A contribution to construction monitoring with simultaneous application of various types of observations

Prispevek k spremljanju objektov s simultanimi meritvami različnih tipov

Milivoj Vulić[1], Gregor Uranjek[2]

[1] University of Ljubljana, Faculty of Natural sciences and Engineering, Department of Geo-technology and Mining Engineering, Aškerčeva cesta 12, SI-1000 Ljubljana, Slovenia;
E-mail: milivoj.vulic@ntf.uni-lj.si
[2] Premogovnik Velenje d.d., Partizanska cesta 78, 3320 Velenje, Slovenia;
E-mail: gregor.uranjek@rlv.si

Abstract: The presented observations, adjustment and analysis of the spatial heterogeous local network initial epoch will serve together with following epochs for object's characteristic points mutually spatial position monitoring. Spatial heterogeous local network is observed with simultaneous observations of various types. Observations between characteristic points could not be applied. From the initial epoch results is concluded that on the base of precision estimations of slope distances between object's characteristic points is expected that will be possible to monitor slope distance changes larger than 10 mm in any direction in space (at $\tau = 2$, the probability is 95.45 %). If the most favorable condition are considered, it will be possible to monitor slope distance changes larger than 3 mm (at $\tau = 2$, the probability is 95.45 %).

Izvleček: Predstavljena je izmera, izravnava in analiza začetne terminske izmere prostorske heterogene merske mreže, ki bo skupaj z naslednjimi terminskimi izmerami služila za analizo spremljanja medsebojnih prostorskih položajev karakterističnih točk objektov. Heterogena prostorska mreža je merjena s simultanimi meritvami različnih tipov. Meritve poševnih razdalj med karakterističnimi točkami niso bile mogoče. Iz rezultatov začetne terminske izmere je zaključeno, da se bodo lahko na osnovi ocen natančnosti poševnih razdalj med karakterističnimi točkami spremljale spremembe poševnih razdalj večje kot 10 mm v poljubni smeri v prostoru pri $\tau = 2$ (verjetnost je 95,45 %). Ob upoštevanju najugodnejših primerov pa se pričakuje, da se bodo lahko zaznale spremembe poševnih razdalj večje od 3 mm pri $\tau = 2$ (verjetnost je 95,45 %).

Scientific paper

Key words: spatial heterogeneous networks, 3D adjustment, estimation of the precision, monitoring of mutual spatial relations, characteristic points, confidence pedaloid (surface)

Ključne besede: prostorska heterogena merska mreža, 3D izravnava, ocena natančnosti, spremljanje medsebojnih prostorskih položajev, spremljanje medsebojnih prostorskih relacij, karakteristčne točke, pedaloid (ploskev) pogreškov

Introduction

The discussed example deals with simultaneous observations and simultaneous adjustment of spatial heterogeneous local network. The purpose of the local network will be monitoring of mutual spatial positions of characteristic points, with a possibility of constraining local network into the existing network. Observations between object's characteristic points could not be applied.

Slope distances between characteristic points are afterwards determined from adjusted characteristic points spatial coordinates. Estimation of slope distances precision is based on variance-covariance matrix of unknowns $\Sigma_{\hat{x}\hat{x}}$ of the observed network which is the result of the adjustment.

For the construction (pillars) monitoring purpose four characteristic points (one per pillar) and two auxiliary points in pillars proximity have been reconnaissanced and materialized. Characteristic points are observed from auxiliary points which are observed from existing network points.

Observation method of heterogeneous local network

Heterogeneous observation system is combined from different types of observation systems. Heterogeneous observation system contains observed points, observations, network adjustment and results interpretation. Regardless the observations types and observation systems, respectively, which are containing heterogeneous observation system all observations, are simultaneously adjusted.

Simultaneous observations of heterogeneous local network contain three observation systems:
- baselines of static DGPS observations (Differential Global Positioning System),
- height differences of differential leveling,
- microtriangulation and microtrilateration:
    - horizontal directions,
    - zenith distances,
    - slope distances.

From existing network points (*XI/A1* and *X/5*) the auxiliary points (*Pom1* and *Pom2*) are observed with baselines of DGPS observation and height differences of differ-

ential leveling and from auxiliary points characteristic points (*STk1*, *STk2*, *STk3* and *STk4*) are observed with combined resections (Figure 1) (horizontal directions, zenith distances and slope distances) using the sets of angles method.

The results of local network observation are most probable values and *a priori* precision estimations of individual observations.
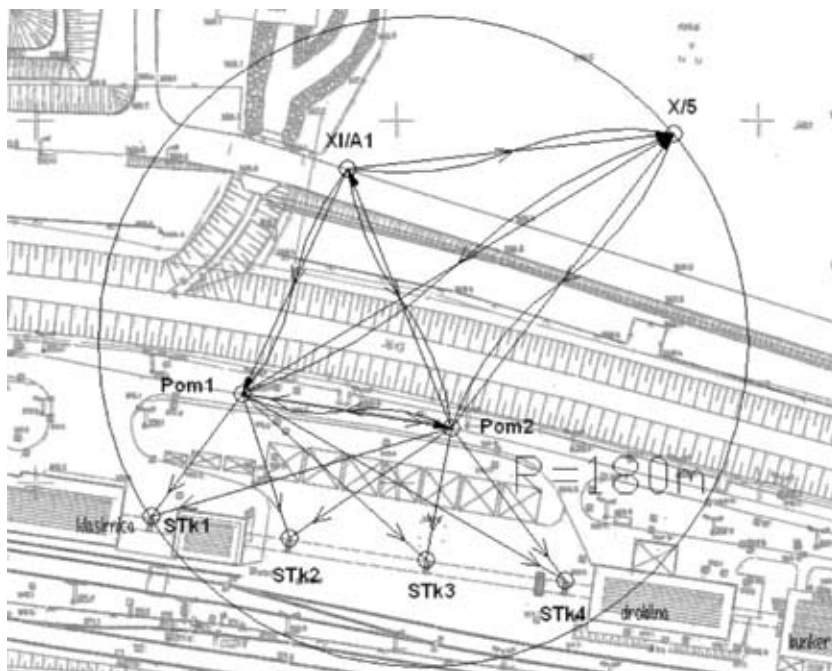

