ANALYSIS OF DEFORMATIONS IN THE AUSTRIAN REFERENCE NETWORK

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Abstract: The Austrian federal reference network has a very long tradition. Due to historical measurement methods, instruments, network design and other influencing factors (e.g. difficult measurement conditions in mountainous regions), local and regional distortions mapped into the official reference network. These deformations can be regarded as local systematic effects, which cannot be captured by a 7-parameter similarity transformation covering the whole Austrian territory, not even by parameters valid for a single Austrian province. Nowadays, GNSS measurements allow for establishing homogeneous networks, even for larger regions. Thus, when performing e.g. GNSS RTK-measurements a major problem is the availability of optimal parameters to transform the ITRF coordinates into the local datum with remaining sufficiently small residual vectors.
Usually the parameter sets are determined by comparison of points, which are known in both systems. The ITRF coordinates used in this work were determined during the installation of several regional GNSS permanent station networks in Austria. The aim of the study is to set up an automated process for detecting groups of points with similar deformation behaviour of the national coordinates w.r.t. the ITRF. The resulting local deformation patterns can help to optimally fit the transformation parameters to local distortions or to overlay regional parameters with local polynomial corrections, compensating for the deformations of the official network. This procedure can lead to smaller horizontal residuals for the transformed points and substantially decrease the number of necessary parameter sets due to the optimally adapted compensation of the deformations.

1. INTRODUCTION

From 1998 onwards several regional reference GNSS networks became operational in Austria. About 50% of these service providers offer the ability to use both active satellite navigation systems, GPS and GLONASS. To enable the transformation from the realized ITRF (currently most providers tied their stations to ITRF2000, epoch 1997.0) to the national datum more or less dense grids of national reference points were selected and their ITRF coordinates have been determined with cm accuracy. The problems to derive optimal parameter sets are manifold:

- the transformation model has to match the models implemented in the rover hardware. This usually restricts us to a 7-parameter similarity transformation of type Bursa-Wolf.
- the remaining residual vectors should not exceed bounds which are critical for the user applications.
- the number of control points is limited due to availability and economic reasons.
- the boundaries of the area of validity for each set has to be clearly defined in nature (e.g. by means of a highway, a river, a national border,…) to avoid a misuse of sets. This problem can be solved by future RTCM standards (see section 5).

Thus, most of the Austrian regional GNSS service providers decided to establish parameter sets which allow for a regional mapping with horizontal residuals of less than 15 cm for 90% of the control points. These parameter sets are good for most applications and allow to establish a homogeneous coordinate system close to the national coordinate system. For cadastral purposes the tie by means of close local reference points is still required and asked for by the national surveying authority.

2. INITIAL TRANSFORMATIONS

For the current investigation we selected a subset of about 300 points of the Austrian federal reference network, situated in northern Austria, in the provinces Vienna, Lower and Upper Austria, Burgenland (see figure 1).

