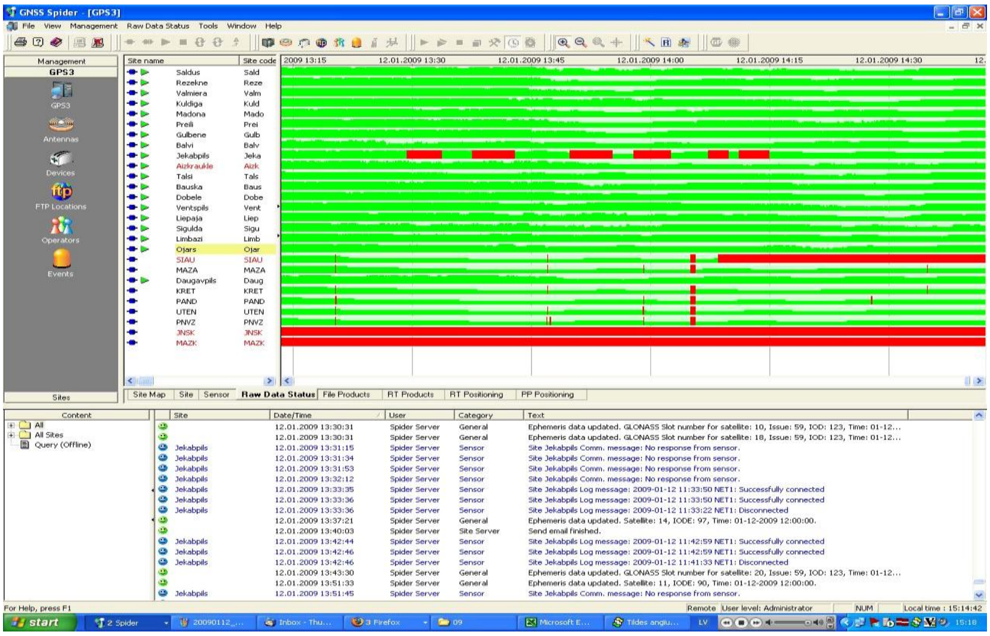
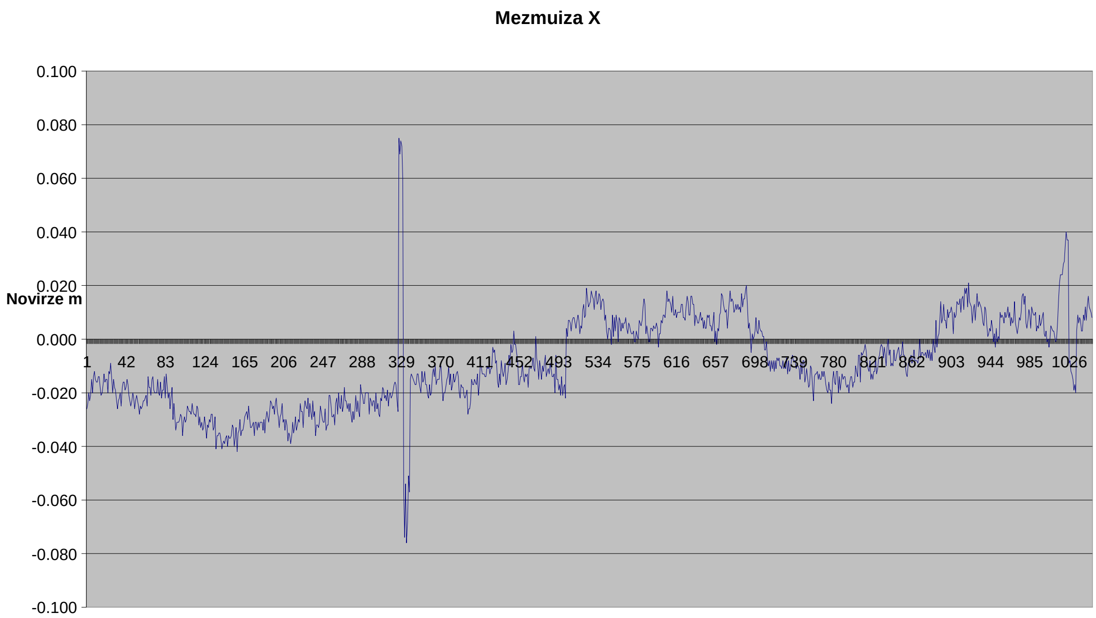


Fig. 14 Interface of software Spider Site Server. Data flow continuity.

Data transmission interruptions may be caused by damage to the cable, by damage to data transmission equipment – switch or router. GPS base station is provided with uninterruptible power supply UPS. Not all data transmission equipment are provided with uninterruptible power source and are not maintained from part of LatPos administrators, therefore it is not possible to preclude interruptions of this type.