Figure 1. Heterogeneous local network
Slika 1. Lokalna heterogena merska mreža

ADJUSTMENT OF LOCAL NETWORK

The entering adjustment data are known points' coordinates of the existing network and the approximate coordinates of characteristic and auxiliary points and most probable values and *a priori* precision estimations of individual observations.

Adjustment strategy of local network
The simultaneous adjustment procedure of terrestrial and GPS observations is realized in three steps:
 - observation testing with adjustment of inner constrained or minimally constrained networks upon individual observation types or observation systems,

- quality known points control of the existing network which is illustrated with combined adjustment comparison (GPS network and leveling network) in minimally constrained network and

fully constrained network in which the known points are datum,
- combined adjustment of terrestrial and GPS observations.

ADJUSTMENT OF HETEROGENEOUS LOCAL NETWORK WITH PROGRAMME PACKAGE LEICA GEO OFFICE 5.0

Local network, which is observed with terrestrial and GPS observations, is adjusted as spatial (3D) network with orthometric heights in programme package *Leica Geo Office 5.0* (module *Adjustment*). *Leica Geo Office 5.0* in module *Adjustment* is using processing kernel *MOVE3 3.4* of well known programme for network adjustment *MOVE3*. Module *Adjustment* is one of the programme package *Leica Geo Office 5.0* modules and it is suitible for the design, adjustment and quality control of 3D, 2D and 1D measuring networks.

3D model for combined adjustment of terrestrial and GPS observations (Local geodetic) in the programme package *Leica Geo Office 5.0,* is in ellipsoidal coordinates (φ, λ, h) in local coordinate system. This kind of 3D model, which is implemented in programme package *Leica Geo Office 5.0*, has following advantages (BOEKELO, 1996):
- The mathematical model is "truly" 3D;

designed to model 3D reality (in stead of the 2D map), it complies with the modern surveying needs.
- The model does not require reductions to sea level or to the horizontal plane, nor corrections for earth curvature or for the projection.
- As mapping/projection is an auxiliary process there is no model-constraint limiting the network size.
- The model is best suited for the combination of GPS and terrestrial measurements.
- Original observations are tested (in stead of derivatives) using an uncompromised statistical model.

In programme package *Leica Geo Office 5.0* the precision estimation of 3D position is visualized in two parts so that the standard deviation of plane position (X, Y) is presented with confidence ellipse, and standard deviation of height (H) is presented separately with a bar in the same scale as confidence ellipse (Figures from 2 to 5). Precision estimation of observations is presented only with relative confidence ellipse (2D).

OBSERVATION TESTING

In order to test observations regarding to blunders (gross errors), the observation systems are adjusted separately in inner constrained networks or minimally constrained networks. With this procedure the known points influence is unabled.

All observations have been tested with standardized residuals with observations *a priori* variances (VULIĆ, 2005/2006):

$$v_{n_i} = \frac{v_i}{\sigma_{ll_i}} \qquad (1)$$

v_{n_i} - standardized residual with *a priori* observation variances

v_i - observation residual

σ_{ll_i} - *a priori* observation variance

Separately observations have been tested with statistical tests F-test (global test) and W-test (datasnooping test), which are programme package *Leica Geo Office 5.0* tools. The results of all observation tests show that observations are blunders free.

QUALITY CONTROL OF KNOWN POINTS

Known points acquired data unfortunately did not include *a posteriori* precision estimation of known points. The known points influence on *a posteriori* precision estimation of auxiliary points is illustrated with combined network (DGPS baselines and height differential leveling differences) adjustments comparison in minimally constrained network and fully constrained network in which the known points are datum. The *a posteriori* precision estimation of auxiliary points at minimally constrained network adjustment is influenced only by observations incompatibility (Figure 2) and the *a posteriori* precision estimation of auxiliary points at fully constrained network adjustment is influenced with observations incompatibility and mutual position of known points quality (Figure 3).

COMBINED ADJUSTMENT OF TERRESTRIAL AND GPS OBSERVATIONS

Objects will be monitored with slope distances changes between characteristic points. For that matter the slope distances precision is important. For precise slope distances determining the quality of auxiliary points mutual position is important. From known points quality control is concluded, that the known points are determined with centimeter's precision at best. Observation testing show that the characteristic points can be determine with millimeter's precision by combined resections from auxiliary points.