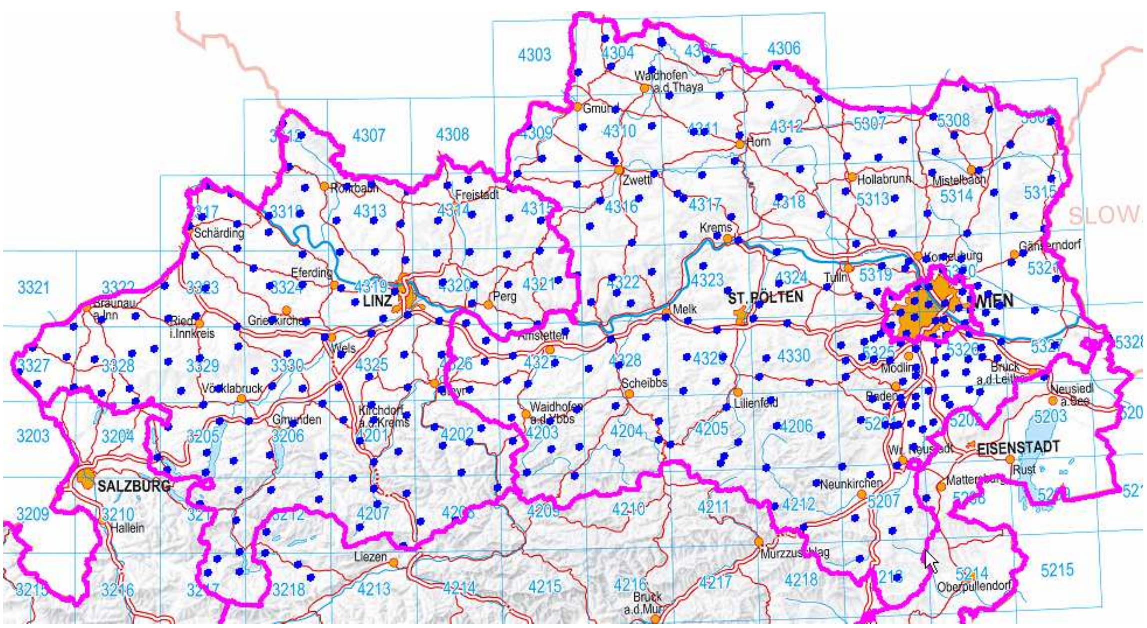

Figure 1 - Distribution of measured points in northern Austria.

To establish reasonable transformation parameters, usually the measurements of the whole region are split up to several areas with a common pattern of the residuals. For each of these areas, an extra set of transformation parameters is calculated. With this method, local trends in the Austrian federal reference network can be considered, resulting in locally better suitable transformation parameters, smaller residuals and a random distribution of the residuals.

The splitting of the control points to some smaller areas with a common pattern of movement is usually done manually, requiring many hours of expert work. To speed up this analysis and to optimize the identification of boundaries, an automated block detection for the areas with a similar pattern of movement was used in this study (see section 3).

In a first step we converted the national coordinates of all control points to a common local projection system (Gauss-Krüger coordinates, M34 system). The detection of block boundaries is based on the comparison of horizontal residual vectors after an initial transformation. For the calculation of this 7-parameter transformation between the ITRF and the local coordinate system the commercial software 'Leica GeoOffice' (LGO) was used. A closer look at the remaining horizontal residuals indicates rather large values of up to 70 cm (see table 1) and moreover a distribution far from a random distribution (see figure 2). The pattern of the residuals is obviously governed by the strong influence of the introduced common scale factor. To compensate for the systematic distortions this deviation field would ask for individual scale factors at least along both coordinate axes. Because the transformation model does not allow for individual scale factors on the one hand and our block detection algorithm does not correctly interpret such rotation fields on the other we repeated the transformation this time without scale factor (6-parameter-transformation). The resulting residuals are shown in table 2 and figure 3. Do due the missing significant parameter the residuals logically increase up to 1 meter but the remaining field can now be interpreted as a number of diverging piles of measurement points and therefore be used as input data for our block detection algorithm. We do not account for the vertical residuals at this stage but the height problem will be discussed in some detail in section 4.

	Residuals East [m]	Residuals North [m]	Residuals 2D position [m]
maximum	0. 6917	0.6604	0.7030
mean value	-	-	0.2629

Table 1 - Absolute residuals of the initial 7-parameter-transformation.

	Residuals East [m]	Residuals North [m]	Residuals 2D position [m]
maximum	1.0964	1.0103	1.1051
mean value	-	-	0.4328

Table 2 - Absolute residuals of the 6-parameter-transformation.

