

# **APPLICATION OF VIRTUAL REFERENCE STATIONS IN ASG-EUPOS SYSTEM FOR OPTIMALIZATION OF REFERENCE ELEMENTS SET IN THREE DIMENSIONAL POINTS SETTING OUT NETWORKS ESTABLISHED USING SATELLITE GNSS TECHNIQUE**

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## **SUMMARY**

The paper presents the method of application of virtual reference stations (VRS) created in ASG-EUPOS system using POZGEO-D system. Such solution enables significant enhancement of reference elements set, it can also result in improvement of geometric construction of created network.

Performed investigations proved, that such attitude enables relatively easy improvement of quality parameters of construction surveying network. It leads to increasing of external reliability connected with reference conditions and improves accuracy in particular in absolute sense (determination of GPS vectors and errors of points locations).

In particular the solution seems valuable by planning construction surveying networks on linear objects.

## **1. INTRODUCTION**

The determination of points coordinates is a basic task of geodesy. Lately in connection with widespreading of satellite technics, determination of points coordinates is often replaced with positioning. However for the both tasks the basis is correctly determined and realized reference system, which is physically realized by coordinates system connected with the Earth by geodesic networks points [Kadař 2009]. This connection was up to now used by so called “passive” networks. Now, we do this using Active Geodetic Networks (reference stations), which are given particular geodesic coordinates in the process of permanent measurements. In Poland nowadays we have reference stations of ASG-EUPOS system, determined precisely on the basis of long term measurement sessions GPS, which included also permanent stations of EPN [Kenyeres A., Bruyninx C. 2004] network and a part of POLREF network points. Thanks to that, the stations create (in assumption) for the whole country area particular, and homogenous reference system. However always in such situations occurs the problem of certain local and global disconnect of “new” reference system disconnect. In turn, the task of geodesist on this phase of work relies on implementation of such solution, to obtain by skillful using GNSS technic coordinates of constructed local network characterized by high absolute accuracy. Such possibilities are given by made accessible

in Poland on 2nd June 2008 Multifunctional Precise Satellite Positioning System ASG-EUPOS. Its task is to aid precise positioning, using satellite technics by disclosing fitting corrections in the real time, observations from reference stations and automatic postprocessing service. Present paper contains the proposition of certain solutions leading to optimization of reference elements configuration in 3 dimensional, local construction surveying networks using POZGEO-D service. Suggested method enables strengthening and connection of a classic measured GPD network, but independent performing of calculations enables more elastic approach to the whole process of network elaboration and provides more scope regarding correctness verification and methods of points determination.

## 2. LAY OUT OF DETERMINED POINTS OF NETWORK

Construction surveying network under consideration consists of ten points distributed on about 8 kilometers of space. It was a standard linear network placed for the needs of a carriageable road modernization service. GPS measurements points fixed in the ground were situated in such way that would enable efficient performing of classical surveying connected with modernized object service. Points were fixed with the use of concrete post with protruding metal pin, which constituted simultaneously mark for horizontal and vertical reference system. The points were situated in road lane on both sides of modernized object Location of measured points of the geodesic network is presented in fig. 1.

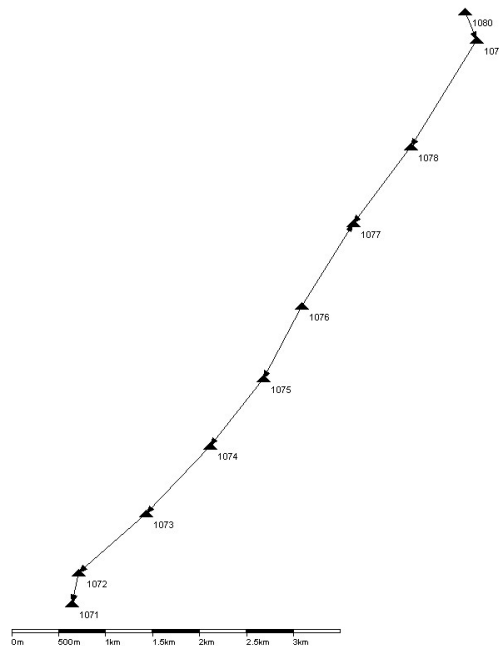


Fig. 1. Location of determined points.

## 3. GPS MEASUREMENTS

GPS measurements were performed in accordance with assumptions of technical instructions project.