From known points quality control and observation testing is obvious that carrying errors from known points to local network are not reasonable. Because of the stated findings the simultaneous adjustment of terrestrial and GPS observations is executed in two steps. In first step the datums in adjustment are existing network points (Figure 4). With first step the auxiliary points mutual position is determined. In second step the datums in adjustment are auxiliary points adjusted coordinates determined in first step. With second step the adjusted (Figure 5) characteristic points coordinates and variance-covariance matrix of unknowns is determined.
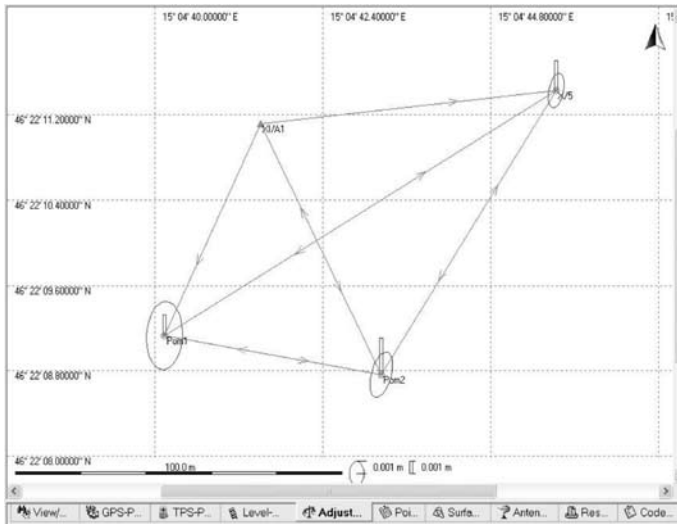
Figure 2. Adjustment of DGPS baselines and differential leveling height differences in minimally constrained network
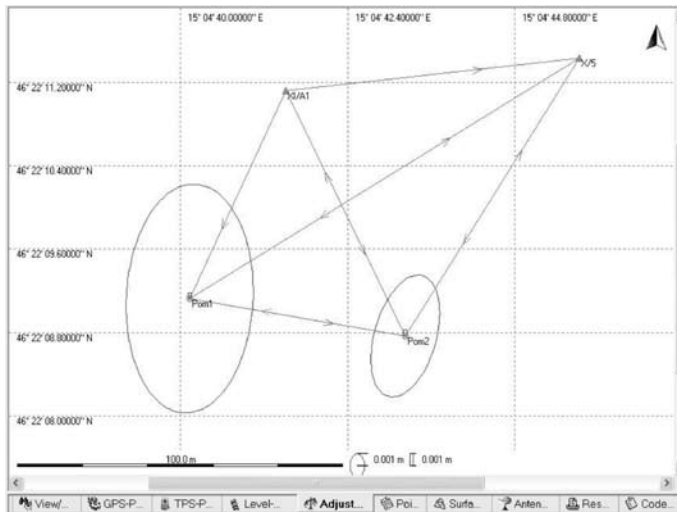**Slika 2.** Izravnava minimalno vpete mreže baznih vektorjev in višinskih razlik geometričnega nivelmana

Figure 3. Adjustment of DGPS baselines and differential leveling height differences in fully constrained network
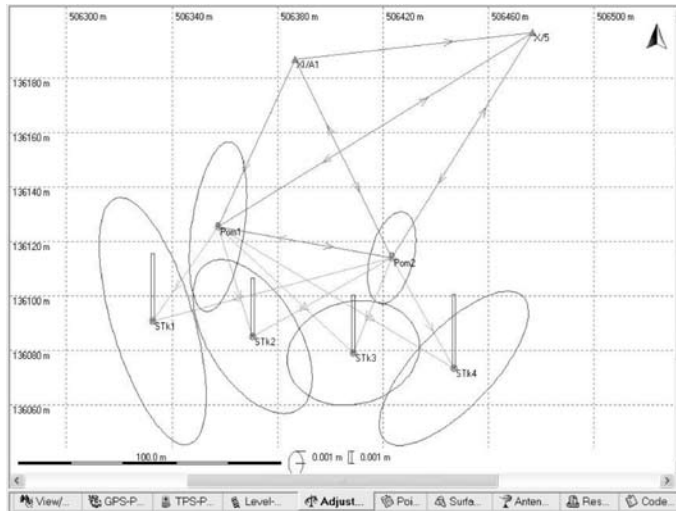**Slika 3.** Izravnava vpete mreže baznih vektorjev in višinskih razlik geometričnega nivelmana

Figure 4. First step of terrestrial and GPS observations simultaneous adjustment
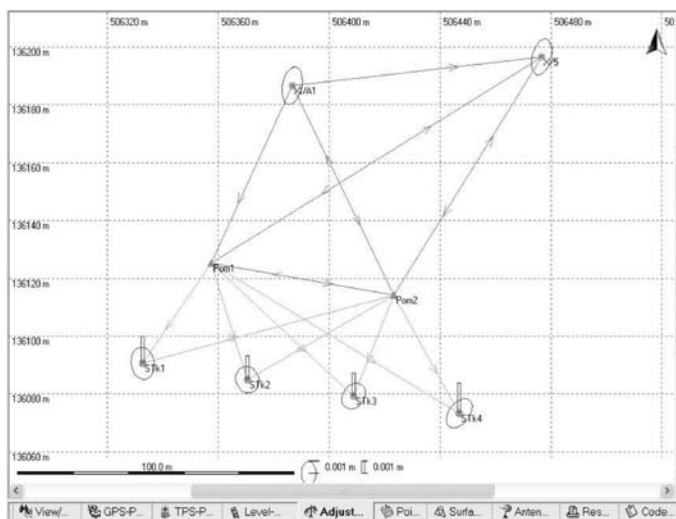**Slika 4.** Prvi korak skupne izravnave terestričnih in GPS opazovanj

