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COORDINATE TRANSFORMATION USING THE AUTHOR'S SOFTWARE IN GIS CLASS SYSTEM – CASE STUDY

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Abstract

In order to implement the provisions of the INSPIRE Directive, it is necessary for the Member States of the European Union to take appropriate measures to enable combining in a uniform manner spatial data deriving from different sources and sharing use of them by many users and many applications. Spatial data regarding underground hard coal mining in Poland should also be available in the national spatial reference system. Mining enterprises run a cartographic resource in the different rectangular flat coordinate systems. The standard transformation procedure does not provide the required accuracy because these are areas affected by mining activity, and the stability of points is limited, hence, studies were undertaken. The result is the development of software that can be used in Geographic Information Systems to transform spatial data from a system used in mine to the national system. The article described shortly a chosen coordinates systems used in Polish underground mines, elaborated procedure for selection of the degree and the type of a transformation polynomial in the transformation task. It presents its practical application of procedure for the area of one of hard coal mines using the author's software elaborated in the results of above-mentioned research.

TRANSFORMACJA WSPÓLRZĘDNYCH Z WYKORZYSTANIEM AUTORSKIEGO OPROGRAMOWANIA W SYSTEMIE KLAS GIS – STUDIUM PRZYPADKU

Słowa kluczowe: System Informacji Geograficznej, informatyka w górnictwie, układy współrzędnych, oprogramowanie do transformacji

Abstrakt

W celu realizacji postanowień dyrektywy INSPIRE konieczne jest podjęcie przez państwa członkowskie Unii Europejskiej odpowiednich działań umożliwiających łączenie w sposób jednolity danych przestrzennych pochodzących z różnych źródeł i współdzielenie ich przez wielu użytkowników i wiele aplikacji. Dane przestrzenne dotyczące podziemnego wydobycia węgla

kamiennego w Polsce powinny być również dostępne w krajowym układzie odniesień przestrzennych. Przedsiębiorstwa górnicze prowadzą zasób kartograficzny w lokalnych prostokątnych płaskich układach współrzędnych. Standardowa procedura przekształceń nie zapewnia wymaganej dokładności, ze względu na to, że są to tereny objęte działalnością górnictwem, a stabilność punktów jest ograniczona, dlatego podjęto badania. Efektem końcowym jest opracowanie oprogramowania, które można wykorzystać w Systemach Informacji Geograficznej do przekształcania danych przestrzennych z systemu używanego w kopalni do systemu krajowego. W artykule opisano pokrótce wybrane układy współrzędnych stosowane w polskich kopalniach podziemnych, opracowaną procedurę doboru stopnia i rodzaju wielomianu transformacji w zadaniu transformacji. Przedstawiono praktyczne zastosowanie procedury na terenie jednej z kopalń węgla kamiennego z wykorzystaniem autorskiego oprogramowania opracowanego w wynikach powyższych badań.

1. INTRODUCTION

The issue concerning the implementation of transformation tasks between the local rectangular flat coordinate systems and the national system is connected with the provisions contained in the INSPIRE Directive (Directive, 2007). The Directive requires Member States of the European Union to take appropriate measures to obtain uniform spatial data deriving from different sources and use them jointly by many users and many applications. The provisions of the Directive apply to spatial data held by public authorities or on their behalf. Spatial data sets should be brought into mutual coherence and adapted to shared use. In Poland, legal mechanisms have been introduced in accordance with the requirements, which allow to ensure interoperability and cooperation in the scope of data, metadata, electronic services, coordination of development of construction and infrastructure. According to them, also spatial data regarding underground hard coal exploitation should be available in the national coordinate system, which is a part of the national spatial reference system. At the same time, the implementing regulations for the Geological and Mining Law allow for keeping surveying-geological documentation in the local coordinate systems, provided that it is possible to transform them to the national system, which is currently the PL-2000 system (Regulation, 2015). The significance of the issue related to the implementation of the transformation task in the above-mentioned situations also results from the fact that the issue concerns areas affected by the influence of mining exploitation, hence, it is necessary to apply such a procedure that allows the transformation to be performed at the required accuracy level. Research carried out at the Silesian University of Technology in 2017 (Sokoła-Szewioła 2017) showed that in the past several coordinate systems of supra-local and local importance were used in Polish mining cartography. The analysis

carried out for 238 areas, existing and abandoned mining enterprises exploiting hard coal in Poland showed that cartographic documentation was usually kept in the following systems: Sucha Góra (1885, 1901, 1923, 1926, ROW- Rybnik Coal Area, GOP- Upper Silesian Industrial Region), Borowa Góra, 1965, S-JTSK (System of the Unified Trigonometrical Cadastral Network) and KUL (Union of Lublin Mound- Lviv). This state of affairs was also influenced by the political situation of Poland, which did not exist in the 19th century on the map of Europe, as well as the multiple changes in the course of the Polish-German border. Mining maps prepared in the 19th century were created on the basis of the geodetic control points, for which the coordinates were determined in the systems applicable in the area of partitioning states. Currently, most mining enterprises use as main local rectangular flat coordinate systems of Sucha Góra only in one enterprise the PL-2000 system. On the other hand, as the auxiliary systems are applied the Borowa Góra, PL-1992 and 1965 systems. A brief description of the most commonly used coordinate systems in mines is presented in chapter The coordinate systems currently used in the underground hard coal mining companies.