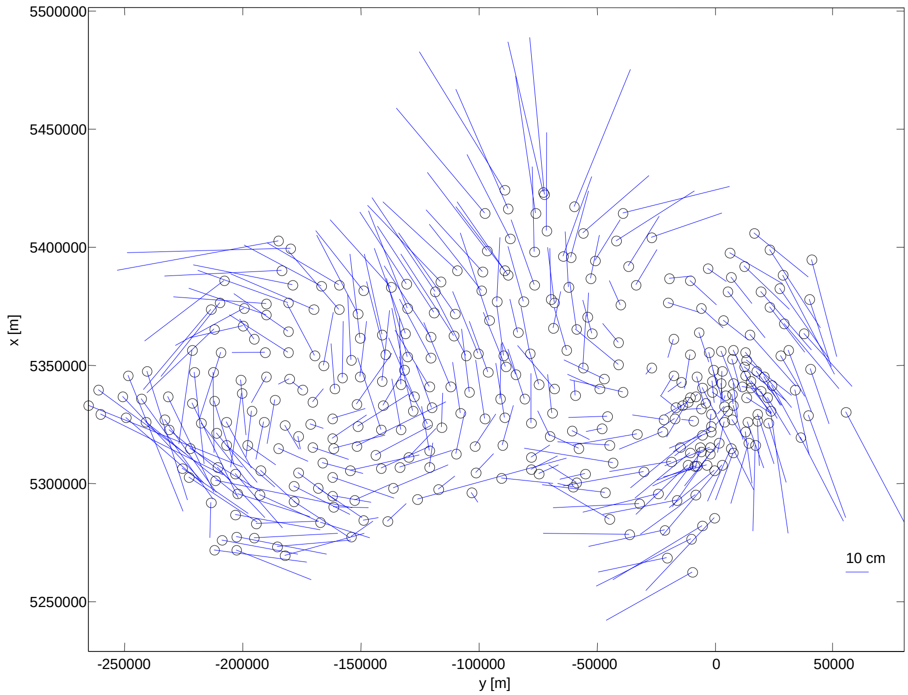

Figure 2 - Residuals of the first 7-parameter-transformation.

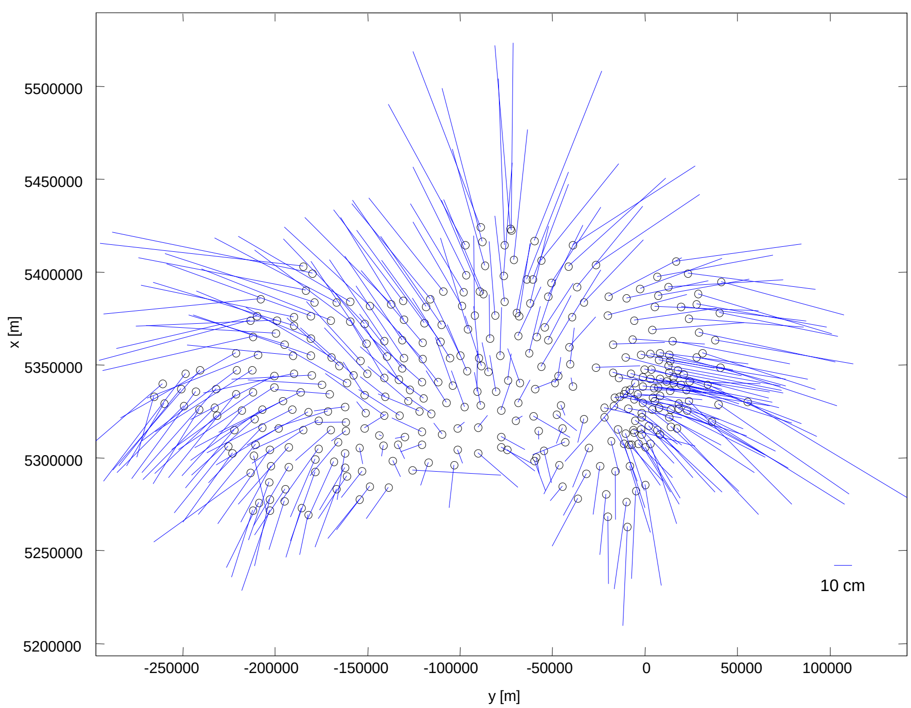

Figure 3 - Residuals of the second transformation without a common scale factor (6-parameter-transformation).

3. BLOCK DETECTION ALGORITHM

Looking at figure 3, some blocks with a clear common trend of the residuals can be identified. The block detection algorithm used for the analysis of the optimal block separation was implemented in Matlab®. Initially, the algorithm was developed for landslide area applications, e.g. detecting areas with homogenous movement direction and velocity. To reach a high level of reliability in the block separation process, strain analysis parameters and indicators like direction and length of the displacement vectors are used. These different types of information were fed into a fuzzy system, imitating the human way of interpreting figures showing a great number of displacement vectors.