Figure 5. Second step of terrestrial and GPS observations simultaneous adjustment
Slika 5. Drugi korak skupne izravnave terestričnih in GPS opazovanj

DETERMINATION AND PRECISION ESTIMATION OF SLOPE DISTANCES BETWEEN CHARACTERISTIC POINTS

Adjusted characteristic points spatial coordinates are determined with 3D adjustment model in ellipsoidal coordinates (φ, λ, h), which are then projected on a plane (Gauss-Krüger projection). Heights are defined with orthometric heights. Characteristic points plane coordinates (Y, X) and orthometric heights (H) are adopted in further calculations as spatial coordinates (Y, X, H) because of the small local network dimensions (Figure 1).

From adjusted characteristic points coordinates are determined slope distances $d_{slope_{ij}}$ between characteristic points with expression

$$d_{slope_{ij}} = \sqrt{(Y_j - Y_i)^2 + (X_j - X_i)^2 + (H_j - H_i)^2} \quad (2)$$

Index i is for slope distance starting point and index j is for slope distance finishing point.

A posteriori precision estimation of slope distances between characteristic points is acquired from variance-covariance matrix of unknowns $\Sigma_{\hat{x}\hat{x}}$ (Figure 6) which is adjustment product (simultaneous adjustment of all observations). Variance-covariance matrix $\Sigma_{\hat{x}\hat{x}}$ is containing information about *a posteriori* precision estimation of all points' spatial coordinates (variances) which are taking part in adjustment and interdependence between all points' spatial coordinates (covariances).

Upon our suggestion[1] the programme package *Leica Geo Office* producer has add variance-covariance matrix $\Sigma_{\Delta ij}$ between module *Adjustment* results in version 5.0.

At network adjustment the variance-covariance matrix $\Sigma_{\hat{x}\hat{x}}$ elements are saved in separated ASCII file (AdjVar2).

From variance-covariance matrix $\Sigma_{\hat{x}\hat{x}}$ (Figure 6) submatrixes (3×3) the covariance matrixes $\Sigma_{\hat{x}\hat{x}}$ for each slope distance are composed, for which the precision estimation is wanted. The belonging slope distance covariance matrix $\Sigma_{\hat{x}\hat{x}}$ is then determine with taking into consideration the variance-covariance propagation law for random variables linear functions (VULIĆ, 206):

$$\Sigma_{\Delta ij} = J_{ij} \cdot \Sigma_{ij} \cdot J_{ij}^T$$

$$\Sigma_{\Delta ij} = \begin{bmatrix} -I_{3\times3} & I_{3\times3} \end{bmatrix} \cdot \begin{bmatrix} \Sigma_{\hat{x}_i\hat{x}_i} & \Sigma_{\hat{x}_i\hat{x}_j} \\ \Sigma_{\hat{x}_i\hat{x}_j}^T & \Sigma_{\hat{x}_j\hat{x}_j} \end{bmatrix} \cdot \begin{bmatrix} -I_{3\times3} \\ I_{3\times3} \end{bmatrix}$$

$$\Sigma_{\Delta ij} = \begin{bmatrix} \Sigma_{\Delta ij_{xx}} & \Sigma_{\Delta ij_{xy}} & \Sigma_{\Delta ij_{xz}} \\ \Sigma_{\Delta ij_{xy}} & \Sigma_{\Delta ij_{yy}} & \Sigma_{\Delta ij_{yz}} \\ \Sigma_{\Delta ij_{xz}} & \Sigma_{\Delta ij_{yz}} & \Sigma_{\Delta ij_{zz}} \end{bmatrix} \quad (3)$$

J_{ij} - the Jacobian matrix for slope distance's $d_{slope_{ij}}$ components functions

$\Sigma_{\hat{x}_i\hat{x}_i}$, $\Sigma_{\hat{x}_j\hat{x}_j}$, $\Sigma_{\hat{x}_i\hat{x}_j}$, $\Sigma_{\hat{x}_j\hat{x}_i}$ - submatrixes (3×3) of covariance matrix $\Sigma_{\hat{x}\hat{x}}$ of parameters

$\Sigma_{\Delta ij}$ - covariance matrix $\Sigma_{\Delta ij}$ of slope distance between characteristic points i and j

After all slope distances covariance matrixes determination $\Sigma_{\Delta ij}$ it is proceeded to confidence surface's defining elements

---

[1] We purchased programme package *Leica Geo Office 4.0* in which the complete cofactors matrix $Q_{xx}(\Sigma_{\hat{x}\hat{x}} = \hat{\sigma}_0^2 \cdot Q_{xx})$ extraction is not supported. If we have to determine cofactors matrix Q_{xx} by our selves (as we did before purchase) the programme package is unnecessary because we must execute complete adjustment to determine cofactors matrix Q_{xx} which is one of the adjustment results. After contact with producer's technical support, they added the complete variance-covariance matrix $\Sigma_{\hat{x}\hat{x}}$ between module Adjustment results in version 5.0 and they upgraded our programme package to *Leica Geo Office 5.0*.