G-1.12. In the task ten sets of GPS receivers were used: Trimble 4700, Trimble R6, Trimble R8 i Trimble SPS881. Before beginning the actual measurements, a plan of satellite observations was elaborated on the basis of measurements conditions analysis

and location of points, and according to the plan the measurements were performed. Measurements were performed using static method, assuming following parameters:

- measurement session lasting 4 hours,
- data registration interval 5 seconds,
- horizon cut-off angle 10 grades.

It was assumed, that new determined points will be connected to ASG-EUPOS network points, therefore the measurements were performed only on determined points. Measuring conditions were similar on all points, without significant limitations of approach to sky sphere .

#### 4. ELABORATION OF MEASUREMENT RESULTS

##### 4.1 Elaboration of measurements results using POZGEO service

Elaboration of collected observational data was performed in two basic variants. Basic solution was performed using POZGEO service sending observational files from each receiver in universal RINEX format to system server. Adjustment for each of ten determined points was performed with connection to six nearest reference stations. There were four Polish stations of ASG-EUPOS system(KATO, WODZ, TARG, ZYWI) and two Chech station of CZEPOS system (CFRM – Frydek Mistek i CBRU – Brutal), all mentioned stations belong to a broader, congeneric European system of spatial references EUPOS including some hundreds of reference stations. The lengths of vectors connecting network were contained in an interval from 7 - 10 km for WODZ station to over 81 km for CBRU station.

In calculations of automatic postprocessing (APPS) Rapid orbits were used. The system determined coordinations of all measured points and generated for them reports from calculations. On their basis in Tab. 1 the list of adjusted coordinates and their mean square errors was set up:

**Tab. 1. List of Cartesian coordinates determined using POZGEO service**

Point number	Cartesian coordinates ETRF-89					
	X	mx	Y	My	Z	mz
1071	3897258.203	0.0044	1307067.427	0.0045	4860860.784	0.0043
1072	3896999.247	0.0047	1307056.325	0.0049	4861072.462	0.0045
1073	3896317.525	0.0044	1307576.189	0.0049	4861476.772	0.0040
1074	3895574.853	0.0040	1308048.527	0.0045	4861934.952	0.0038
1075	3894890.052	0.0042	1308420.518	0.0046	4862409.282	0.0040
1076	3894194.173	0.0044	1308614.740	0.0049	4862902.782	0.0042
1077	3893383.209	0.0043	1308921.808	0.0048	4863470.957	0.0041
1078	3892612.204	0.0042	1309312.406	0.0048	4864014.510	0.0040
1079	3891567.625	0.0051	1309699.970	0.0059	4864746.192	0.0047
1080	3891389.054	0.0053	1309508.449	0.0055	4864937.594	0.0052

Mean square errors of coordinates of points did not exceed 6 mm (Tab.1) Average value of the error for X coordinate was equal 4.5 mm, for coordinate Y was equal 4.9 mm, and for Z it was 4.3 mm.

#### 4.2. Laboration of measurements results using POZGEO-D service

To check the system and obtained accuracies, an alternative own specific adjustment of measured network was performed. All points were determined as one network in ten different variants of connection. In the first stage of the elaboration using www page observations from physical reference stations of the ASG-EUPOS system were derived, next observations for virtual stations were created using POZGEO-D service. As physical stations were applied points which were closest to measured network, namely stations: WODZ, KATO, TARG and ZYWI. Creating data 5 seconds measurement interval was assumed and observation time the same as on determined points.

Three basic variants of elaboration were applied:

- the first variant assumed use in elaboration only physical (CORS – Continuously Operating Reference Station),
- in the second variant applied as a connection of network – combination of physical stations (CORS) and virtual stations (VRS – Virtual Reference Station),
- in the third variant only connections to virtual stations (VRS) were applied.

Solutions for the first and second variant were performed in several subvariants using different combinations of physical and virtual stations as connections for measured network.

In variant denoted as „1A” four reference stations were used as the network connection (Fig.2). Elaboration was performed using Trimble Total Control ver. 2.73 software using approximate Rapid orbits and absolute antennas models calibrated according to IGS standards. In the first stage vector components for the network were determined basing on frequency L1 and L2 combination. Next, after elimination from the solution vectors of type different than fixed exact solution accordingly to the method of the mean squares was performed for determined points in connection to points assumed as fixed. The results of adjustment were obtained in ETRF-89 system [Torres J.A., Altamimi Z. 2008]. Mean square errors of determined points did not exceed here 2 mm (Tab.2). The average value of GPS vector correction was 1.5 mm, and the maximum was 2.1 mm.

