Solution to Improve the Horizontal and vertical Position Accuracy of Points Measured by GNSS/CORS Technology in Creation of Large-Scale Topographic Maps in Vietnam

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Abstract

In Vietnam, when creating large-scale topographic maps using Global Navigation Satellite Systems (GNSS) technology combined with Continuously Operating Reference Stations (CORS) and traditional electronic total station measurements, there will be shifts in both horizontal and vertical positions. To address this issue, we perform map adjustments by updating the map in an assumed coordinate system. In the assumed coordinate system, the shapes and elevation differences of the changed objects are accurately observed to meet the requirements corresponding to the map scale. The coordinates and elevations of clear points on the map or control points in the field obtained from different methods have differences that are larger than the permissible values according to the map scale. Applying a 2-dimensional coordinate transformation and the geoidal height calculated for each point with its weight, the coordinates and elevations of the points can be computed in a unified coordinate system.

Keywords: *GNSS accuracy, topographic map, Geodetic Network*

1. Introduction

Currently, Vietnam's Ministry of Natural Resources and A map is a scaled-down image that provides a generalized depiction of a large part of the Earth's surface on a plane applying various map projection methods. A topographic map is a type of general geographic map, of which the contents include information about natural elements such as terrain, hydrology, vegetation cover, and elements related to economy, culture, and society such as population, road systems, bridges, service facilities, public works, and administrative boundaries [1], [4].

In Vietnam, when creating large-scale topographic maps, an optimal solution that is being widely applied is the combination of GNSS/CORS technology and electronic total stations. The electronic total station is highly reliable, flexible, and efficient in residential areas and vegetated areas. In contrast, GNSS/CORS technology, such as Real-Time Kinematic (RTK) or Virtual Reference Station (VRS), enhances the accuracy and increases the distance from the base station. Additionally, RTK is advantageous in providing quick observations and economic efficiency in open areas, without relying on the construction of control networks. However, GNSS/CORS technology is based on the international WGS-84 coordinate system and ellipsoidal heights, while topographic maps are created on the national coordinate system of Vietnam (VN-2000) using the UTM reference system and leveling heights.

Despite its advantages, the VN-2000 system is not yet a 3D coordinate system and is not connected to the International Terrestrial Reference Frame (ITRF). This limits the exploitation of GNSS technology in determining spatial positions, data acquisition and sharing, and international cooperation to solve regional and global problems. Additionally, GNSS/CORS technology provides ellipsoidal heights with the reference ellipsoid, but the Vietnam national height system uses normal heights with the reference quasigeoid. To apply GNSS/CORS technology in height measurement, the difference between the quasigeoid and the ellipsoid at each point must be known. This requires a local quasigeoid model at the study area with sufficient accuracy for using GNSS/CORS technology as a replacement for traditional leveling methods [5].

In this study, a theoretical and experimental research is conducted to draw specific conclusions about the solution of combining surveying technologies in the creation of large-scale topographic maps in Vietnam. This is a new direction resquiring more extensive research and serious evaluation in practical production to best utilize the advantages of the various surveying methods in the creation of topographic maps in Vietnam.

2. Synchronization of topographic observation data

2.1 Coordinate Transformation between GNSS/CORS and ITRF

The transformation of the GNSS/CORS coordinates to the ITRF coordinate system ensures the consistency and accuracy of geographic data worldwide. The coordinate transformation between ITRF reference frames (ITRF, 2019) or between the VN-2000 coordinate system and ITRF is carried out using the general formula [6] as follows:

$$X_{(2)} = T + (1 + D)R^T X_{(1)} \tag{1}$$

where X(2) and X(1) are the coordinate vectors in the VN2000 and ITRF systems, respectively, T is the translation vector between the origions of the two systems, D is the scale factor, R is the rotation matrix about the axes in radians [7].

$$\boldsymbol{R^T} = \begin{vmatrix} 1 & -R_3 & R_2 \\ R_3 & 1 & R_1 \\ -R_2 & R_1 & 1 \end{vmatrix} \tag{2}$$

Since the value D.RT is a small quantity, the second-order term can be neglected, and therefore (1.1) can be written as:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{(2)} = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{(1)} + \begin{bmatrix} T_1 \\ T_2 \\ T_3 \end{bmatrix}_{(1)} + D \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{(1)} + \begin{bmatrix} 0 & -R_3 & R_2 \\ R_3 & 0 & -R_3 \\ R_2 & R_1 & 0 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{(1)} \tag{3}$$

2.2 Conversion of the elevation of topographic points measured using GNSS/CORS technology to leveling height

There are different methods for height anomalies interpolation, in which polynomial, kriging, collocation, and spline interpolations are commonly applied. In this study, we apply the polynomial interpolation method for each measurement point by adding weighting factors, which are the inverse distances to the common points.

2.2.1 Interpolation of height anomalies using the polynomial model

In order to interpolate height anomalies, common points with known grid coordinates (x, y), ellipsoidal heights (H), and leveling heights (h^γ) are required, based on which the height anomalies can be calculated [3]:

$$\zeta = \mathrm{H} - \mathrm{h}^{\gamma} \tag{4}$$

Those points with both known ellipsoidal and leveling heights are termed as common points in this study. GNSS technology provides us with highly accurate ellipsoidal heights, but leveling heights are needed in practice. Therefore, the transformation from ellipsoidal heights to leveling heights is needed, which can be conducted using a global geoid model, such as OSU91A, EGM-96, or EGM2008. However, practical experiments indicated that global geoid models have low accuracy in Vietnam. Additionally, an accurate local geoid model has not been published so far in Vietnam.