Figure 6. Variance-covarince matrix $\Sigma_{\hat{x}\hat{x}}$ of parameters of local network
Slika 6. Variančno-kovariančna matrika $\Sigma_{\hat{x}\hat{x}}$ neznanih veličin lokalne mreže

calculation (confidence pedaloid defining elements). Main (characteristic) standard deviations of slope distances are determined with slope distance's covariance matrix Σ eigenvalues λ_i :

$$\hat{\sigma}_{\xi\xi} = \sqrt{\lambda_{\xi\xi}}$$
$$\hat{\sigma}_{\eta\eta} = \sqrt{\lambda_{\eta\eta}}$$
$$\hat{\sigma}_{\zeta\zeta} = \sqrt{\lambda_{\zeta\zeta}}$$

(4)

Main standard deviations components of slope distances are determined with slope distance's covariance matrix $\Sigma_{\Delta ij}$ eigen-

$$\hat{\sigma}_{\xi\xi} \cdot \mathbf{s}_{\xi\xi}^T = \left| s_{\xi x} \quad s_{\xi y} \quad s_{\xi z} \right|$$
$$\hat{\sigma}_{\eta\eta} \cdot \mathbf{s}_{\eta\eta}^T = \left| s_{\eta x} \quad s_{\eta y} \quad s_{\eta z} \right|$$
$$\hat{\sigma}_{\zeta\zeta} \cdot \mathbf{s}_{\zeta\zeta}^T = \left| s_{\zeta x} \quad s_{\zeta y} \quad s_{\zeta z} \right|$$

(5)

In three-dimensional (3D) perpendicular coordinate system the confidence pedaloid is determined with main standard deviations (the half-axis confidence pedaloid values) and with main standard deviations components (the half-axis confidence pedaloid directions). The precision estimation results are in Table 1.

The slope distance's main standard deviations visualization is constructed in CAD programme *Rhinoceros* (Figures from 10 to 13) with slope distances confidence ellipsoids because in programme package *Leica Geo Office 5.0* 3D estimated 3D quantities main standard deviations visualization is limited with confidence ellipses (*Y, X*) and separately with heights standard deviations (*H*), (Figures from 2 to 5).

Confidence ellipse is confidence pedal approximation (confidence curve), analogous is confidence ellipsoid confidence pedaloid approximation (confidence surface). Confidence pedal is cross-section of confidence pedaloid and optional plane which is intersecting the confidence pedaloid's center. In programme package *Leica Geo Office 5.0* the intersecting plane is always parallel with horizontal plane *YX*. Confidence pedaloid (VEHOVEC, 2005) is surface which is presenting (Figures from 7 to 9) estimated quantity errors values in optional direction in space. That is important in detailed analysis at construction monitoring.

Table 1. Defining elements of slope distances confidence pedaloids (ellipsoids) between characteristic points at $\tau = 2$ (the probability is 95.45 %)

Tabela 1. Elementi pedaloidov (elipsoidov) pogreškov poševnih razdalj med karakterističnimi točakami pri $\tau = 2$ (verjetnost je 95,45 %)

From	To	a [m]	a_X, a_Y, a_H [m]	b [m]	b_X, b_Y, b_H [m]	c [m]	c_X, c_Y, c_H [m]
STk1	STk2	0,006	0,0016	0,003	0,0028	0,002	-0,0007
			0,0006		-0,0010		-0,0023
			0,0058		-0,0007		0,0005
STk1	STk3	0,006	0,0017	0,003	-0,0030	0,003	0,0002
			0,0007		-0,0001		-0,0026
			0,0058		0,0009		0,0003
STk1	STk4	0,007	0,0011	0,004	-0,0036	0,004	0,0007
			0,0006		-0,0010		-0,0026
			0,0066		0,0007		0,0001
STk2	STk3	0,006	0,0014	0,003	-0,0025	0,003	0,0009
			0,0002		-0,0009		-0,0024
			0,0054		0,0007		-0,0001
STk2	STk4	0,006	0,0008	0,003	-0,0031	0,003	0,0009
			0,0001		-0,0012		-0,0025
			0,0063		0,0005		-0,0001
STk3	STk4	0,006	0,0007	0,003	-0,0028	0,002	0,0012
			0,0001		-0,0017		-0,0020
			0,0062		0,0003		-0,0001

a - main standard deviation value (major)
b - main standard deviation value (semi)
c - main standard deviation value (minor)
a_X, b_X, c_X - main standard deviations components in direction X
a_Y, b_Y, c_Y - main standard deviations components in direction Y
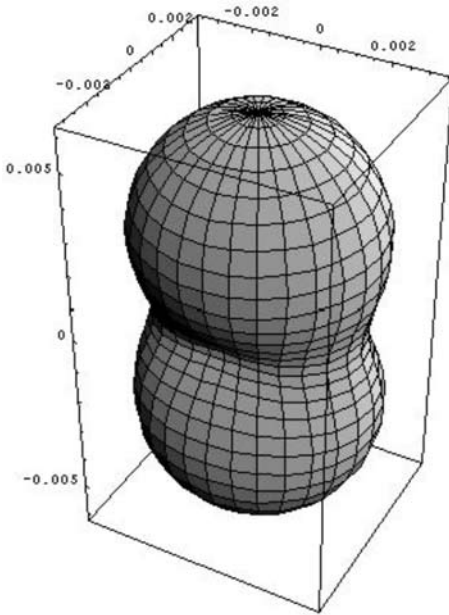a_H, b_H, c_H - main standard deviations components in direction H