The block detection algorithm was applied to several regional landslide areas as well as to a global application (plate tectonics). Details can be found e.g. in Haberler (2005) or Haberler-Weber (2005).

4. RESULTS

The analysis of the data shown in figure 3 with the block detection algorithm described in section 3 results in the following blocks (see figure 4 and table 3):

	Nr. of points	Colour in fig. 3
Block 1	74	Blue
Block 2 – west	67	Red
Block 3	63	Green
Block 4	59	Magenta
Block 5	22	Cyan
Block 6	4	Orange
Block 7	5	Blue dotted
Block 8	5	Green dotted

Table 3 - Order and number of points within the detected blocks (see figure 3).

In a first step, the points shown in blue are grouped to one common block. The second block is formed by the points shown in red. When looking at figure 4, the red block seems to be split up in an eastern and a western part. This effect is based on the Delaunay triangulation, which is used to build a model of neighbourhood properties. The Delaunay triangulation computes a convex hull for the given point cloud, so the eastern and western point at the lower part of this point cloud are fully connected regarding neighbourhood. For the real life application of calculating transformation parameters this property does not make sense, so in the following investigations only the western part of the red block is used with 67 points instead of 86 points all together.

Blocks 3, 4 and 5 are detected in the next steps. Blocks 6, 7 and 8 are small blocks consisting of 4 resp. 5 points each. The practical calculation of transformation parameters for these small blocks is not useful, so they are also neglected during the following analysis.

The vectors shown in black in figure 4 represent the points remaining after the block detection analysis. These 10 points can be regarded as outliers, which should not be used for the calculation of optimal transformation parameters, because their residuals do not match with any of the neighbouring blocks. Thus, the outlier points are also neglected in the following calculations.