To enhance the accuracy of height measurement using GNSS/CORS technology in the creation of topographic maps, we propose using high-precision level points in the surveying area to create a local geoid model by which to adjust the heights measured by GNSS technology. Based on the coordinates of points measured using GNSS technology (X, Y, Z) and leveling heights measured accurately in the national height system, we generate a geoid model at each surveyed point to transform the ellipsoidal heights to leveling heights as in [3]:

$$\mathrm{h}^{\gamma} = \mathrm{H} - \zeta \tag{5}$$

Depending on the number of existing common points in the surveying area, the local geoid model takes the form of a polynomial of zero-, first-, second-, or third-degree. The equation of the height anomaly is of the form:

$$\zeta i = \mathrm{F}(xi\ , yi) \tag{6}$$

where ζi is the height anomaly of the point located at the coordinates xi , yi. The specific polynomial forms of the height anomaly are as follows:

With 3 common points, the first-degree polynomial function is used to calculate 3 coefficients ζ0, A, B. With 6 common points, the second-degree polynomial function is used, and with 10 common points, the third-degree polynomial function is used. When the number of common points exceeds the number of coefficients, the least squares method is employed to calculate the coefficients.

Taking ζ as the measurement with n common points, the system of measurement equations is formed as follows (for first-degree polynomial) [3]:

Zero-degre: ζi = ζ0
First-degre: ζi = ζ0 + Axi + Byi
Second-degre: ζi = ζ0 + Axi + Byi
+Cxi 2 + Dyi 2 + Exiyi
Third-degre: ζi = ζ0 +Axi+Byi+Cxi 2 +Dyi 2
+ Exiyi + Fxi 3 + Gyi 3 + Hxi 2yi + Kxi yi 2 (7)

$$\begin{bmatrix} \zeta_1 \\ \zeta_2 \\ \dots \\ \zeta_n \end{bmatrix} = \begin{bmatrix} x_1 & y_1 & 1 \\ x_2 & y_2 & 1 \\ \dots & \dots & \dots \\ x_n & y_n & 1 \end{bmatrix} \times \begin{bmatrix} a \\ b \\ c \end{bmatrix} \tag{8}$$

Then, we can derive the system of correction equations:

$$\begin{bmatrix} v_1 \\ v_2 \\ \dots \\ v_n \end{bmatrix} = \begin{bmatrix} x_1 & y_1 & 1 \\ x_2 & y_2 & 1 \\ \dots & \dots & \dots \\ x_n & y_n & 1 \end{bmatrix} \times \begin{bmatrix} a \\ b \\ c \end{bmatrix} - \begin{bmatrix} \zeta_1 \\ \zeta_2 \\ \dots \\ \zeta_n \end{bmatrix} \tag{9}$$

where vi is the correction for the anomalous height measurement ζi. With the number of common points exceeds the number of unknowns, the least squares method is applied ([vv]=Min) to form the system of normal equations [2]:

$$\begin{bmatrix} x_1 & y_1 & 1 \\ x_2 & y_2 & 1 \\ \dots & \dots & \dots \\ x_n & y_n & 1 \end{bmatrix}^T \times \begin{bmatrix} x_1 & y_1 & 1 \\ x_2 & y_2 & 1 \\ \dots & \dots & \dots \\ x_n & y_n & 1 \end{bmatrix} \times \begin{bmatrix} a \\ b \\ c \end{bmatrix} - \begin{bmatrix} x_1 & y_1 & 1 \\ x_2 & y_2 & 1 \\ \dots & \dots & \dots \\ x_n & y_n & 1 \end{bmatrix}^T \times \begin{bmatrix} \zeta_1 \\ \zeta_2 \\ \dots \\ \zeta_n \end{bmatrix} = 0 \tag{10}$$

In the matrix form:

$$A^T PA.X + A^T PL = 0$$

where $A = \begin{bmatrix} x_1 & y_1 & 1 \\ x_2 & y_2 & 1 \\ \dots & \dots & \dots \\ x_n & y_n & 1 \end{bmatrix}, X = \begin{bmatrix} a \\ b \\ c \end{bmatrix}, L = \begin{bmatrix} \zeta_1 \\ \zeta_2 \\ \dots \\ \zeta_n \end{bmatrix}$

We can then solve the parameter vector X and the uncertainty of the interpolation model:

$$X = \begin{bmatrix} a \\ b \\ c \end{bmatrix} = R^{-1} A^T PL = QA^T PL \tag{11}$$

$$m_0 = \sqrt{\frac{[pvv]}{n-t}} \tag{12}$$

Using the obtained model parameters to calculate the anomalous height for any GNSS measurement point P with coordinates (xP, yP) by Equation (11). In solving for the geoid model parameters, we consider the different influences of common points on the correction for each point. Specifically, for each measurement point, we calculate its own model parameters with weights assigned to common points as inversely proportional to the distances to the measurement point:

Pi = 1/Si or Pi = 1/Si2.