Taking into account the above issue of coordinate transformation between systems becomes even more important. Fig. 1 shows the mining areas of the mines in the region of the Upper Silesian Coal Basin (USCB) and the coordinate systems used.

Additionally, considering the impact of mining operations on the surface of the area, and resulting from it the observed surface deformations, such tasks should be performed with accordance with a suitably selected procedure, which is presented in the article, ensuring the accomplishment of transformation and determination of transformation parameters at the required level of accuracy, taking into account the specificity of areas on which underground exploitation is being conducted. Surveying-geological documentation in mining enter-

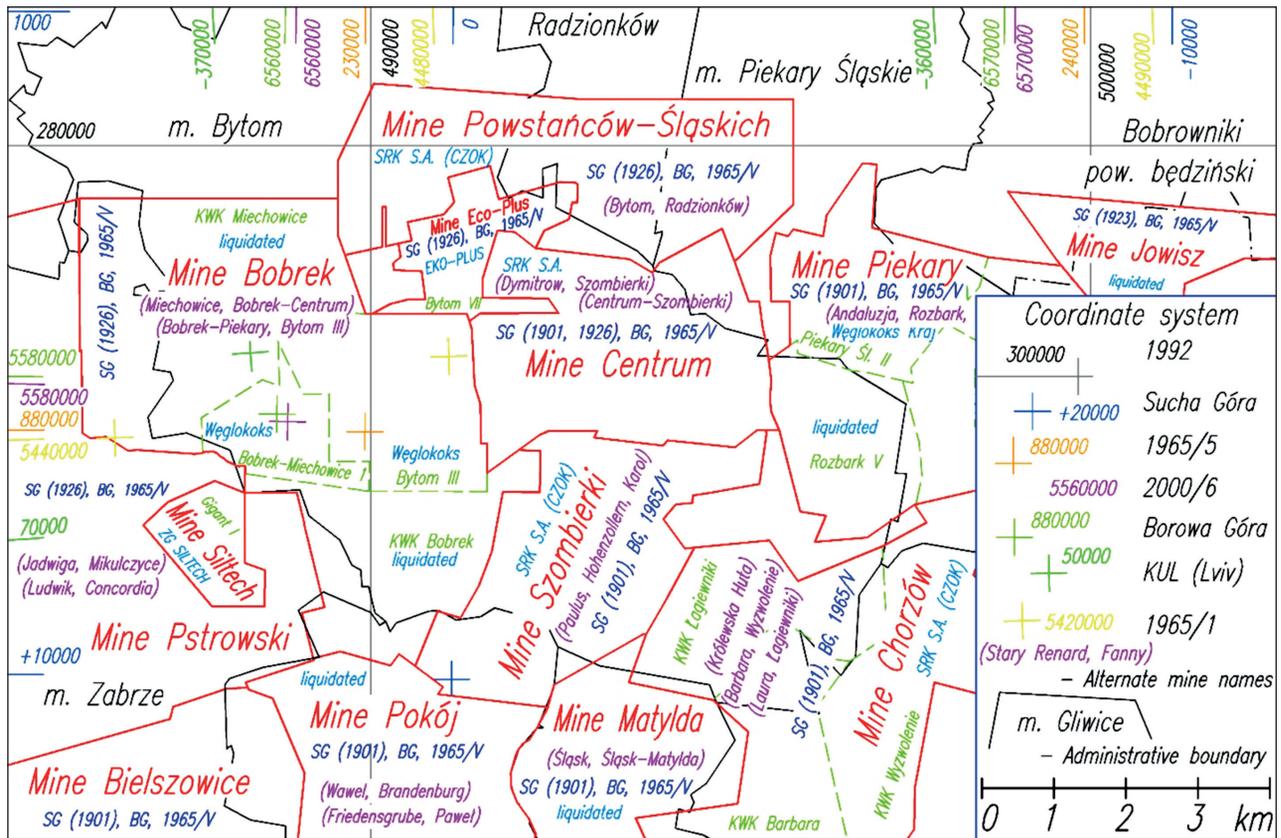


Fig. 1. Mining areas and coordinate systems
Ryc. 1. Obszary górnicze i układy współrzędnych

prises in Poland, is conducted in the GIS class systems. Most of them are based on a solution that uses software that operates the LISP programming language. Therefore, the presented software has been developed to be used in such systems. Issues related to the use of this class systems were presented, among others, in the works (Sokoła-Szewioła et al. 2017; Sokoła-Szewioła, Zygmuniak 2017). The issue of transformation is the subject of a number of other works. In the work (Janssen 2009) where the author discusses transformations between various coordinate currently used in Austria. While some practical solutions to the problem of transformation between local geodetic coordinate sets and also between the local geodetic system and global reference systems are described in the work (James, Steed 2012). In work (Varga et al. 2017) was presented empirical research on coordinate transformation models that enable coordinate transformations between the historical astro-geodetic datums and datums related to the European Terrestrial Reference System (ETRS), on

the base of case study of the Republic of Croatia. The significance of the transformation accuracy is presented in the work (Yuanxi et al. 2002). Also, in the case of using INSAR technology (Chen et al. 2020) and LIDAR technology (Al-Rawabdeh et al. 2020) an important element is correct performance of the transformation task.