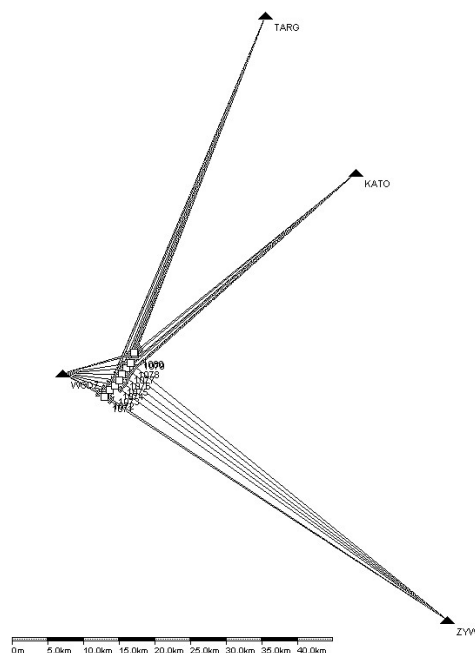


Fig. 2. GPS points network connection in „1A” variant.

Additionally in Tab. 2 were listed as  $\Delta X$ ,  $\Delta Y$ ,  $\Delta Z$  the results of comparison of coordinates obtained from the own solution elaborated using POZGEO-D service and the results of automatic postprocessing obtained from POZGEO service.

Tab. 2. Analysis of accuracy from network points adjustment for variant „1A”

Point number	Mean errors of coordinates			Coordinates differences		
	mx	my	mz	$\Delta X$	$\Delta Y$	$\Delta Z$
1071	0.0015	0.0013	0.0016	0.001	-0.003	0.005
1072	0.0016	0.0014	0.0017	-0.032	-0.011	-0.031
1073	0.0016	0.0014	0.0017	0.020	0.018	0.039
1074	0.0015	0.0013	0.0016	0.023	-0.003	0.025
1075	0.0014	0.0012	0.0015	0.029	0.011	0.038
1076	0.0014	0.0012	0.0015	0.019	-0.009	0.029
1077	0.0014	0.0012	0.0015	0.016	-0.002	0.028
1078	0.0015	0.0013	0.0016	0.023	-0.007	0.037
1079	0.0018	0.0016	0.0019	-0.035	0.001	-0.039
1080	0.0015	0.0013	0.0017	0.003	0.006	0.006
MIN	0.0014	0.0012	0.0015	-0.035	-0.011	-0.039
MAX	0.0018	0.0016	0.0019	0.029	0.018	0.039
AVG	0.0015	0.0013	0.0016	0.007	0.000	0.014
	0.0001	0.0001	0.0001	0.023	0.009	0.028

The differences occurred significant because they were enclosed in intervals: for X from -3.5 cm to +2.9 cm, for Y from -1.1 cm to +1.8 cm, and for Z from -3.9 cm to +3.9 cm.

Analogous elaborations were performed for the other variants presented in Figures from 3 to 11. Variants „1B” and „1C” included solutions for the network based on connections to three physical stations (CORS).

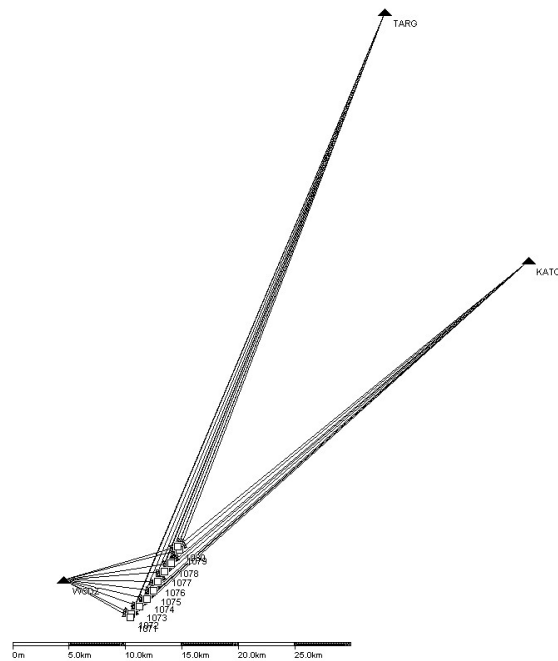


Fig. 3. GPS points network connection in „1B” variant.