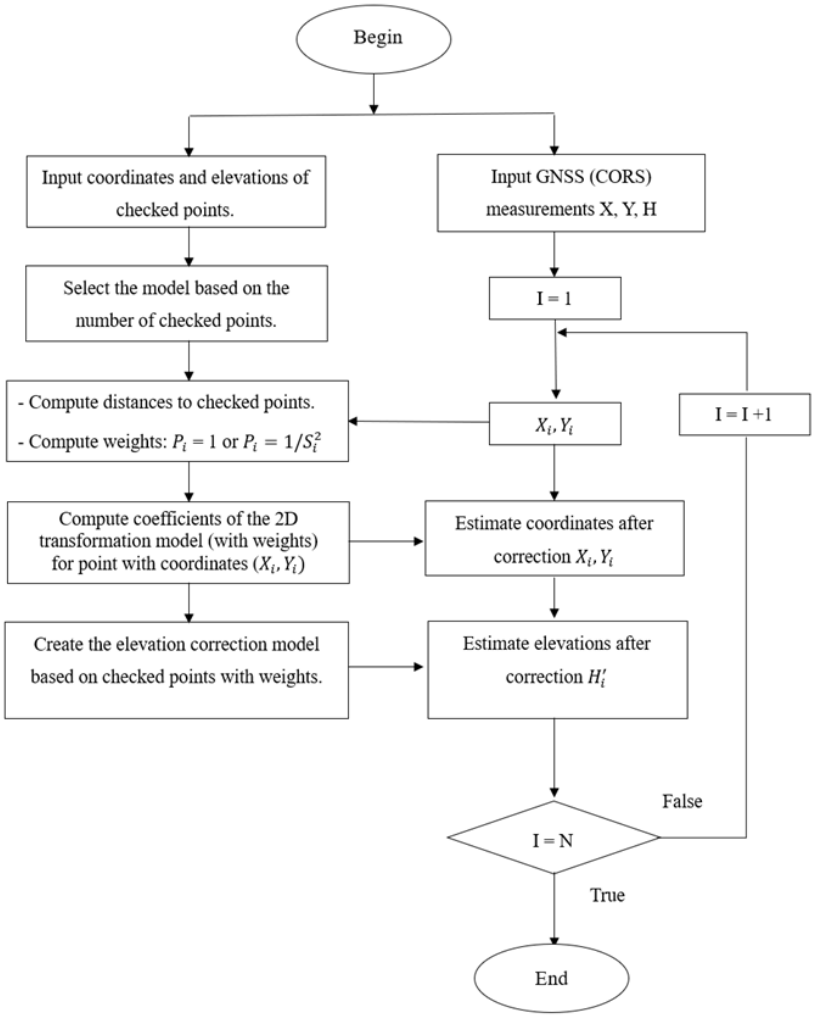

Fig. 1. Workflow of coordinate transformation and conversion of GNSS/CORS points
Rys. 1. Proces transformacji współrzędnych i konwersji punktów GNSS/CORS

2.2.2. Transformation between WGS-84 Geocentric and VN-2000 Grid Coordinates

With the coordinates of points (X, Y, Z) measured using GNSS technology in the global geocentric coordinate system WGS-84, we first transform them to the geocentric coordinates X1, Y1, Z1 in the VN-2000 coordinate system, and then to the geodetic coordinates B, L, H. Finally, the derived coordinates B, L are converted to grid coordinates using the UTM projection. At the same time, ellipsoidal heights are converted to leveling heights [3]:

(XYZ)WGS-84 ---> (XYZ)VN-2000 ----> (BLH)VN-2000 ---> (xyh)VN-2000

The transformation formulas are as follows:

a. Transformation of geocentric coordinates from WGS-84 to VN-2000

$$\begin{aligned} X1 &= \Delta X0 + k \cdot (X - \omega 0 \cdot Y + \psi 0 \cdot Z) \\ Y1 &= \Delta Y0 + k \cdot (\omega 0 \cdot X + Y - \varepsilon 0 \cdot Z) \\ Z1 &= \Delta Z0 + k \cdot (-\psi 0 \cdot X + \varepsilon 0 \cdot Y + Z) \end{aligned} \quad (13)$$

where k is the scale factor, ω0, ψ0, ε0 are the Euler rotation angles about the X, Y, Z axes, and ΔX0, ΔY0, ΔZ0 are the coordinates of the center of the international WGS-84 system in the VN-2000 system.

b) Conversion from geodetic coordinates (B, L) to grid coordinates (x, y)

According to [3], we have:

$$(x - X) = \frac{N}{2\rho''^2} \sin B \cos B \, 1''^2 + \frac{N}{24\rho''^4} \sin B \cos^3 B \, (5 - t^2 + 9\eta^2 + 4\eta^2) 1''^4 + \frac{N}{720\rho''^6} \sin B \cos^5 B (61 - 58t^2 + t^4) 1''^6 \quad (14)$$

$$y = \frac{N}{\rho''} \cos B \, 1'' + \frac{N}{6\rho''^3} \cos^3 B \, (1 - t^2 + \eta^2) 1''^3 + \frac{N}{120\rho''^5} \cos^5 B \, (5 - 18t^2 + t^4 + 14\eta^2 - 58t^2\eta^2) 1''^5 \quad (15)$$

c) Conversion from grid coordinates (x, y) to geodetic coordinates (B, L)

According to [3], we have:

$$B_1 - B = \frac{\rho'' t_1}{2M_1N_1} y^2 - \frac{\rho'' t_1}{2M_1N_1^3} (5 + 3t_1^2 + \eta_1^2 - 9t_1^2\eta_1^2) y^4 + \frac{\rho'' t_1}{720M_1N_1^5} (61 + 90t_1^2 + 45t_1^2) y^6 \quad (16)$$

$$l = \frac{\rho''}{N_1 \cos B_1} y - \frac{\rho''}{6N_1^3 \cos B_1} (1 + 2t_1^2 + \eta_1^2) y^3 + \frac{\rho''}{120N_1^5 \cos B_1} (5 + 28t_1^2 + 24t_1^4 + 6\eta_1^2 + 8t_1^2\eta_1^2) y^5 \quad (17)$$

where X is the length of the meridian arc determined based on the known latitude B, N is the radius of curvature of the prime vertical. The coefficients l, M, N, t, h are calculated as follows:

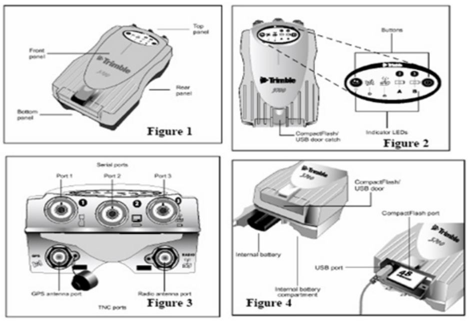

Fig. 2. Components of Trimble R7 GNSS receivers
Rys. 2. Komponenty odbiornika GNSS Trimble R7