The coordinate systems used in the underground hard coal mining companies in Poland:

- The system with the starting point at the Union of Lublin Mound in Lviv. The system was used in the lands annexed by Austria. Its triangulation was performed independently of the first order triangulation in Austria. The projection used in this system showed many features in common with the Soldner projection. Until the mid-20th century, it was used for cadastral purposes. In the geological survey documentation, it can be found in the mines located in the eastern part of the Upper Silesian Coal Basin, e.g.: Siersza, Janina, Sobieski, Porąbka-Klimontów.

- The system with the point of application in Ze-grze (Borowa Góra). This system was officially introduced for use in 1936 by the Military Geographical Institute. Maps in this system were created using the Bessel ellipsoid and the quasi-stereographic projection. In 1947 a resolution was passed that the country maps would be created in Gauss-Krüger projection. The Polish area was divided into the four three-stages meridional bands, each of which had an independent coordinate system. Maps created in the 1950–60 were sometimes made using that system. (mines: Piekary, Halemba, Boże Dary, Silesia).
- System Sucha Góra in the initial period, the surface of the sphere was adopted using the modified Cassini-Soldner equidistant projection on the Bessel ellipsoid. The second variation of the subject coordinate system characterize the application of Gaussian conformal projection with the use of a reference surface in the form of an elliptic cylinder, tangential to the Bessel ellipsoid at the starting point of the system. System Sucha Góra 1901 is commonly used today by, among others, mines e.g. Budryk, Knurów, Szczygłowice, Bolesław-Śmiały. System Sucha Góra 1923 is used by mines: Sosnowiec, Porąbka-Klimontów, Kazimierz-Juliusz. System SG 1926 was used by mines: Sońnica, Makoszowy, Gliwice, Pstrowski. In the area of Wodzisław Śląski, Rybnik, Jastrzębie-Zdrój, Żory you can find the system „Sucha Góra ROW”. In the 1950s the system Sucha Góra in the area of Upper Silesian Industrial Region was divided into three areas: west – GOP I, middle – GOP II and east – GOP III. In mines: Brzeszcze, Piast, Boże Dary and Ziemowit GOP II is used.
- System „1965” – rectangular flat coordinate system. The reference surface was the Krasowski ellipsoid with the application point in Pułkowo and the Azimuth Ag oriented towards Bugry. The Krasowski ellipsoid with the application point in Pułków and the azimuth A_g oriented towards Bugry was adopted as the reference surface (Instruction 1978). It was used to prepare civil elaboration in the years 1968 to 2010 (Maciaszek 2010). Documentation using the 1965 system can be found in almost all mines. Mining maps were created using system 1965 (zone V) for the area of coal mine Morcinek. In that mine we can also find the Czech system S-JTSK.
- The „1992” system – a rectangular flat coordinate system, based on the Gauss-Krüger projection for the GRS’80 ellipsoid, in one ten-degrees zone. System is intended for medium and small-scale elaborations. This system is used on the maps of the Żory and Budryk mines.
- PL-2000 flat rectangular coordinate system. In Poland, it has been in force since 2000 and is used to prepare maps in scales bigger than 1: 10,000. For the PL-2000 system, the Gauss-Krüger projection was adopted, and the area of the country was divided into four projection zones in the form of three-degree meridional stripes, marked in the range of 5–8. Each mine must be able to transform maps conducted in local systems to the PL-2000 system. In practice, a grid is put on the maps in this coordinate system. At present – coal mine Silesia keep records in that system.
- Materials and Methods

2.1. Materials

The study uses, among others, the following documents and software:

- Technical Guidelines G-1.10. Projection formulas and parameters of coordinate (Kadaj 2001).
- Regulation of the Council of Ministers of October 15, 2012 on the national system of spatial references (Regulation 2012).
- G-2 instruction. A detailed horizontal and altitudinal geodetic control and the conversion of coordinates between systems (project) (Instruction 2001).
- GEONET 2006 software package, including the UNITRANS program.
- Geolisp software, operating in the CAD graphic environment, developed by Marian Poniewiera.
- AutoCAD software.
- Materials obtained from the resources of the surveying-geological department of Budryk coal mine: a map of the area, a list of coordinates of the border points in the systems – Sucha Góra and PL-2000 – zone 6.
- The list of control points in the systems Sucha Góra and PL-2000 – zone 6.

- Coordinates of the selected points in the area of the Budryk coal mine, established as a result of field measurement in the PL-2000 system, and coordinates of these points in the Sucha Góra system obtained from the coal mine Budryk.

In addition, basic maps obtained from the Districts Center for Geodetic and Cartographic Documentation Gliwice and Mikołów for selected fragments of the mining area of the Budryk coal mine were used.

The above was used to establish the transformation procedure, to conduct a practical transformation task for the area of the above-mentioned coal mine, and then to develop the software constituting the subject of the article.

2.2. Transformation task

In order to carry out transformation tasks, it is recommended to use specific calculation procedures. Conversion of geodetic coordinates B, L to the coordinate rectangular system X, Y (and inverse conversions), performed using the cartographic projection formulas accepted for these systems, is performed with numerical accuracy not worse than 0,001 m. In the case of transformations covering points lying on large areas, it is possible to apply the polynomials transformation, conformal and non-conformal of higher degrees, to convert coordinates of the point. Transformation error m_t should be calculated by the Equation (1), and its value should not be higher than 0.05 m:

$$m_t = \sqrt{\frac{[V_x V_x] + [V_y V_y]}{n - \frac{u}{2}}}, \quad (1)$$

where:

- V_x, V_y – deviations of coordinates x, y for contact points,
- n – the number of contact points,
- u – number of unknown transformation parameters.).