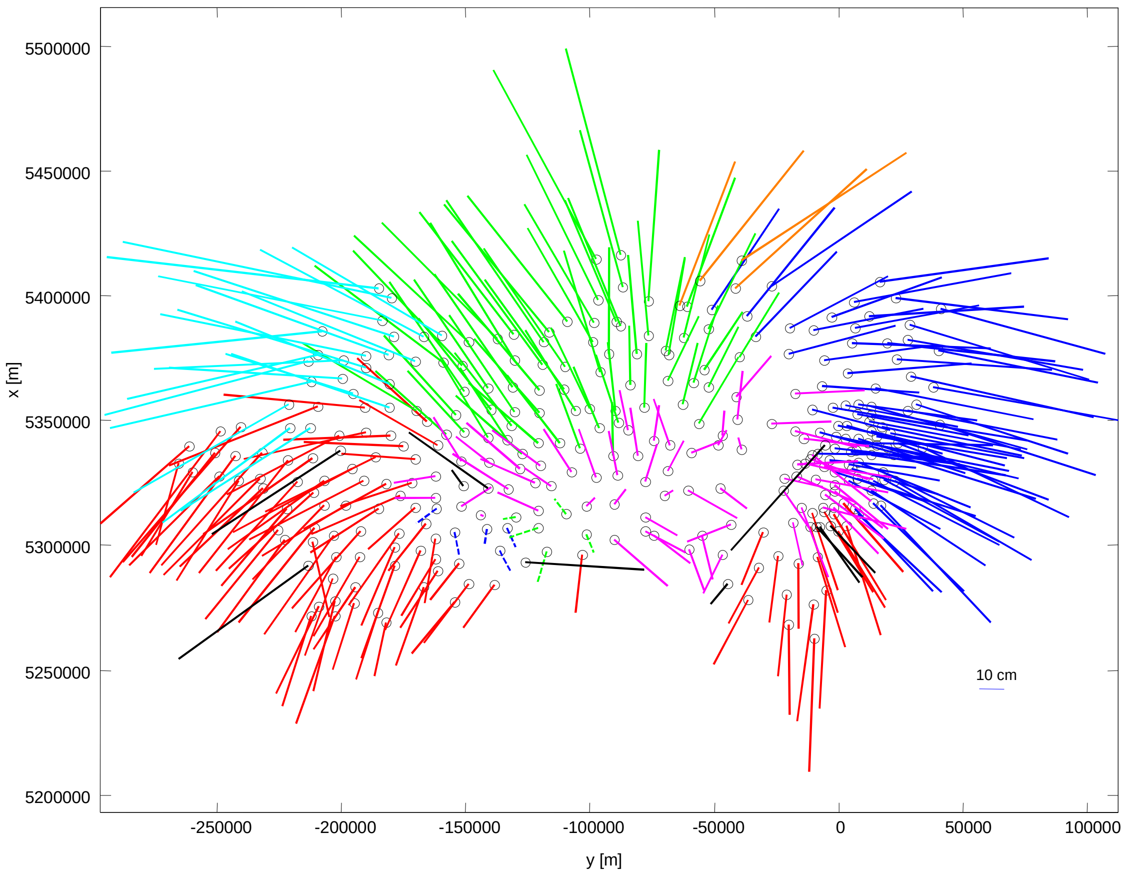

Figure 4 - Detected blocks in blue, red, green, magenta, cyan, orange, blue dotted, green dotted. Remaining outliers shown in black.

After this block detection, the calculation of transformation parameters between the ITRF and the local coordinate system was repeated for each of the detected blocks 1 to 5. In table 4 the remaining maximum horizontal residuals (root of the squared east plus north components) as well as the standard deviations of the 3D-transformation process for the five blocks are listed. Figure 5 shows one example for the 2D-residuals after the transformation (Block 2-west). As requested, the residuals show a random pattern. This implicates optimal transformation parameters for this area.

	Block 1	Block 2-west	Block 3	Block 4	Block 5
maximum residuals [m]	0. 2317	0.3449	0. 2812	0.3041	0.1687
std. dev. 3D-Tr. [m]	0.1013	0.0988	0.2186	0.3055	0.0796

Table 4 - Horizontal residuals for the 5 blocks after the separated transformation calculation.

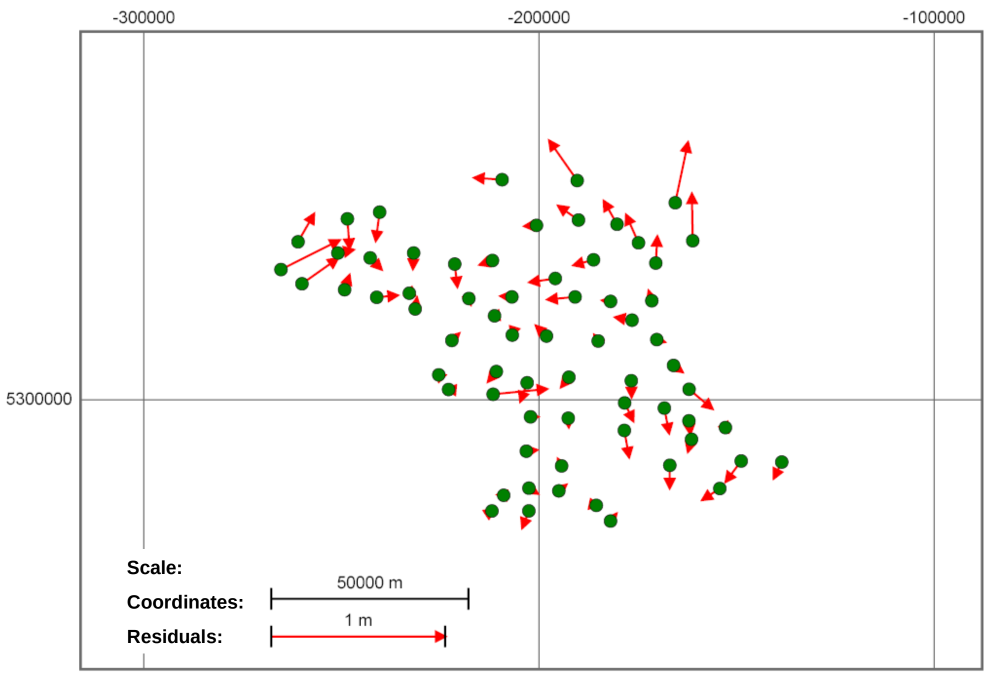

Figure 5 - One example for the 2D-residuals (block 2-west).