Fig. 3. Trimble R7 GNSS antenna
Rys. 3. Antenna GNSS Trimble R7

l = L – L0, (L0 is the central meridian);
t = tgB; t1 = tgB1; h2 = e'2cos2B ;

$$M = \frac{a(1-e^2)}{(1-e^2\sin^2 B)^{3/2}};$$
$$N = \frac{a}{(1-e^2\sin^2 B)^{1/2}}$$

e and e' are the first and second eccentricities, a is the semi major axis of the Ellipsoid.

d) Conversion from geodetic to geocentric coordinates

To convert from the geodetic coordinates B, L, H to the geocentric coordinates X, Y, Z of a point within the same coordinate system, we use the following equation [3]:

$$\begin{aligned} X &= (N+H)\cos B.\cos L \\ Y &= (N+H)\cos B.\sin L \\ Z &= [N(1-e^2)+H]\sin B \end{aligned} \tag{18}$$

e) Conversion from geocentric to geodetic coordinates

According to [3], we have:

$$tgL = \frac{Y}{X};\quad tgB = \frac{Z + Ne^2.\sin B}{R};\quad H = Z/\sin B - N(1-e2);\quad R = (X2 + Y2)1/2 \tag{19}$$

2.2.3 Transformation of coordinates measured by GNSS/CORS technology

The transformation of 2D coordinates from the first system (xoy)1 to the second system (xoy)2 is carried out using the Helmert transformation [2]:

$$\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{pmatrix} x_0 \\ y_0 \end{pmatrix} + m\begin{pmatrix} \cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha \end{pmatrix}\begin{pmatrix} x \\ y \end{pmatrix} \tag{20}$$

which can be rewritten as:

$$\begin{aligned} x' &= x_0 + (m.\cos\alpha)x - (m.\sin\alpha)y \\ y' &= y_0 + (m.\sin\alpha)x + (m.\cos\alpha)y \end{aligned} \tag{21}$$

with the notations $m.\cos\alpha = a;\ m.\sin\alpha = b;\ x_0 = c;\ y_0 = d.$

$$\begin{aligned} x' &= a.x - b.y + c \\ y' &= b.x + a.y + d \end{aligned} \tag{22}$$

we can from a system of correction equations as:

$$\begin{aligned} vx' &= x.a - y.b + 1.c + lx \quad \text{với} \quad lx = -x' \\ vy' &= y.a + x.b + 1.d + ly \quad \text{với} \quad ly = -y' \end{aligned} \tag{23}$$

Thus, we have a system of correction equations with 4 unknowns, which requires at least 2 common points to solve for the unknowns a, b, c, d.

2.3.4 Workflow of 2D coordinate transformation

The process of coordinate transformation and conversion of GNSS/CORS points to grid coordinates and leveling elevation is performed according to the workflow shown in Figure 1.

3. Experiment

3.1 Study area, data used, and instrument

The study area is located in Mu Cang Chai district, Yen Bai province, with an area of 400 km2. Mù Cang Chải is a highland district located in the western part of Yen Bai Province. It is 185km away from the provincial center and 365km away from the capital city of Hanoi. The district covers an area of 120,095.83 hectares, most of which is mountainous terrain originating from the Hoang Lien Son mountain range. This includes many successive mountain ranges running in the northwest-southeast direction, with streams and valleys belonging to the Red River and Da River basins between them. The lowest absolute elevation is the Cao Pha field at 650m, and the highest is the Lung Cung peak in Nam Co commune at 2,963m above sea level. The terrain is heavily dissected, creating long slopes with an average gradient of 300m, though in some places it reaches over 450m. It borders Van Ban District of Lao Cai Province to the north, Muong La District of Son La Province to the south, Van Yen and Van Chan Districts to the east, and Than Uyen District of Lai Chau Province to the west.

The study area covers approximately 400km^2, encompassing the Mo De, Che Cu Nha, La Pan Tan, and De Xu Phinh communes (figure 4). There are 5 national geodetic control points 77423, 77432, 77434, 77437, and 77451, and 5 nation-