Figure 7. Confidence pedaloid (at $\tau = 2$, the probability is 95.45 %) of slope distance STk1-STk2

Slika 7. Pedaloid pogreškov (pri $\tau = 2$, verjetnost je 95,45 %) poševne razdalje STk1-STk2
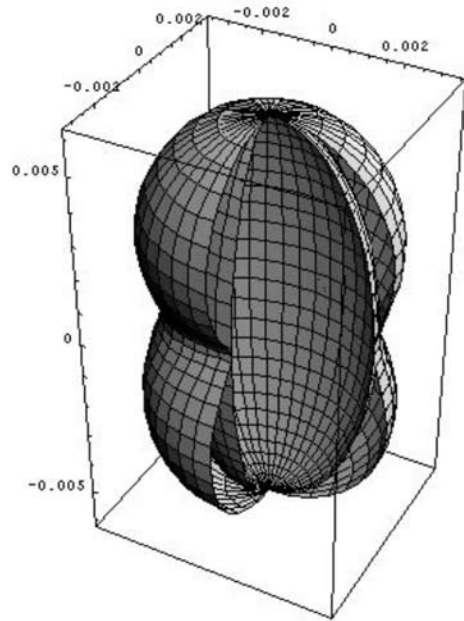

Figure 8. Confidence pedaloid and confidence ellipsoid cross-section (at $\tau = 2$, the probability is 95.45 %) of slope distance STk1-STk2

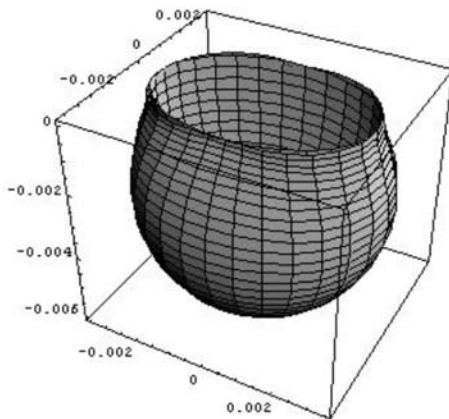**Slika 8.** Presek pedaloida in elipsoida pogreškov (pri $\tau = 2$, verjetnost je 95,45 %) poševne razdalje STk1-STk2

Figure 9. Slope distance STk1-STk2 confidence pedaloid and confidence ellipsoid cross-section with horizontal plane (at $\tau = 2$, the probability is 95.45 %)

Slika 9. Presek pedaloida in elipsoida pogreškov (pri $\tau = 2$, verjetnost je 95,45 %) poševne razdalje STk1-STk2 s horizontalno ravnino
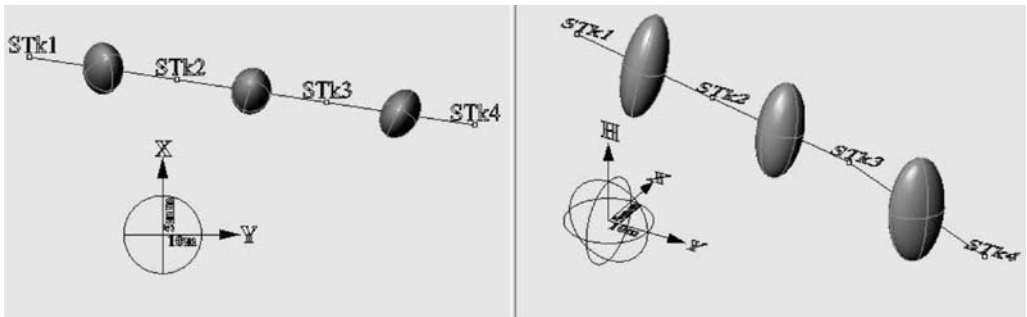
Figure 10. Confidence ellipsoids of slope distances STk1-STk2, STk2-STk3 and STk3-STk4 (at $\tau = 2$, the probability is 95.45 %) in orthogonal projection on YX plane (left) and in aksonometric projection (right)

Slika 10. Elipsoidi pogreškov poševnih razdalj STk1-STk2, STk2-STk3 in STk3-STk4 (pri $\tau = 2$, verjetnost je 95,45 %) v pravokotni projekciji na ravnino YX (levo) in poševni projekciji (desno)
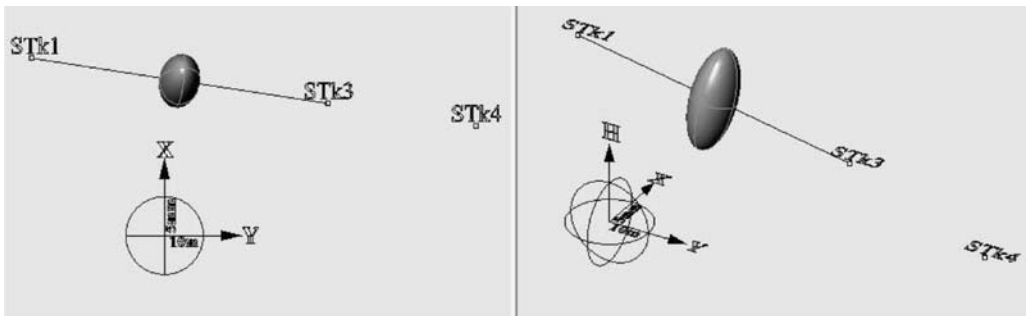