**Tab. 3. Analysis of accuracy for network points adjustment for variant „1B”**

Point number	Mean errors of coordinates			Coordinates differences		
	mx	my	Mz	$\Delta X$	$\Delta Y$	$\Delta Z$
1071	0.0015	0.0013	0.0016	0.002	-0.002	0.005
1072	0.0016	0.0014	0.0017	-0.031	-0.009	-0.032
1073	0.0016	0.0014	0.0017	0.022	0.020	0.038
1074	0.0015	0.0013	0.0016	0.024	-0.002	0.024
1075	0.0014	0.0012	0.0015	0.031	0.013	0.037
1076	0.0014	0.0012	0.0015	0.020	-0.007	0.028
1077	0.0014	0.0013	0.0016	0.017	-0.001	0.026
1078	0.0015	0.0013	0.0017	0.024	-0.005	0.036
1079	0.0018	0.0016	0.0019	-0.033	0.003	-0.040
1080	0.0015	0.0013	0.0017	0.004	0.007	0.006
MIN	0.0014	0.0012	0.0015	-0.033	-0.009	-0.040
MAX	0.0018	0.0016	0.0019	0.031	0.020	0.038
AVG	0.0015	0.0013	0.0017	0.008	0.002	0.013
	0.0001	0.0001	0.0001	0.023	0.009	0.028

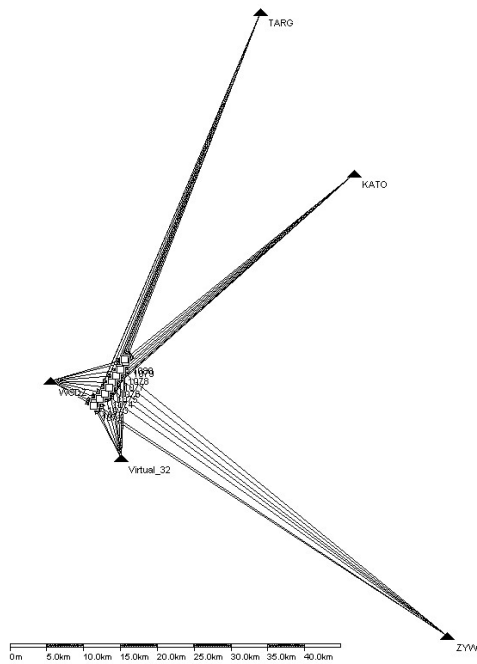
Variants denoted as: „2A”, „2B”, „2C”, „2D”, „2E” i „2F” used to connection several combination of physical and virtual stations. However solution denoted as variant “3A” (Fig. 11) was based only on virtual stations.



**Fig. 4. GPS points network connection in „1C” variant.**

**Tab. 4. Analysis of accuracy for network points adjustment for variant „1C”**

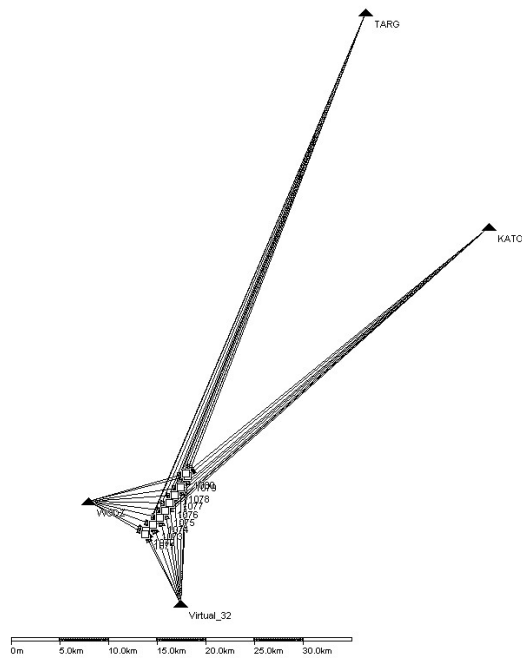
Point number	Mean errors of coordinates			Coordinates differences		
	mx	my	mz	$\Delta X$	$\Delta Y$	$\Delta Z$
1071	0.0015	0.0013	0.0016	0.001	-0.003	0.006
1072	0.0016	0.0013	0.0017	-0.032	-0.011	-0.031
1073	0.0016	0.0013	0.0016	0.020	0.018	0.039
1074	0.0015	0.0013	0.0016	0.023	-0.003	0.025
1075	0.0014	0.0012	0.0015	0.029	0.011	0.038
1076	0.0014	0.0012	0.0015	0.019	-0.009	0.030
1077	0.0014	0.0012	0.0015	0.016	-0.002	0.028
1078	0.0015	0.0013	0.0016	0.023	-0.007	0.037
1079	0.0018	0.0016	0.0019	-0.035	0.001	-0.039
1080	0.0014	0.0013	0.0016	0.003	0.006	0.006
MIN	0.0014	0.0012	0.0015	-0.035	-0.011	-0.039
MAX	0.0018	0.0016	0.0019	0.029	0.018	0.039
AVG	0.0015	0.0013	0.0016	0.007	0.000	0.014
	0.0001	0.0001	0.0001	0.023	0.009	0.028