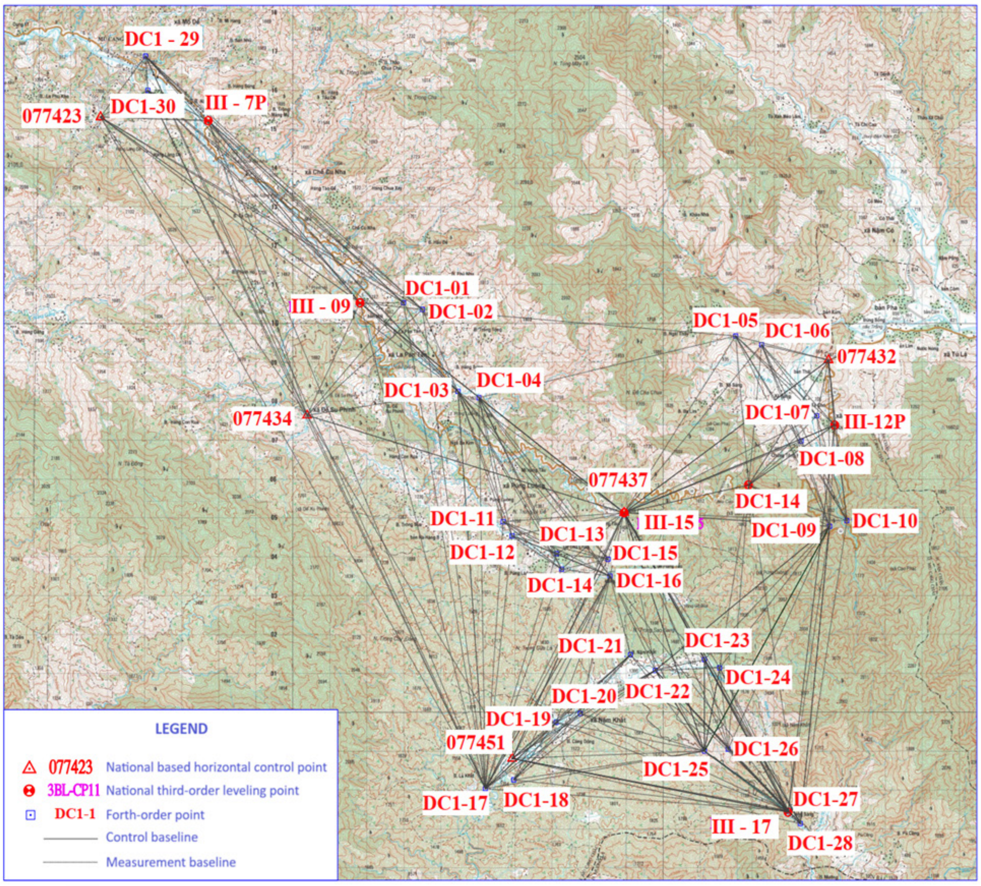

Fig. 4. Study area in Mu Cang Chai district, Yen Bai province

Rys. 4. Obszar objęty badaniami w okręg Mu Cang Chai, prowincja Yen Bai

al third-order level points III_09, III_7P, III_12, III_14, and III_17. The X, Y and H of these points are as in Table 1. The measurement network consists of those mentioned national geodetic control points and national third-order level points as well as 30 unknown first-order traverse points. The measurements are made using Trimble R7 GNSS receivers (figures 3 and 4), with horizontal and vertical fast static accuracies of 5mm + 0.5ppm and 5mm + 1ppm, respectively. The measurements were carried out with 6 receivers over 8 60-minute static measurement sessions.

3.2 Experimental procedure

The 30 GNSS points distributed across the entire study area are measured using Trimble R7 GNSS dual-frequency receivers based on the 5 national geodetic control points and 5 national third-order state leveling points. The observations are then processed by the Trimble Business Center software. The derived coordinates are subsequently adjusted using the 2D coordinate transformation, and the elevations of the measurement points are converted to leveling heights using the geoid undulation interpolation problem with the weight factor of P=1 and P = 1/Si2, where Si is the distance from the measurement point to the nearest control point. Finally, the results are analyzed and the experiment is concluded.

3.3 Results and discussion

The observations are processed using the Trimble Business Center (TBC) with the results shown in Table 2. The coordinates and elevations of the national third-order control points measured by GNSS and processed by the proposed workflow. The results are as shown in Table 3 and Table 4.

From Table 3, with coordinates and heights corrected according to the chosen weight factor P=1, we have: [ΔΔ]= 0.127303, n = 39, m = ±0.057 (m); with all corrections applied to the coordinates and levels of the control points are non-zero.

From Table 4, with coordinates and heights corrected according to the chosen weight factor $P=1/S^2$, we have: [ΔΔ]= 0.125443, n = 39, m = ±0.056 (m) with all corrections applied to the coordinates and levels of the control points are zero.

Tables 3 and 4 show the coordinates and elevations of the national third-order control points measured by GNSS and processed by the proposed workflow in this study. It is shown that the height deviations of the points III_09, III_7B, III_12, and III_14 are 0.023m, -0.012m, 0.013m, and -0.003m, respectively, when P=1 is applied, while those for the same points are 0.000m when $P=1/S^2$ is applied. Therefore, using weight $P=1/S^2$ has higher accuracy compared to using weight P=1.

From the corrections to convert GNSS-derived elevations to leveling heights, and the leveling heights shown in Table 4, we construct a site map and a height anomalies digital model as follows on Fig. 5.

Figure 5 shows a contour map of interpolated height anomalies determined based on the national leveling points, and Figure 6 shows their corresponding digital model. It can be concluded that the results based on the proposed workflow in this study applying $P=1/S^2$ is highly reliable.

Tab. 1. Coordinates and elevations of the national third-order level points and geodetic control points
Tab. 1. Współrzędne i wysokości krajowych punktów trzeciego rzędu i punktów kontroli geodezyjnej

No	Point name	Coordinates of the national third-order level points		
		X(m)	Y(m)	H(m)
1	77423	2415895.97	430623.605	1405.150
2	77432	2409679.742	450301.045	787.160
3	77434	2408234.513	436219.215	1400.972
4	77437	2405746.667	444786.447	1321.099
5	77451	2399421.409	441772.429	1361.617
6	III_09	2411130.052	437642.588	1127.604
7	III_7P	2415807.232	433534.639	971.193
8	III_12	2408008.217	450468.008	899.032
9	III_14	2406462.48	448147.867	1430.969
10	III_17	2398054.598	449225.164	1126.724

Tab. 2. GNSS processed coordinates
Tab. 2. Współrzędne przeliczone z pomiarów GNSS