Figure 11. Confidence ellipsoid of slope distance STk1-STk3 (at $\tau = 2$, the probability is 95.45 %) in orthogonal projection on YX plane (left) and in aksonometric projection (right)

Slika 11. Elipsoid pogrešov poševne razdalje STk1-STk3 (pri $\tau = 2$, verjetnost je 95,45 %) v pravokotni projekciji na ravnino YX (levo) in poševni projekciji (desno)
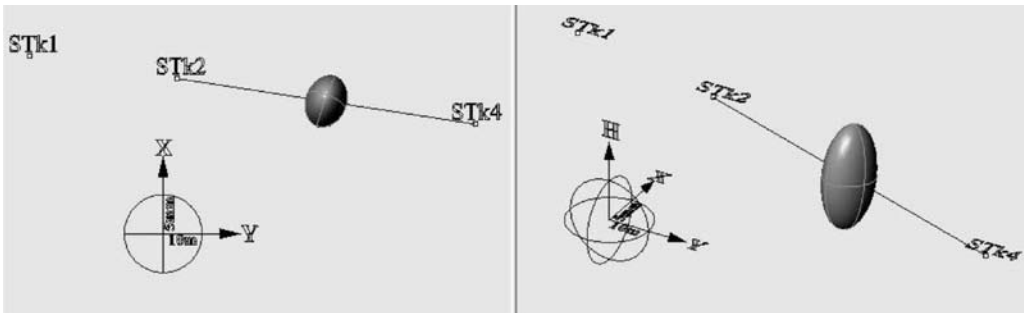
Figure 12. Confidence ellipsoid of slope distance STk2-STk4 (at $\tau = 2$, the probability is 95.45 %) in orthogonal projection on YX plane (left) and in aksonometric projection (right)

Slika 12. Elipsoid pogreškov poševne razdalje STk2-STk4 (pri $\tau = 2$, verjetnost je 95,45 %) v pravokotni projekciji na ravnino YX (levo) in poševni projekciji (desno)
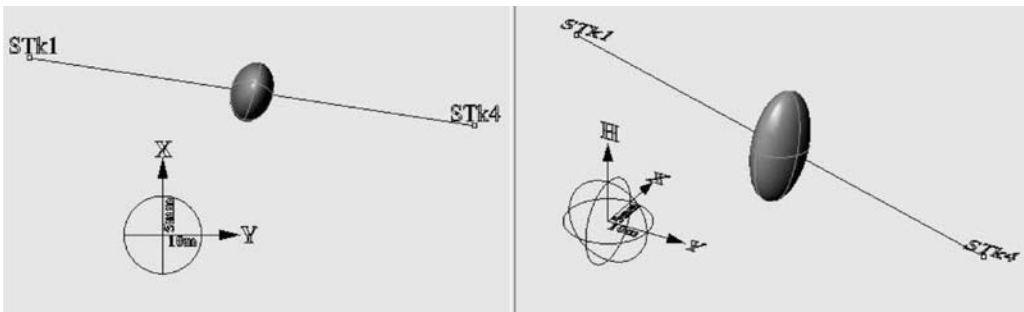

Figure 13. Confidence ellipsoid of slope distance STk1-STk4 (at $\tau = 2$, the probability is 95.45 %) in orthogonal projection on YX plane (left) and in aksonometric projection (right)

Slika 13. Elipsoid pogrešov poševne razdalje STk1-STk4 (pri $\tau = 2$, verjetnost je 95,45 %) v pravokotni projekciji na ravnino YX (levo) in poševni projekciji (desno)

Conclusions

Defined and estimated slope distances as described in this article, between object characteristic points at the initial epoch will be together with the following epochs, used for analyze at construction monitoring.

On base of slope distance precision estimations in two epochs and with consideration of variance propagation law for mutual independent random variables, there can be an estimation of precision made for slope distance changes between two epochs. The standard deviation values of slope distance changes between two epochs (Equation 6) are at the same time the values of minimal changes that can be monitored.

$$\hat{\sigma}_{\Delta ij_{\max}}^2 = \hat{\sigma}_{i_{\max}}^2 + \hat{\sigma}_{j_{\max}}^2 \qquad (6)$$

$\hat{\sigma}_{\Delta ij_{\max}}$ - the maximal standard deviation of slope distance change between two epochs

$\hat{\sigma}_{i_{\max}}$ - the maximal main standard deviation of slope distances in epoch i

$\hat{\sigma}_{j_{\max}}$ - the maximal main standard deviation of slope distances in epoch j

From the initial epoch results (Table 1) and if the initial epoch results are adopted for following epoch there can be determined (Equation 7) expected minimal slope distance change that can be monitored between two epochs:

$$\hat{\sigma}_{\Delta ij_{\max}}^2 = 2 \cdot \hat{\sigma}_{\max}^2 \qquad (7)$$

$$\hat{\sigma}_{\Delta ij_{\max}} = \sqrt{2} \cdot \hat{\sigma}_{\max} = \sqrt{2} \cdot 0{,}007m = 0{,}0099m = 10\,mm$$

From maximal value of slope distances main standard deviation of initial epoch (7 mm at $\tau = 2$, the probability is 95.45 % , Table 1) can be concluded that without any local network survey method improvement it will be possible to monitor slope distance changes between object's characteristic points between two epochs larger than 10 mm in any direction. If there are most favorable conditions considered (minimal main slope distance standard deviation is 2 mm at $\tau = 2$, the probability is 95.45 % , Table 1) it will be possible to monitor slope distance changes down to 3 mm.