**Fig. 5. GPS points network connection in „2A” variant.**

**Tab. 5. Analysis of accuracy for network points adjustment for variant „2A”**

Point number	Mean errors of coordinates			Coordinates differences		
	mx	my	mz	$\Delta X$	$\Delta Y$	$\Delta Z$
1071	0.0014	0.0012	0.0015	0.001	-0.002	0.005
1072	0.0015	0.0012	0.0016	-0.032	-0.010	-0.032
1073	0.0015	0.0013	0.0015	0.020	0.018	0.039
1074	0.0014	0.0012	0.0014	0.022	-0.003	0.025
1075	0.0013	0.0011	0.0013	0.029	0.011	0.038
1076	0.0013	0.0011	0.0013	0.019	-0.008	0.029
1077	0.0013	0.0011	0.0014	0.016	-0.002	0.028
1078	0.0014	0.0012	0.0015	0.022	-0.006	0.037
1079	0.0016	0.0014	0.0018	-0.035	0.002	-0.039
1080	0.0014	0.0012	0.0015	0.003	0.007	0.006
MIN	0.0013	0.0011	0.0013	-0.035	-0.010	-0.039
MAX	0.0016	0.0014	0.0018	0.029	0.018	0.039
AVG	0.0014	0.0012	0.0015	0.007	0.001	0.014
	0.0001	0.0001	0.0002	0.023	0.009	0.028

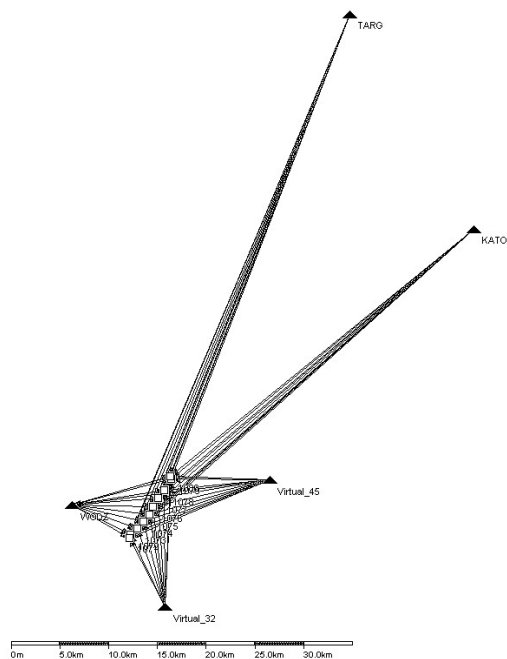


**Fig. 6. GPS points network connection in „2B” variant.**



**Tab. 6. Analysis of accuracy for network points adjustment for variant „2B”**

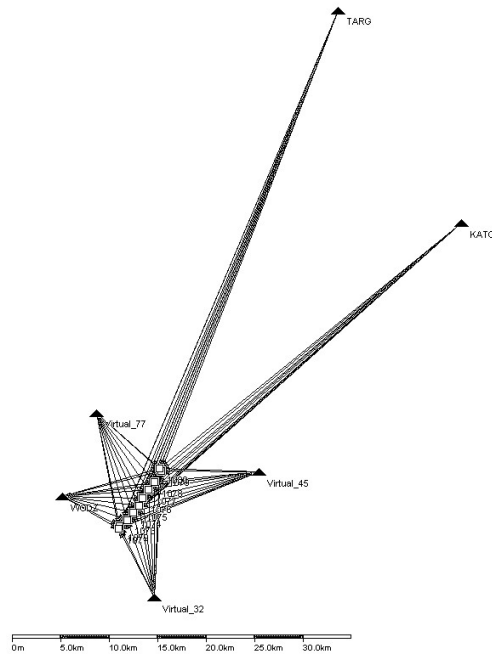
Point number	Mean errors of coordinates			Coordinates differences		
	Mx	my	mz	$\Delta X$	$\Delta Y$	$\Delta Z$
1071	0.0014	0.0012	0.0015	0.001	-0.002	0.005
1072	0.0014	0.0012	0.0016	-0.032	-0.010	-0.032
1073	0.0014	0.0012	0.0015	0.020	0.018	0.039
1074	0.0013	0.0012	0.0014	0.022	-0.003	0.025
1075	0.0012	0.0011	0.0013	0.029	0.011	0.038
1076	0.0013	0.0011	0.0013	0.019	-0.008	0.029
1077	0.0013	0.0011	0.0013	0.016	-0.002	0.028
1078	0.0013	0.0012	0.0015	0.022	-0.006	0.037
1079	0.0016	0.0014	0.0017	-0.035	0.002	-0.039
1080	0.0014	0.0012	0.0015	0.003	0.007	0.006
MIN	0.0012	0.0011	0.0013	-0.035	-0.010	-0.039
MAX	0.0016	0.0014	0.0017	0.029	0.018	0.039
AVG	0.0014	0.0012	0.0015	0.007	0.001	0.014
	0.0001	0.0001	0.0001	0.023	0.009	0.028