Covering of a geodetic point impacts accuracy of measurements directly, therefore measurement by GPS is not admissible also in sparse trees, because result obtained may be doubtful.



Measurements

Fig. 15 Fluctuations of coordinate X on point Mežmuiža

When measurements are made on geodetic point that is situated in an open field and there are no interruptions of satellite visibility, it is possible to get fluctuations of real corrections sent by system LatPos without the impact of environment. Fluctuations, which are observed in figure 5.38, are result of total error of measurements sent by system. Fluctuations within four centimeters now can be considered as absolute and close to best parameters of the system.

Fig. 16 Geodetic point Mežmuiža

CONCLUSIONS

In Thesis, effective geodetic measurement with global positioning is studied and elaborated.

1. Present-day methods of global positioning measurements are evaluated and trends of development of GPS base station networks in Europe and world are studied. Base station systems provide performance of global positioning measurements in short time (measurement time one minute) and give homogeneous measurements in the entire territory of base station coverage. When base station network is established, RTK method is applied, in order to calculate measurement. The main advantage is fact that user need not have his own base station and person that is guarding it. Data security increases, because calculations can be made from several base stations.
2. In experimental way, when global positioning measurements were made, the optimal distance between base stations (approx. 70km) is determined for geographic circumstances of Latvia. Measurements on geodetic points, coordinates of which are determined by performing calculations in the network, were made. With increase of distance from base station in RTK mode, solution is reached in the long period of time, because factors affecting signal – ionosphere, troposphere and jointly visible satellites differ. The optimal distance 35 km is found, when initialization of the tool is reached within one minute and accuracy of survey is 4 cm.
3. Analytically elaborated GPS base station model is optimized, taking into account the affecting factors: visibility of sky, possibilities of fastening of antenna, data transmission network availability and security against vandalism. Stone buildings with data transmission network availability in the entire territory of Latvia. The existing data transmission network is used, in which GPS data transmission is examined in experimental way and conclusion was drawn that it provides (necessary) data transmission speed and continuity.
4. Study of operation of the optimized system LatPos on accuracy and homogeneity of measurements in the entire territory of Latvia. Special attention was paid to strategic places – Rīga and beyond the coverage of base stations of LatPos. Measurements made by RTK method proved that in territory of Rīga for 90%

cases standard deviation of measurements is not greater than 2 cm. Beyond coverage of LatPos measurement error does not exceed 4 cm.

5. Speed of performance of geodetic measurements and accuracy that can be reached by measurements from classical geodetic network and from LatPos system is compared. Study proves that when measurements are made from classical geodetic network, residuals up to 15 centimeters are possible, while LatPos system secures homogeneous measurements in the entire territory of Latvia with residuals up to 4 cm. The speed of performance of the measurement increases four times by use of LatPos system, because it is not necessary to search geodetic point, it is not necessary to make gājienu to object. Measurements can be made by one surveyor. In order to reach two centimeters accuracy it is necessary measurement of ten seconds unlike twenty minutes of the classical measurement.
6. It is calculated that maintenance of LatPos system is five times cheaper than maintenance of local networks. LatPos system is monitored in real time and operation problems are determined momentarily. Maintenance is performed by two employees. Maintenance of geodetic networks is performed by several institutions, because regular inspection of geodetic points in the field and update of database is necessary.
7. It is shown that LatPos system is not only geodetic support system. It is base for entire GIS information that is coordinated. Determination of coordinates is necessary for control of farm machines, forest management, by use of handheld GPS, inspection of agricultural lands by use of handheld GPS. Improved LatPos system is used also for purposes of aviation.

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Summary of PhD Thesis

Submitted to Rīga Technical University
For obtaining of degree of Doctor of Engineering

Thesis for obtaining of degree of Doctor of Engineering will be publicly defended at June 29, 2012 at 14:00, Faculty for Civil Engineering of Riga Technical University, Āzenes street 16, in council room.

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Confirmation

I am confirming that I have elaborated the present thesis that is submitted for consideration at Riga Technical University for obtaining of degree of Doctor of engineering.
The thesis is not submitted at any other university for obtaining of scientific degree.

Jānis Zvirgzds ....(Signature)

Date: ....

The thesis is written in Latvian and consists of introduction, 4 chapters, conclusions, reference list, 6 annexes, 118 figures, 9 tables, in total 169 pages. There are 91 titles in reference list.

Zvirgzds J. Rational System LatPos.
Summary of PhD Thesis.
-R.:RTU, 2012.-35 pages.