Deviations at the contact points must not exceed a triple value of a transformation error and should be removed using the Hausbrandt method. In 2001, in order to streamline and unify geodetic calculation works related to the transformation of coordinates between systems, technical guidelines G 1.10, containing mapping formulas and coordinate system parameters, were

developed in Poland (Kadaj 2001). To the guidelines, the TRANSPOL v.1.0 program was included, which can be used to control the correctness of conversion of the coordinates between systems belonging to the national spatial reference system. The guidelines included, among others, a general scheme of direct transformation shifts between coordinate systems and presented an algorithm of transformation of the Cartesian coordinates between different ellipsoids.

In the case of transformation between different ellipsoids, which takes place in the discussed task, the conversion should take place via a direct transformation between the coordinate systems of B, L, H or Cartesian coordinates X, Y, Z.

The conversion scheme of this type can be presented as follows:

- coordinates (X, Y) from the local system are projected to the reference surface, i.e. the Bessel ellipsoid, obtaining geodetic coordinates (B, L),
- geodetic coordinates (B, L) are transformed to the reference surface of the ETRF89 system, i.e. the ellipsoid GRS80, obtaining (B, L) ETRF89, according to the parameters of the 7-parameter transformation established for the area of Poland,
- the coordinates (B, L) of ETRF89 are projected on the plane according to the Gauss-Krüger projection parameters (for the given meridian zone from the 2000 system), obtaining mathematical coordinates (X, Y) '2000,
- the coordinates (X, Y) '2000 are transformed on the coordinates of the geodetic control points (X, Y) 2000 using the local transformation developed on the basis of contact points selected for a given area, having coordinates in the local system and the PL-2000 system.

The above-mentioned stages implement the process of introducing transformation corrections into the global and local coordinates.

In order to determine the transformation formulas between the local system and the PL-2000 system (in the zone in which the local system is located) the transformation by polynomials, conformal and non-conformal of the higher degrees, can be applied. Such a solution, allowing to replace the above conversion scheme, was used in the article. Adjustment points should be evenly distributed throughout the area that is subject to transformation. Most preferably, they should be ar-

ranged so that the edges points form a convex figure that includes the transformed area. In the case of the developed software, a polynomial conformal transformation and a general polynomial one was adopted. The general polynomial model of transformation has the forms Equations (2) and (3):

$$X = \sum_{i,j=0..n} a_{ij} x^i y^j, \quad (2)$$

$$Y = \sum_{i,j=0..n} b_{ij} x^i y^j, \quad (3)$$

where:

a_{ij}, b_{ij} – unknown parameters for $i, j = 0 \dots n$

$$x = (x - x_s) C$$

$$y = (y - y_s) C$$

x, y – coordinates of the point in the original system,

x_s, y_s – centering parameters determined a priori,

C – a scaling factor determined a priori,

X, Y – coordinates in the secondary (national) system.

Parameters of transformation are determined by the method of least squares based on the coordinates of the so-called adjustment points (points for which coordinates are known in both coordinate systems). We select the degree of a polynomial out of the condition that increasing the degree by one does not cause a significant decline of the transformation error.

Assuming the use of fewer number of parameters, the general polynomial is reduced to a complex polynomial. Transformation can be carried out according to the formula Equation (4).

$$Z = c_0 + c_1 z + c_2 z^2 + \dots + a c_n z^n, \quad (4)$$

where:

$Z = (X, Y)$ – a transformed point in the secondary system,

$c_0, c_1, c_2 \dots c_n$ – complex polynomial parameters, where $n = 1, 2, 3 \dots n$

z – complex argument, centered with regard to the center of gravity of the area, normalized by a parameter that is scaling primary coordinates,

$$z = (x - x_0) \alpha, z = (y - y_0) \alpha,$$

(x, y) – coordinates of the point in the local system,

(x_0, y_0) – coordinates of the established centering point,

α – scaling factor such that $\|z\| < 1$.

Due to the polygonal transformation, it is possible to determine the components of the distortion field, i.e. the elementary linear scale, and the convergence determining the mutual twisting of the axes.

2.3. Procedure for determining the degree and type of a transformation polynomial and determining the transformation parameters

The development of the software requires determining the degree and type of the transformation polynomial and determining the transformation parameters. To this end, taking into account the principles described in chapter Transformation task, a transformation algorithm has been developed, including the following steps:

- Determining the optimal degree and type of transformation based on the generated adjustment points, arranged in a regular grid, located in the area covered by the transformation task, which ensures a flawless adjustment between the coordinate systems. The number of points should be chosen empirically to ensure a sufficient numerical over determination of equations system.
- Performing an accuracy analysis, including the analysis of deviations of transformation at generated points. The most important should be the value of the location error, which should not exceed 0.05 m. The degree and type of a polynomial is selected out of a condition, because the lowest degree of a polynomial, i.e. the one at which the increase of a degree by one does not cause a significant decline of the error of transformation, is accepted as the final one.
- Selection of contact points to be transformed, and accuracy analysis including deviations at contact points, maximum deviation and a transformation error. The transformation error should not exceed 0.05 m.
- Control of transformation parameters by analyzing the discrepancy of coordinates obtained as a result of transformation with coordinates obtained from the mine. The analysis should include at least the X, Y coordinates difference, and the resultant difference dx, dy .
- Verification of transformation accuracy using the coordinates of points from the area under transformation, based on the analysis of discrepancies

of coordinates of the points obtained as a result of transformation and those obtained from the mine or as a result of field measurements. The verification should include at least the analysis of coordinate differences and the resultant difference.