No	Point name	WGS-84 coordinates		
		X(m)	Y(m)	Z(m)
1	77423	-1441162.2847	5746484.0925	2358410.7752
2	77432	-1460685.7912	5743315.5849	2352476.7272
3	77434	-1447312.2826	5747860.7325	2351315.7667
4	77437	-1455834.6258	5746570.7882	2349004.4970
5	77451	-1453518.3229	5749615.1725	2343131.8469
6	DC1-01	-1449556.8312	5746183.4792	2354019.5203
7	DC1-02	-1450065.5566	5746100.7344	2353854.8807
8	DC1-03	-1451155.0426	5746451.2906	2351834.1915
9	DC1-04	-1451722.2769	5746382.7343	2351690.8972
10	DC1-05	-1458256.3442	5743960.0941	2353139.8973
11	DC1-06	-1458935.1637	5743773.5249	2352894.2997
12	DC1-07	-1460515.8402	5743913.2417	2351145.3561
13	DC1-08	-1460186.5905	5744310.8179	2350568.6649
14	DC1-09	-1461207.5309	5745169.6658	2348641.9460
15	DC1-10	-1461615.2307	5744886.6552	2348732.7435
16	DC1-11	-1452921.8315	5747402.4856	2348380.3853
17	DC1-12	-1452661.0998	5747360.7446	2348730.8786
18	DC1-13	-1454143.7086	5747322.3845	2347985.2397
19	DC1-14	-1454318.0662	5747441.2862	2347617.8883
20	DC1-15	-1455520.0755	5747086.8324	2347881.1862
21	DC1-16	-1455611.5684	5747211.3012	2347471.4612
22	DC1-17	-1452896.1308	5750091.7296	2342416.8262
23	DC1-18	-1453617.7817	5749821.1209	2342633.0695
24	DC1-19	-1454583.1420	5749004.4930	2344009.4154
25	DC1-20	-1455195.3580	5748771.5598	2344227.1410
26	DC1-21	-1456369.5582	5747921.5992	2345646.8400
27	DC1-22	-1457054.9876	5747880.9472	2345270.8530
28	DC1-23	-1458330.1120	5747518.4952	2345559.8015
29	DC1-24	-1458748.2721	5747491.0286	2345362.9305
30	DC1-25	-1458552.9290	5748342.5893	2343366.9848
31	DC1-26	-1459173.9030	5748188.2307	2343424.6805
32	DC1-27	-1460835.6911	5748030.7095	2341827.6246
33	DC1-28	-1461161.2425	5748053.4930	2341518.9026
34	DC1-29	-1442102.0335	5745271.1303	2359726.5703
35	DC1-30	-1442234.0701	5745509.8574	2358883.8895
36	III_09	-1448356.6812	5746225.3194	2353908.9780
37	III_7P	-1443895.5225	5745411.8659	2358178.4849
38	III_12	-1461031.1133	5743974.7341	2350966.1604
39	III_14	-1459050.2383	5745582.2676	2349720.6425
40	III_17	-1460817.0764	5748051.2827	2341798.1099

The application of GNSS technology with the proposed algorithm to derive horizontal coordinates and leveling heights of points based on height anomalies of existing benchmarks in the study area for large-scale topographic mapping has both scientific and practical meanings in the context of Vietnam. This is because it meets technical requirements and economicly efficient for large-scale topographic mapping. The experiment over the study area of 400 km² with 5 to 10 benchmark points shows that the application of GNSS technology with the proposed workflow ensures required accuracy for large-scale topographic mapping in Vietnam. This method is particularly practical in Vietnam when mapping with GNSS technology in areas with difficult terrain such as border regions, coastal areas, and islands.

4. Conclusions

The algorithm proposed in this study, which focuses on the transformation of 2D coordinates and the determination of leveling heights based on the height anomalies of existing points within the designated study area, presents a compelling

Tab. 3. Corrections of GNSS to leveling heights using weight factor, P=1
Tab. 3. Korekty GNSS do wysokości niwelacyjnych z wykorzystaniem współczynnika wagowego, P=1