**Fig. 7. GPS points network connection in „2C” variant.**

**Tab. 7. Analysis of accuracy for network points adjustment for variant „2C”**

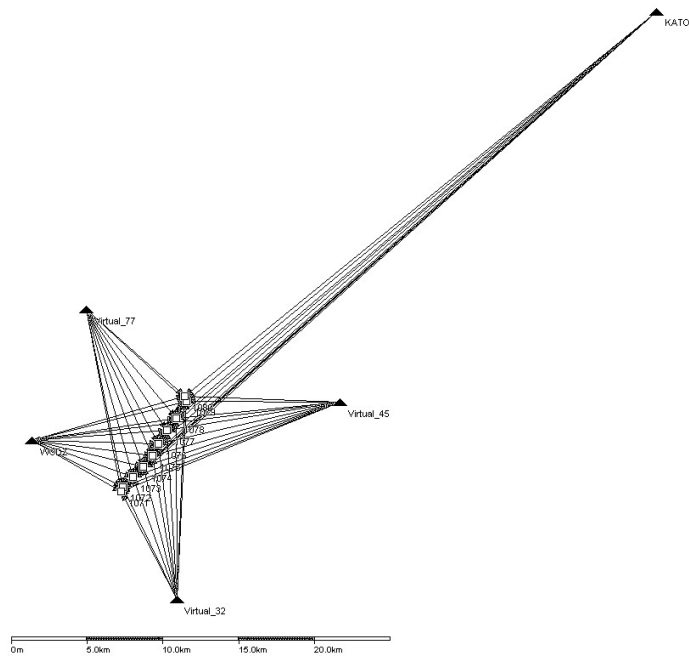
Point number	Mean errors of coordinates			Coordinates differences		
	mx	my	mz	$\Delta X$	$\Delta Y$	$\Delta Z$
1071	0.0013	0.0011	0.0014	0.001	-0.002	0.005
1072	0.0013	0.0011	0.0015	-0.032	-0.009	-0.032
1073	0.0013	0.0012	0.0014	0.019	0.019	0.039
1074	0.0012	0.0011	0.0013	0.022	-0.002	0.025
1075	0.0012	0.0010	0.0012	0.028	0.012	0.038
1076	0.0012	0.0010	0.0012	0.019	-0.008	0.030
1077	0.0012	0.0010	0.0012	0.016	-0.001	0.028
1078	0.0013	0.0011	0.0014	0.022	-0.006	0.037
1079	0.0015	0.0013	0.0016	-0.035	0.002	-0.039
1080	0.0013	0.0011	0.0014	0.003	0.007	0.006
MIN	0.0012	0.0010	0.0012	-0.035	-0.009	-0.039
MAX	0.0015	0.0013	0.0016	0.028	0.019	0.039
AVG	0.0013	0.0011	0.0014	0.006	0.001	0.014
	0.0001	0.0001	0.0001	0.023	0.009	0.028