The presented algorithm was used in practice for the mining area of Budryk coal mine what was included in chapter Application of the transformation task procedure on the example of the coal mine Budryk. The developed transformation parameters were used to develop the software described in chapter Software development.

2.4. Application of the transformation task procedure on the example of the coal mine Budryk

2.4.1. Determination of the optimal type and degree of transformation polynomial

Budryk coal mine is located in the region of the Upper Silesian Coal Basin. The cartographic resource is conducted in the local rectangular flat coordinates system, Sucha Góra. Within the mining area of the mine a grid of around 1000 evenly spaced points was generated, which allowed to determine the type and degree of the transformation polynomial. The distance between the points in the grid is 250 m. The number of points were chosen empirically – it provides a sufficient nu-

merical over-determination of the system of equations. The grid was made in the Geolisp program environment (Poniewiera 2018). The coordinates of these points in the Sucha Góra local system were transformed to the PL-2000 system using the Geolisp and Unitrans programs, receiving a set of contact points in the local and national systems. For the generated set of contact points in the Geonet program, the general polynomial and conformal (polynomial complex) transformations of the degree 1–3 were performed, obtaining the deviations presented in Table 1.

The obtained results (Table 1) indicate that a conformal or general-polynomial transformation of degree 2, is the optimal transformation of the flat coordinates between the Sucha Góra and the PL-2000 systems, for the examined mining area of the Budryk coal mine. Due to the fact that currently applied systems are characterized by conformity of the mapping of the surface of the ellipsoid, conformal transformation of degree 2 is assumed for further consideration.

2.4.2. Selection of contact points for transformation

The coordinates of 958 points of the detailed geodetic control point of the 358/1 seam (Fig. 2) were received from the Budryk coal mine. Due to the fact that these points did not cover the entire mining area, the set of these points was supplemented by 26 points of the area and mining area of the Budryk coal mine, which had the coordinates in both systems.

Table 1. Deviations of flat coordinates transformations between the systems of Sucha Góra and PL2000
Tabela 1. Odchyłki transformacji współrzędnych płaskich między układami Sucha Góra i PL 2000

A type and a degree of transformation	Deviations values [m]			
	V_x^1	V_y^1	V_{max}^2	m_t^3
Conformal of degree 1	0,008	0,008	0,032	0,012
Conformal of degree 2	0,001	0,001	0,002	0,001
Conformal of degree 3	0,001	0,001	0,002	0,001
General polynomial of degree 1	0,008	0,008	0,028	0,012
General polynomial of degree 2	0	0	0	0
General polynomial of degree 3	0	0	0	0

¹ V_x, V_y – medium-square deviation,
² V_{max} – maximum resultant deviation,
³ m_t – transformation error – calculated by the formula 1.

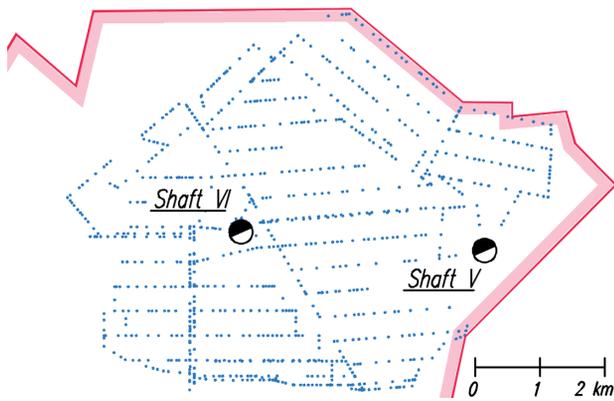


Fig. 2. Selected contact points (blue colour) form the basis of the transformation algorithm between the Sucha Góra and the PL-2000 systems, the border of coal mine in red

Ryc. 2. Wybrane punkty łączne (kolor niebieski) stanowiące podstawę algorytmu transformacji pomiędzy systemem Sucha Góra a PL-2000, granica kopalni zaznaczono kolorem czerwonym

A second degrees conformal transformation was performed for so created set of the 984 contact points. The results of calculations are presented in Table 2.

Table 2. Deviations of coordinate transformation – contact points

Tabela 2. Odchyłki transformacji współrzędnych – punkty łączne

A type and a degree of transformation	Values of deviations [m]			
	Vx^l	Vy^l	$Vmax^2$	m_t^3
Conformal of degree 2	0,004	0,004	0,012	0,006

¹ Vx , Vy – medium-square deviation

² m_t – resultant deviation (transformation error),

³ $Vmax$ – maximum resultant deviation.

Obtained results indicate that the transformation meets the requirement of 0.05 m positional error (Instruction 2001).