Inspecting the standard deviations of the five transformations, blocks 3 and 4 show larger values than the other blocks. The reason is that these numbers refer to the spatial transformation between geometrically defined ITRF coordinates and partly physically defined national coordinates. The Austrian national heights are of type orthometric and therefore strictly speaking a geoid separation model, if available, has to be taken into account in advance. On the other hand for the block detection, only the 2D residuals were used because they are almost not effected by introducing geoid separations.

For the majority of about 300 points used in this analysis, geoid undulations were calculated for the points in the western part (mainly Upper Austria) due to the varying topography. For the eastern flat parts of Austria (Vienna, Burgenland, parts of Lower Austria), the geoid separation behaves quite smooth. Separations are therefore not absolutely necessary to be accounted for to obtain reasonable results of the transformation to the national frame, even for the height. So, for these eastern parts, no geoid undulations were available.

The 3D standard deviation (given in first column of table 5) is derived by the square sum of the weighted residuals, known as [pvv] or $v^T pv$. An analysis of the square sums (separated to easting, northing and height components) shows that e.g. for the blocks in the western part of the area (blocks 2 and 5), the effects on the standard deviation of 2D-position and height are almost the same (about 35 %, see table 5, grey values). Here, geoid undulations were available for all points within the blocks.

Block 1 is situated in the eastern part of the point cloud, with no geoid undulations available. Here, the effects of the height component on the standard deviation are clearly visible (69%). But the worst scenario is given for blocks 3 and 4. Here the 3D standard deviation is much higher compared to the other blocks. A closer look at the residuals shows that in both cases, the height component is responsible for the large standard deviations (89 and 94%, shown in yellow in table 5). These two blocks are situated in rough topography, but unfortunately geoid separations were available only for a subset of points. So, this example clearly shows that a mixed use of geoid separations is not recommended to establish transformation parameters which deliver reasonable national heights but it does not really harm the horizontal mapping to the national datum.

	3D std. dev. [m]	% [pvv] east	% [pvv] north	% [pvv] height	2D std. dev. [m]	Undulations available?
Block 1	0.1013	12	19	69	0.0694	No
Block 2 – west	0.0988	28	35	37	0.0970	Yes
Block 3	0.2186	7	4	89	0.0885	Mixed
Block 4	0.3055	4	2	94	0.0951	Mixed
Block 5	0.0796	28	34	38	0.0791	Yes

Table 5 - Analysis of the standard deviations and contribution of east-, north- and height-components on the results in percent.

Our example demonstrates that the investigated area might by divided in about 6 zones if the targeted limit for horizontal residuals is 20-25 cm. This division could be viewed as an optimal first guess. Obviously a further division will result in smaller residuals but the gain rapidly decreases while the number of parameter sets increases. In reality the various service providers offer currently not less than 21 Helmert-parameter sets with maximum residuals of 15 cm to cover the mentioned area.

5. CONCLUSIONS

The presented approach allows for an automated determination of groups of control points affected by a similar systematic displacement pattern. This information might be used to establish so-called optimal individual parameter sets which absorb local and regional systematic distortions (as far as possible by means of the spatial similarity transformation) and therefore deliver minimum and randomly distributed residual vectors. Unfortunately the boundaries limiting the area of validity of the parameter sets usually does not correspond with any physically defined nature boundaries to be easily identified by the rover operator in field. But this drawback can be covered by future revised versions of the RTCM 3 standard which will allow for delivering both the transformation parameters as well as a geoid model to the user. These transformation messages are designed for the use in VRS networks. The advantage of this method is that the geoid and transformation models are centrally administrated and the same models (and therefore implicitly the area boundaries) are available to every user in the field. The disadvantage is that bidirectional communication is required to use these messages effectively.

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