**Fig 8. GPS points network connection in „2D” variant.**

**Tab. 8. Analysis of accuracy for network points adjustment for variant „2D”**

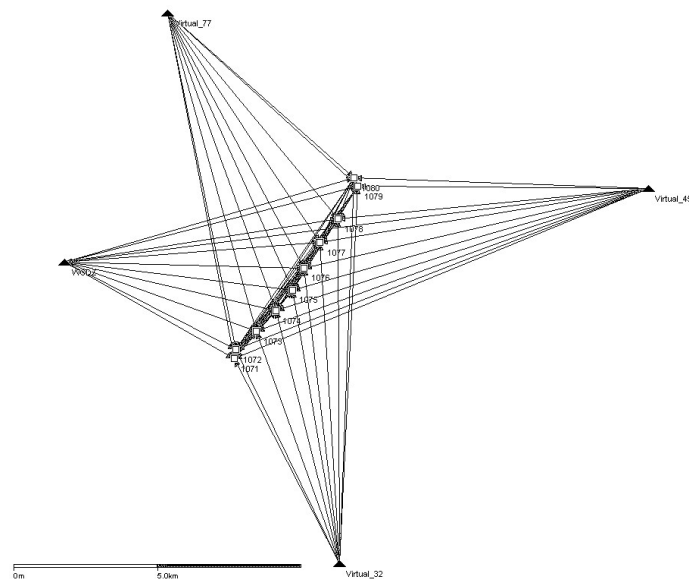
Point number	Mean errors of coordinates			Coordinates differences		
	mx	my	mz	$\Delta X$	$\Delta Y$	$\Delta Z$
1071	0.0012	0.0010	0.0012	0.001	-0.001	0.005
1072	0.0013	0.0011	0.0014	-0.032	-0.009	-0.031
1073	0.0012	0.0011	0.0013	0.019	0.019	0.039
1074	0.0012	0.0010	0.0012	0.022	-0.002	0.026
1075	0.0011	0.0009	0.0011	0.028	0.012	0.038
1076	0.0011	0.0009	0.0011	0.019	-0.008	0.030
1077	0.0011	0.0010	0.0011	0.016	-0.001	0.028
1078	0.0012	0.0010	0.0013	0.022	-0.006	0.037
1079	0.0014	0.0012	0.0015	-0.035	0.002	-0.039
1080	0.0012	0.0010	0.0013	0.003	0.007	0.006
MIN	0.0011	0.0009	0.0011	-0.035	-0.009	-0.039
MAX	0.0014	0.0012	0.0015	0.028	0.019	0.039
AVG	0.0012	0.0010	0.0013	0.006	0.002	0.014
	0.0001	0.0001	0.0001	0.023	0.009	0.029



**Fig 9. GPS points network connection in „2E” variant.**

**Tab. 9. Analysis of accuracy for network points adjustment for variant „2E”**

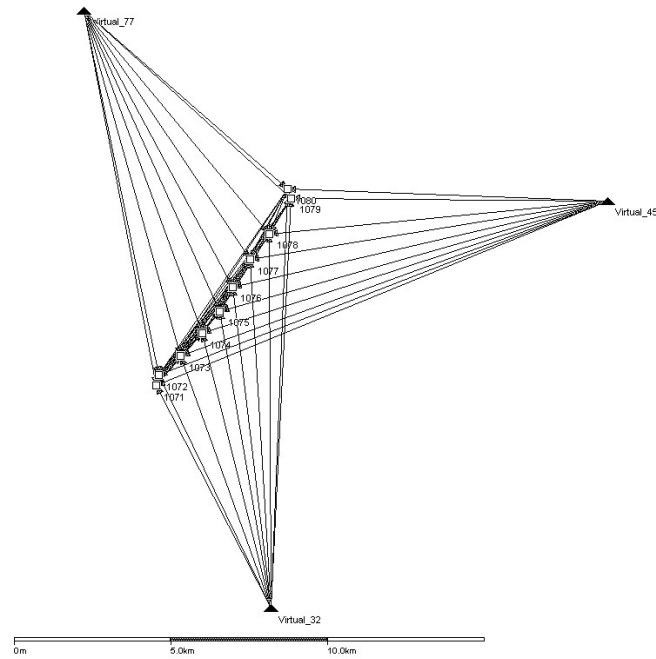
Point number	Mean errors of coordinates			Coordinates differences		
	mx	my	mz	$\Delta X$	$\Delta Y$	$\Delta Z$
1071	0.0011	0.0009	0.0012	0.001	0.000	0.006
1072	0.0012	0.0010	0.0013	-0.032	-0.008	-0.032
1073	0.0013	0.0011	0.0013	0.021	0.021	0.038
1074	0.0011	0.0010	0.0012	0.023	-0.001	0.025
1075	0.0011	0.0009	0.0011	0.029	0.013	0.037
1076	0.0011	0.0009	0.0011	0.020	-0.006	0.029
1077	0.0011	0.0010	0.0011	0.016	0.001	0.027
1078	0.0012	0.0010	0.0012	0.023	-0.004	0.036
1079	0.0014	0.0012	0.0015	-0.035	0.004	-0.040
1080	0.0012	0.0010	0.0012	0.003	0.009	0.007
MIN	0.0011	0.0009	0.0011	-0.035	-0.008	-0.040
MAX	0.0014	0.0012	0.0015	0.029	0.021	0.038
AVG	0.0012	0.0010	0.0012	0.007	0.003	0.013
	0.0001	0.0001	0.0001	0.023	0.009	0.028