2.4.3. Determination of transformation coefficients

For transformation of the flat coordinates between the Sucha Góra system, called the original one, and the PL-2000 system, called the secondary one, for the Budryk coal mine the following values of transformation coefficients were determined:

Centres of gravity of the sets of adjustment points.

Primary system (1): -23612.7646 -8281.1431 (x0, y0)
 Secondary system (2): 5562770.5680 6554207.7502 (X0, Y0)
 Numerical scale = 1.57373975475741E-0004

COMPLEX POLYNOMIAL COEFFICIENTS, AND ROOT MEAN SQUARE ERROR

a[0]:= -2.11147651811006E-0003 RMSE= 2.47791235430162E-0005
 b[0]:= -3.10411046887236E-0004 RMSE= 2.47791235430162E-0005
 a[1]:= 6.35345480708309E+0003 RMSE= 4.44782468741763E-0005
 b[1]:= -7.47740896650349E+0001 RMSE= 4.44782468741763E-0005
 a[2]:= -1.39696397526471E-0003 RMSE= 6.96541663296369E-0005
 b[2]:= -3.38364758014133E-0002 RMSE= 6.96541663296369E-0005

TRANSFORMATION MODEL (complex polynomial):

$$Z-Z_0 = c[0] + c[1]*z + c[2]*z*z + c[3]*z*z*z + \dots$$

where:

Z = (X, Y) – resultant coordinates,

Z₀ = (X₀, Y₀) – the center of gravity in the secondary system,

z = [(x-x₀) * scale, (y-y₀) * scale] – complex argument,

(x, y) – primary coordinates,

(x₀, y₀) – the center of gravity in the original system,

c [0] = (a [0], b [0]), c1 = (a [1], b [1]), ..., c [n] = (a [n], b [n]) – polynomial coefficients.

For the return transformation from the PL-2000 system, called the primary system, to the Sucha Góra system, called the secondary system, the transformation coefficients were also determined.

2.4.4. Control of transformation parameters

All the points obtained from the mine were used to control the calculated transformation parameters. The differences (dx, dy) between the above-mentioned coordinates and coordinates obtained as a result of the second degrees conformal transformation, and the resultant difference dxy, were calculated according to Equation (5).

$$d_{xy} = \sqrt{dx^2 + dy^2}, \tag{5}$$

Fig. 3 shows the ellipsis of the maximum discrepancies of the coordinates of points in the second-degree conformal transformation between the systems of Sucha Góra and PL-2000, points with a discrepancy higher than 0,010 m were marked with red, navy blue >0,005 m, cyan >0,003 m, and with green the others. Coordinates rounded up to 0.01m were obtained from the mine, which causes that a few millimeter errors result from rounding calculations. The remaining component of the error results from the first-degree conformal transformation, which was used in the mine in the process of calculating the coordinates.

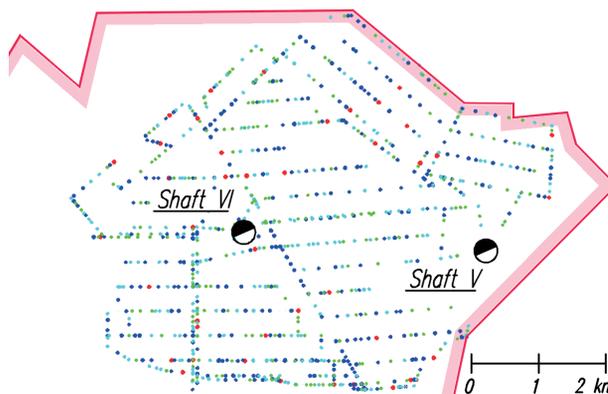


Fig. 3. Ellipses of discrepancies of the coordinates of points in the second degrees conformal transformation between the systems of Sucha Góra and PL-2000 (description in the text)

Ryc. 3. Elipsy rozbieżności współrzędnych punktów w transformacji konforemnej drugiego stopnia między układami Sucha Góra i PL-2000(opis w tekście)

The distribution of obtained discrepancies is shown in the graph (Fig. 4).

The analysis showed that the maximum discrepancy of coordinates obtained as a result of transformation and obtained from the mine does not exceed 0.013 m. In both cases, about 30% of the points obtained a discrepancy of up to 0.003 m and up to 0,005 m. About 38% obtained a discrepancy of up to 0.010 m. Only in 2% of cases, differences above 0.010 m were found. The obtained discrepancies indicate that the accuracy

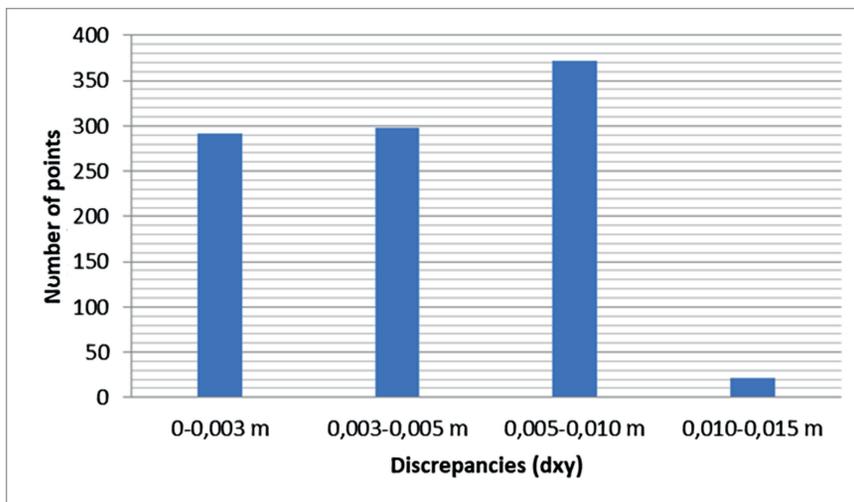


Fig. 4. Distribution of coordinates discrepancies between the values obtained from the second-degree conformal transformation and obtained from the mine