Povzetki

Prispevek k spremljanju objektov s simultanimi meritvami različnih tipov

Določene in ocenjene poševne razdalje, na način predstavljen v članku, med karakterističnimi točkami stebrov iz začetne terminske izmere bodo skupaj z naslednjimi terminskimi izmerami služile za analizo pri spremljanju stebrov.

Na osnovi spremembe posamezne poševne razdalje med terminskima izmerama, katerih je ocenjena natančnost in z upoštevanjem zakona o prirastku pogreškov za medsebojno neodvisne veličine, se lahko oceni natančnost takšne spremembe. Vrednost standardne deviacije spremembe poševne razdalje $\hat{\sigma}_{\Delta ij_{\max}}$ hkrati tudi pomeni vrednost minimalne spremembe, ki se jo lahko zazna:

$$\hat{\sigma}_{\Delta ij_{\max}}^2 = \hat{\sigma}_{i_{\max}}^2 + \hat{\sigma}_{j_{\max}}^2$$

$\hat{\sigma}_{\Delta ij_{max}}$ - maksimalna standardna deviacija spremembe poševne razdalje med dvema terminskima izmerama

$\hat{\sigma}_{i_{max}}$ - maksimalna glavna standardna deviacija poševne razdalje i-te terminske izmere

$\hat{\sigma}_{j_{max}}$ - maksimalna glavna standardna deviacija poševne razdalje j-te terminske izmere

Iz rezultatov začetne terminske izmere (tabela 1) se lahko s pomočjo spodnje enačbe predvidi minimalno spremembo poševne razdalje, ki jo bo mogoče zaznati po izmeri naslednje terminske izmere:

$$\hat{\sigma}^2_{\Delta ij_{max}} = 2 \cdot \hat{\sigma}^2_{max}$$

$$\hat{\sigma}_{\Delta ij_{max}} = \sqrt{2} \cdot \hat{\sigma}_{max} = \sqrt{2} \cdot 0,007m = 0,0099m = 10\,mm$$

Pri tem je $\hat{\sigma}_{max}$ maksimalni glavni pogrešek poševnih razdalj med karakterističnimi točkami v začetni terminski izmeri pri $\tau = 2$ (verjetnost je 95,45 %).

Iz rezultatov začetne terminske izmere (tabela 1) se lahko sklepa, da se bodo brez izboljšanj metode opazovanja lokalne mreže, lahko spremljale spremembe poševnih razdalj večje od 10 mm v poljubni smeri pri $\tau = 2$ (verjetnost je 95,45 %). Ob upoštevanju najugodnejših primerov (minimalni glavni pogrešek poševnih razdalj je 2 mm, (tabela 1) pri $\tau = 2$ (verjetnost je 95,45 %)) pa se pričakuje, da se bodo lahko zaznale spremembe poševnih razdalj večje od 3 mm.

REFERENCES

BOEKELO, G. (1996): Adjustment Models and Mapping. *The Hydrographic Journal.*; Issue 199607, page 3.

GEOSERVIS d.o.o.: *Uporabniška navodila za LGO*. Ljubljana, marec 2004, 2005.

LEICA GEOSYSTEMS AG: *Printed Documentation LGO 4.0.pdf* (Navodila za uporabo programskega paketa Leica Geo Office v elektronski obliki).

LEICK, A. (1995): *GPS satellite surveying*. Second edition, Department of Surveying Engineering, University of Maine, Orono Main. John Wiley & sons, Inc.

MIHAILOVIĆ, K. (1987): *Geodezija II. I deo*. Drugo izdanje, Naučna knjiga, Beograd

STRANG, G. (Massachusetts Institute if Technology – MIT) & BORRE, K. (Aalborg University) (1997): *Linear Algebra, Geodesy and GPS*. Wellesley-Cambrige Press.

URANJEK, G (2007): *Priloga k spremljanju objektov s simultanimi meritvemi različnih tipov*. Ljubljana, NTF, Oddelek za geotehnologijo in rudarstvo.

VEHOVEC, A (2005): *Ugotavljanje ugrezkov terena s simultano izravnavo več terminskih izmer nivelmanske mreže s pomočjo nD relativnega elipsoida*. Ljubljana, NTF, Oddelek za geotehnologijo in rudarstvo.

VULIĆ, M. (2006): *Metoda najmanjših kvadratov (MNK)*. Naravoslovnotehniška fakulteta, Ljubljana.

VULIĆ, M.: *Interna predavanja 2005/2006*.

WOLFRAM, S. (2003): *The Mathematica book*. 5th edition, Wolfram Media.