**Fig. 10. GPS points network connection in „2F” variant.**

**Tab. 10. Analysis of accuracy for network points adjustment for variant „2F”**

Point number	Mean errors of coordinates			Coordinates differences		
	mx	my	mz	$\Delta X$	$\Delta Y$	$\Delta Z$
1071	0.0010	0.0009	0.0011	0.001	0.001	0.007
1072	0.0011	0.0010	0.0012	-0.033	-0.007	-0.031
1073	0.0012	0.0010	0.0012	0.022	0.022	0.039
1074	0.0011	0.0010	0.0012	0.023	0.001	0.024
1075	0.0010	0.0009	0.0011	0.029	0.015	0.038
1076	0.0010	0.0009	0.0011	0.018	-0.004	0.030
1077	0.0010	0.0009	0.0011	0.016	0.002	0.028
1078	0.0011	0.0009	0.0012	0.022	-0.003	0.037
1079	0.0013	0.0012	0.0014	-0.037	0.006	-0.037
1080	0.0011	0.0009	0.0012	0.002	0.010	0.009
MIN	0.0010	0.0009	0.0011	-0.037	-0.007	-0.037
MAX	0.0013	0.0012	0.0014	0.029	0.022	0.039
AVG	0.0011	0.0010	0.0012	0.006	0.004	0.014
	0.0001	0.0001	0.0001	0.024	0.009	0.028



**Fig. 11. GPS points network connection in „3A” variant.**

Tab. 11. Analysis of accuracy for network points adjustment for variant „3A”

Point number	Mean errors of coordinates			Coordinates differences		
	mx	my	mz	$\Delta X$	$\Delta Y$	$\Delta Z$
1071	0.0012	0.0010	0.0013	0.000	0.001	0.006
1072	0.0012	0.0011	0.0013	-0.034	-0.007	-0.032
1073	0.0013	0.0011	0.0013	0.022	0.023	0.038
1074	0.0012	0.0011	0.0013	0.022	0.001	0.023
1075	0.0011	0.0010	0.0012	0.029	0.015	0.038
1076	0.0011	0.0010	0.0012	0.018	-0.004	0.029
1077	0.0011	0.0010	0.0012	0.015	0.002	0.027
1078	0.0012	0.0010	0.0013	0.021	-0.003	0.037
1079	0.0015	0.0013	0.0015	-0.038	0.006	-0.037
1080	0.0012	0.0010	0.0013	0.001	0.010	0.008
MIN	0.0011	0.0010	0.0012	-0.038	-0.007	-0.037
MAX	0.0015	0.0013	0.0015	0.029	0.023	0.038
AVG	0.0012	0.0011	0.0013	0.006	0.004	0.014
	0.0001	0.0001	0.0001	0.024	0.009	0.028

## 5. RECAPITULATION AND CONCLUSIONS

The paper presents the method of elaboration satellite GPS observations for vector geodesic networks often applied at present for road engineering service. The proposed measurement method and processing of observations takes into considerations the length of GPS observation session and the method of elaboration (connections) of observations. In elaboration reference stations of EUPOS system were applied, which secure stabile connection system and decrease essentially costs of performing such kind of measurements. Investigations shown, that comparing quality of several solutions according to the values of mean square errors of determined coordinates, the best results were obtained for the „2D” and „2E” variants, solutions of which were based on connections combining physical and virtual stations. Besides all own solutions gave results with high consistence of adjusted coordinates. On the other hand the differences of coordinates between solutions obtained from POZGEO-D (own solutions) and automatic postprocessing from POZGEO-D appeared significant. The largest differences of components were for X=1.7 cm, for Y=3.9 cm, for Z=2.4 cm. The results may indicate the need of better calibration (elements EUPOS system) CZEPOS system with the ASG-EUPOS system, however it requires performing of further measurements and investigations in this domain.

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