Ryc. 4. Rozkład rozbieżności współrzędnych pomiędzy wartościami uzyskanymi z transformacji konforemnej II stopnia a uzyskanymi z kopalni

of the transformation is satisfactory. Discrepancies at all points do not exceed 0.050 m.

In order to carry out verification of the transformation, the field measurements were also performed. Compact areas were selected for measurement. The ground elements of the underground utilities were measured, i.e. the middles of the covers for sanitary and sewer manholes as well as the middles of water supply valves included in the situational details of the first accuracy group. The selection of measuring points was made considering the following conditions:

- having coordinates of points in the Sucha Góra local system,
- equable distribution of points in the area of measurements.

The flat coordinates were determined in the PL-2000 system, the national spatial reference system (zone 6). The GNSS receiver was used to achieve this goal.

Analysis of discrepancies (dx , dy) between the coordinates of the measured points calculated by means of transformation, and the coordinates of points obtained from the mine showed that the maximal discrepancy between these coordinates does not exceed 0.015 m. At 78% of points a discrepancy of up to 0,010 m was obtained.

3. RESULTS

3.1. Software development

The TRV program, developed as a result of the research, is used to transform coordinates between different coordinate systems, which can be used in a selected program of the GIS class that supports the LISP programming language, for example: AutoCAD, BricsCAD, GstarCAD, ZwcAD, etc. It uses transformation coefficients calculated using the Geonet program, according to the procedure presented in the previous subsection – see Equation (4). The standard effects of the program are as follows: all transformed points receive new coordinates.

In order to install the software – saved in the file trV.zip:

1. Unpack the trV.zip file. The result is the c: \ TRV directory.
2. Using the `_Appload` command, we load the appropriate source file from the c: \ TRV directory.

- a. To AutoCAD: trV.fas
 - b. To BricsCAD: trV.des
 - c. To GstarCAD: trV.fas
 - d. To ZwcAD: trV.zel
3. Run the program by issuing the trV command.

After starting the trV program, a dialog box appears as in Fig. 5, from which the user can select the appropriate file containing transformation factors. An example of a file containing transformation factors is shown in section The source code of the program in LISP language.

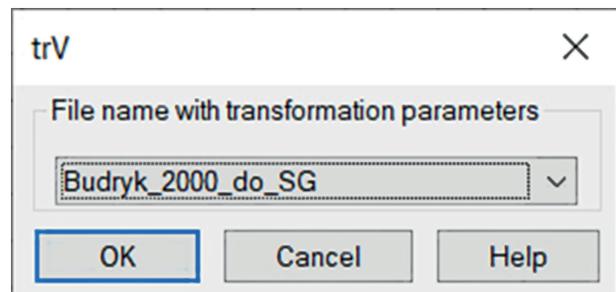


Fig. 5. The trV program dialog box
Ryc. 5. Okno dialogowe programu trV

3.1.1. File containing transformation coefficients from the Sucha Góra system to PL-2000 for the mining area of the Budryk coal mine

```
[Parameters]
info = file with transformation parameters
type = 2
degree = 2
scale = 1.57373975475741E-0004
error = 0.001
```

```
[shift]
x0=-23612.7646
y0=-8281.1431
X0=5562770.5680
Y0=6554207.7502
```

```
[Coefficient]
a0=-2.11147651811006E-0003
b0=-3.10411046887236E-0004
a1=6.35345480708309E+0003
b1=-7.47740896650349E+0001
a2=-1.39696397526471E-0003
b2=-3.38364758014133E-0002
```

3.1.2. The source code of the program in LISP language

Even the shortest representation of the LISP language exceeds the scope of this article. In a few words: LISP is one of the first programming languages, it has undergone numerous changes over the years, the current version of Visual LISP has support for Windows Active X technology. LISP is an abbreviation of LIST Processing and its structure consists of a list of arguments preceded by the name of the function,

all this is inside the parentheses, e.g.: (+ 2 2) will return 4.

The source code of the procedure performing transformation using the method of complex polynomial with accordance to the formula (Equation (4)), is discussed below.

The input data, taken from the file in the format shown in section File containing transformation coefficients from the Sucha Góra system to PL-2000 for the mining area of the Budryk coal mine, is as follows:

st – polynomial degree, e.g. 2,
 c – list of coefficients of a complex polynomial in the form of a geodetic control point: ((a0 b0) (a1 b1) ... (ast bst)),
 x0, y0 – the center of gravity in the primary system,
 X0, Y0 – the center of gravity in the secondary system.

Additionally, we have:

z – known coordinates of the point in the primary system, in the form of a list (x y),
 Z – searched coordinates of a point in the secondary system, in the form of a list (X Y).