No	Point name	Coordinates P=1			Correction			Leveling height (m)	Level difference (m)
		X(m)	Y(m)	H(m)	dx(m)	dy(m)	dh(m)		
1	77423	2415895.970	430623.605	1405.155	-0.0002	0.0000	-3.830	1405.150	0.005
2	77432	2409679.742	450301.045	787.151	0.0001	0.0000	-3.373	787.160	-0.009
3	77434	2408234.513	436219.215	1400.960	0.0003	0.0000	-3.872	1400.972	-0.012
4	77437	2405746.667	444786.447	1321.090	0.0002	0.0000	-3.641	1321.099	-0.009
5	77451	2399421.409	441772.429	1361.620	-0.0001	0.0000	-3.764	1361.617	0.003
6	DC1-01	2411134.251	438816.271	1403.489	0.0006	0.0000	-3.812	1403.482	0.007
7	DC1-02	2410963.048	439328.991	1383.433	0.0006	0.0000	-3.802	1383.409	0.024
8	DC1-03	2408858.463	440291.355	1196.748	0.0005	0.0000	-3.787	1196.746	0.002
9	DC1-04	2408696.452	440857.368	1210.878	0.0005	0.0000	-3.772	1210.861	0.017
10	DC1-05	2410293.655	447790.181	1057.615	0.0004	0.0000	-3.505	1057.605	0.010
11	DC1-06	2410068.473	448493.152	953.719	0.0003	0.0000	-3.470	953.738	-0.019
12	DC1-07	2408245.295	449984.621	792.189	0.0000	0.0000	-3.388	792.196	-0.007
13	DC1-08	2407598.360	449565.609	860.805	-0.0001	0.0000	-3.410	860.768	0.037
14	DC1-09	2405405.192	450336.384	1153.487	-0.0004	0.0000	-3.361	1153.447	0.040
15	DC1-10	2405552.434	450801.616	1025.753	-0.0004	0.0000	-3.334	1025.696	0.057
16	DC1-11	2405143.900	441757.248	1174.905	0.0003	0.0000	-3.755	1174.901	0.004
17	DC1-12	2405508.911	441516.086	1207.803	0.0003	0.0000	-3.762	1207.807	-0.004
18	DC1-13	2404690.436	442959.544	1234.728	0.0002	0.0000	-3.714	1234.735	-0.007
19	DC1-14	2404290.284	443097.949	1245.489	0.0002	0.0000	-3.709	1245.489	0.000
20	DC1-15	2404548.398	444350.776	1297.871	0.0001	0.0000	-3.660	1297.830	0.041
21	DC1-16	2404114.718	444407.387	1279.092	0.0001	0.0000	-3.658	1279.044	0.048
22	DC1-17	2398645.450	441049.791	1385.024	-0.0001	0.0000	-3.790	1385.005	0.019
23	DC1-18	2398875.132	441816.383	1385.478	-0.0001	0.0000	-3.763	1385.476	0.002
24	DC1-19	2400354.647	442957.514	1378.558	-0.0001	0.0000	-3.718	1378.551	0.007
25	DC1-20	2400582.535	443608.796	1388.833	-0.0001	0.0000	-3.692	1388.795	0.038
26	DC1-21	2402094.565	444960.613	1416.317	-0.0001	0.0000	-3.635	1416.285	0.032
27	DC1-22	2401695.351	445633.474	1397.077	-0.0002	0.0000	-3.604	1397.013	0.064
28	DC1-23	2401973.284	446959.125	1468.860	-0.0003	0.0000	-3.540	1468.796	0.064
29	DC1-24	2401973.284	447370.374	1466.871	-0.0003	0.0000	-3.519	1466.785	0.086
30	DC1-25	2399620.923	446964.634	1451.031	-0.0005	0.0000	-3.536	1450.942	0.089
31	DC1-26	2399671.254	447604.477	1475.308	-0.0005	0.0000	-3.503	1475.186	0.122
32	DC1-27	2398087.617	449248.372	1123.538	-0.0009	0.0000	-3.406	1123.360	0.178
33	DC1-28	2397762.053	449557.178	1104.566	-0.0010	0.0000	-3.386	1104.364	0.202
34	DC1-29	2417464.371	431836.793	1015.054	0.0001	0.0000	-3.822	1015.075	-0.021
35	DC1-30	2416583.970	431902.953	946.175	0.0001	0.0000	-3.831	946.189	-0.014
36	III_09	2411130.052	437642.588	1127.627	0.0005	0.0000	-3.834	1127.604	0.023
37	III_7P	2415807.231	433534.639	971.181	0.0003	0.0000	-3.840	971.193	-0.012
38	III_12	2408008.217	450468.008	899.045	-0.0001	0.0000	-3.360	899.032	0.013
39	III_14	2406462.480	448147.867	1430.966	0.0000	0.0000	-3.484	1430.969	-0.003

Tab. 1. Coordinates and elevations of the national third-order level points and geodetic control points

Tab. 1. Współrzędne i wysokości krajowych punktów trzeciego rzędu i punktów kontroli geodezyjnej

No	Point name	Coordinates P=1/S²			Correction			Leveling height (m)	Level difference (m)
		x(m)	y(m)	h(m)	dx(m)	dy(m)	dh(m)		
1	77423	2415895.970	430623.605	1405.150	0.0000	0.0000	-3.835	1405.150	0.0000
2	77432	2409679.742	450301.045	787.160	0.0000	0.0000	-3.364	787.160	0.0000
3	77434	2408234.513	436219.215	1400.972	0.0000	0.0000	-3.860	1400.972	0.0000
4	77437	2405746.667	444786.447	1321.099	0.0000	0.0000	-3.632	1321.099	0.0000
5	77451	2399421.409	441772.429	1361.617	0.0000	0.0000	-3.767	1361.617	0.0000
6	DC1-01	2411134.251	438816.271	1403.469	0.0010	0.0000	-3.833	1403.482	-0.0130
7	DC1-02	2410963.047	439328.991	1383.414	0.0010	0.0000	-3.821	1383.409	0.0050
8	DC1-03	2408858.462	440291.355	1196.740	0.0007	0.0000	-3.795	1196.746	-0.0060
9	DC1-04	2408696.452	440857.368	1210.872	0.0006	0.0000	-3.779	1210.861	0.0110
10	DC1-05	2410293.655	447790.181	1057.621	0.0004	0.0000	-3.499	1057.605	0.0160
11	DC1-06	2410068.473	448493.152	953.727	0.0003	0.0000	-3.462	953.738	-0.0110
12	DC1-07	2408245.295	449984.621	792.183	0.0000	0.0000	-3.393	792.196	-0.0130
13	DC1-08	2407598.360	449565.609	860.801	0.0000	0.0000	-3.414	860.768	0.0330
14	DC1-09	2405405.192	450336.384	1153.480	-0.0003	0.0000	-3.369	1153.447	0.0330
15	DC1-10	2405552.433	450801.616	1025.744	-0.0003	0.0000	-3.344	1025.696	0.0480
16	DC1-11	2405143.901	441757.248	1174.908	0.0002	0.0000	-3.751	1174.901	0.0070
17	DC1-12	2405508.911	441516.086	1207.806	0.0002	0.0000	-3.759	1207.807	-0.0010
18	DC1-13	2404690.436	442959.544	1234.733	0.0001	0.0000	-3.709	1234.735	-0.0020
19	DC1-14	2404290.284	443097.949	1245.493	0.0001	0.0000	-3.704	1245.489	0.0040
20	DC1-15	2404548.398	444350.776	1297.878	0.0000	0.0000	-3.653	1297.830	0.0480
21	DC1-16	2404114.718	444407.387	1279.098	0.0000	0.0000	-3.652	1279.044	0.0540
22	DC1-17	2398645.450	441049.791	1385.019	0.0000	0.0000	-3.795	1385.005	0.0140
23	DC1-18	2398875.132	441816.383	1385.474	0.0000	0.0000	-3.767	1385.476	-0.0020
24	DC1-19	2400354.647	442957.514	1378.558	-0.0001	0.0000	-3.719	1378.551	0.0070
25	DC1-20	2400582.535	443608.796	1388.834	-0.0001	0.0000	-3.692	1388.795	0.0390
26	DC1-21	2402094.565	444960.613	1416.321	-0.0002	0.0000	-3.631	1416.285	0.0360
27	DC1-22	2401695.351	445633.474	1397.080	-0.0002	0.0000	-3.601	1397.013	0.0670
28	DC1-23	2401973.284	446959.125	1468.863	-0.0003	0.0000	-3.537	1468.796	0.0670
29	DC1-24	2401973.284	447370.374	1466.874	-0.0004	0.0000	-3.517	1466.785	0.0890
30	DC1-25	2399620.923	446964.634	1451.032	-0.0005	0.0000	-3.536	1450.942	0.0900
31	DC1-26	2399671.254	447604.477	1475.309	-0.0005	0.0000	-3.502	1475.186	0.1230
32	DC1-27	2398087.617	449248.371	1123.537	-0.0009	0.0000	-3.407	1123.360	0.1770
33	DC1-28	2397762.053	449557.178	1104.564	-0.0009	0.0000	-3.388	1104.364	0.2000
34	DC1-29	2417464.372	431836.793	1015.062	-0.0001	0.0000	-3.814	1015.075	-0.0130
35	DC1-30	2416583.970	431902.953	946.180	0.0000	0.0000	-3.826	946.189	-0.0090
36	III_09	2411130.052	437642.588	1127.604	0.0010	0.0000	-3.857	1127.604	0.0000
37	III_7P	2415807.232	433534.639	971.192	0.0000	0.0000	-3.828	971.192	0.0000
38	III_12	2408008.217	450468.008	899.032	0.0000	0.0000	-3.373	899.032	0.0000