First, two auxiliary functions „z +” and „z *” were defined, which are used to add and multiply complex numbers. The car function used below returns the first element of the list, cadr – the second, caddr – the third. The mapcar function calls a given function, e.g. adding for all elements of a list.

```
(defun z* (z1 z2)      The beginning of the definition of the „z *” function, which multiplies the complex
                      numbers z1 and z2.
(list                 The beginning of a new list (new complex number).
(-                   Subtracting the following arguments:
  (* (car z1)(car z2))      multiplying the first element of the number z1 by the first element z2,
  (* (cadr z1)(cadr z2))    multiplying the second element z1 by the second element z2,
)                     the end of the list of subtraction arguments.
(+                   Adding:
  (* (car z1)(cadr z2))    the result of multiplication of the first element Z1 by the second Z2,
  (* (cadr z1)(car z2))    the result of multiplication of the second element Z1 by the first Z2,
)                     end of adding.
)                     The end of the list of elements of a complex number.
)                     End of the definition of the function „z *”.
(defun z+ (z1 z2)     The beginning of the definition of the „z +” function, which adds complex numbers
                      z1 and z2.
  (mapcar '+ z1 z2)   Adds the first element of the number z1 to the first element of the number z2, the
                      second element to the second one.
)                     End of the „z +” function definition.
```

Next, we define the function „st2”, which counts the value of the complex polynomial of the second degree, i.e. performs the action:

$$Z = c_0 + z * (c_1 + z * c_2)$$

```
(defun st2 (z)
  (z+ (car c) (z* z (z+ (cadr c) (z* z (caddr c))))))
)
```

The primary coordinates are not the argument of the „st2” function, but the coordinates multiplied by the normalizing scale and shifted to the center of gravity in the original system are the argument of this function, i.e.:

$$z = (u, v) \text{ where } u = (x-x_0)*\text{scale}, v=(y-y_0)*\text{scale}$$

In LISP language, this operation can be presented in the form of a function:

```
(letter (* scale (- x x0)) (* scale (- y y0))))
```

To obtain coordinates in the secondary system, the result of the „st2” function (pair of U, V) should be moved by the coordinates of the center of gravity in the secondary system. Finally, the resultant X, Y coordinates are obtained from the operation: $X = U + X_0$ and $Y = V + Y_0$.

In the GIS systems described in the article, we can also define dialog boxes in DCL language (dialog control language). Fig. 6 gives the definition of the dialog box shown in Fig. 4. Shortly speaking: the popup_list element defines the directory from which we select the appropriate transformation file, the ok_button and cancel_button elements cause the „OK” and „Cancel” buttons to appear.

```
Box_TRV : dialog {
  label = "File name with transformation parameters";
  : popup_list { key = "FileName2"; }
  ok_button; cancel_button; help_button;
}
```

Fig. 6. Definition of a dialog box in DCL language
Ryc. 6. Definicja okna dialogowego w języku DCL

4. DISCUSSION

The solution of the transformation task between local systems and the national system being an element of the national system of spatial references presented in the article on the example of the mining area of the Budryk hard coal mine showed that the procedure presented in chapter Application of the transformation task procedure on the example of the coal mine Budryk can be applied in practice, in particular in areas affected by mining exploitation. The transformation errors analyzed in the example as well as the control of its accu-

racy based on the discrepancies between the coordinates obtained from the transformations and those obtained from the mine or by the measured values exceeded the permissible values of 0.05 m. The presented procedure for solving the transformation task it is a new solution so far it has not been applied in mining enterprises. Its use will ensure a significant improvement in the transformation accuracy.

The software developed in the results of research allows transformation in GIS class systems that support the LISP programming language, which do not include in its solutions the specificity of transformation in areas affected by mining exploitation. The program presented in the article is elaborated based on the results obtained for the transformation in the region of the Budryk coal mine. However, it can be extended by data containing in the subsequent files the values of transformation parameters of the areas of other mines. Of course, the values of these parameters should be determined in accordance with the procedure presented in the article.

Due to the fact that the coordinates obtained as a result of transformation are burdened with a certain transformation error, obviously fulfilling the provisions regarding the accuracy of transformation, a problem of the lack of compatibility of coordinates of the border points arises. Most often these coordinates obtained from transformation from different mining areas differ.

5. CONCLUSIONS

The transformation of coordinates between different systems in which cartographic documentation is created or was created due to their multitude and deformation of the terrain surface as a result of conducted underground mining of deposits is still the subject of research, primarily due to its accuracy requirements.

The method of developing the author’s software presented in the article, which can be used for transformation in a selected program of the GIS class that supports the LISP programming language, is a very important result of the work carried out by the team of authors.

Application of the above solution has a significant impact on the quality of spatial databases created e.g. to implement the provisions contained in the INSPIRE Directive.

The presented research has shown that due to the fact that the currently used systems are characterized by conformability of the ellipsoid surface, it is prefer-

able, in the case of transformations of flat rectangular coordinates in areas affected by underground mining exploitation, to use a solution based on conformal transformation using a complex polynomial. By simplifying the existing procedure.

Hence, the procedure for the implementation of the transformation task presented in the work ensures much smaller transformation errors and is recommended for use, especially in areas in which mining exploitation causes surface deformation.

The problem of the incompatibility of the coordinates of the boundary points of neighboring mines determined as a result of the research is the subject of further research carried out by the authors.

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