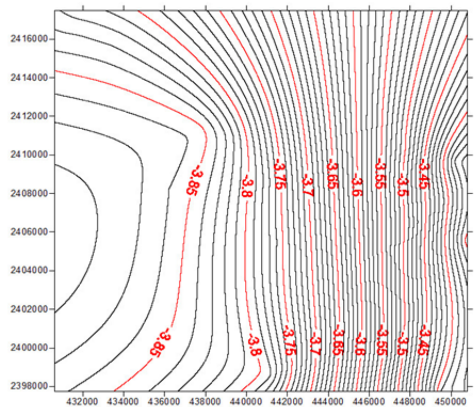

Fig. 5. Height anomalies map [m] determined based on the leveling heights in the Mu Cang Chai study area.

Rys. 5. Mapa anomalii wysokości [m] wyznaczona na podstawie wysokości niwelacyjnych na obszarze badań Mu Cang Chai

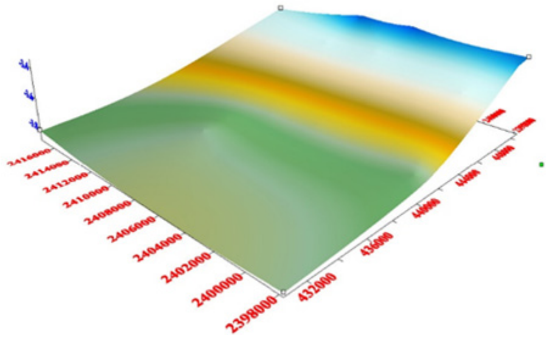

Fig. 6. Height anomalies digital model determined based on the level points in the Mu Cang Chai study area
Rys. 6. Cyfrowy model anomalii wysokości określony na podstawie punktów poziomu na obszarze badań Mu Cang Chai

case for the integration of GNSS technology. This integration, when combined with the measured leveling heights of points, has been shown to meet the stringent accuracy requirements necessary for the creation of large-scale topographical maps.

This innovative approach leverages the power of GNSS technology to capture precise measurements, thereby facilitating the accurate representation of geographical features on a large scale. The results obtained through this method not only meet but potentially exceed the standards set for topographical mapping, thereby offering significant potential for future applications.

In the context of Vietnam, this proposal is particularly relevant and feasible. The unique geographical conditions of Vietnam, characterized by diverse landscapes including border regions, coastal areas, and islands, pose unique challenges for mapping. The use of GNSS technology in these restricted areas offers a practical solution, enabling accurate mapping even in areas where traditional methods may fall short.

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Rozwiązanie poprawiające dokładność pozycji poziomej i pionowej punktów mierzonych technologią GNSS/CORS przy tworzeniu wielkoskalowych map topograficznych Wietnamu

W Wietnamie, podczas tworzenia map topograficznych na dużą skalę przy użyciu technologii Global Navigation Satellite Systems (GNSS) w połączeniu z ciągle działającymi stacjami referencyjnymi (CORS) i tradycyjnymi pomiarami stacji całkowitej, wystąpią przesunięcia zarówno w pozycjach poziomych, jak i pionowych. Aby rozwiązać ten problem, dokonujemy korekt mapy, aktualizując mapę w założonym układzie współrzędnych. W założonym układzie współrzędnych kształty i różnice wysokości zmienionych obiektów są dokładnie obserwowane, aby spełniać wymagania odpowiadające skali mapy. Współrzędne i wysokości wyraźnych punktów na mapie lub punktów kontrolnych na polu uzyskanych z różnych metod mają różnice większe niż dopuszczalne wartości według skali mapy. Stosując dwuwymiarową transformację współrzędnych i wysokość nad geoidą, obliczaną dla każdego punktu z jego wagą, współrzędne i wysokości punktów mogą być obliczane w jednolitym układzie współrzędnych.

Słowa kluczowe: *dokładność GNSS, mapy topograficzne, osnowa geodezyjna*