Getting homogeneous ETRS89 Coordinates

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Landesbetrieb Geoinformation und Vermessung
In 2001 → starting the project:
Transforming large cadastre point fields
– referencing different local frames
(Gauß-Krüger / partly Solder) –
into a unique reference frame
(ETRS89 with UTM projection)
Introduction (2)

- Decision for an interconnected transformation approach of local systems
- Choosing the adjustment program **Systra** of technet GmbH for calculation
- Combination with an integrated GPS campaign
- Getting homogeneous and precise coordinates
ETRS89 (1)

ETRS89 = European Terrestrial Reference System 1989

ETRS89 ( = Cartesian geocentric 3D coordinate system) realised by the European Terrestrial Reference Frame (ETRF) and represented by DREF91/SAPOS.
ETRS89 (2)

<table>
<thead>
<tr>
<th>System (GCS)</th>
<th>ellipsoid</th>
<th>projection</th>
<th>PCS</th>
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<td>Bessel 1841</td>
<td>Transversal Mercator</td>
<td>GK</td>
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<tr>
<td>ETRF89</td>
<td>GRS80</td>
<td>Transversal Mercator</td>
<td>UTM</td>
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</table>

„Geographic coordinate system“ (Reference Frame)

„Projected coordinate system“
ETRS89 (3)

- **ETRS89** = GPS coordinate system standard used for high-quality GPS surveys throughout Europe
- Fixed to the stable part of the Eurasian continental plate
- Used for georeferencing of GIS and geokinematic tasks
- Realized by different GPS measurement campaigns, world-wide
- Adjustment of the data of the European measurement stations in 1989
- Fixing these coordinates
- Densification of measurement stations by European and German countries → EUREF, DREF, HHREF (in Hamburg: 4 SAPOS reference stations)
SAPOS (1)

► SAPOS = SAtellite POSitioning Service of the German National Survey

► SAPOS → Setting up a permanently operated multifunctional Differential GPS service

► 4 SAPOS – Services (EPS, HEPS, GPPS, GHPS)

► SAPOS HEPS → High-Precision Positioning Service

► Producing ETRS89-coordinates with the accuracy in the range of few centimeters
In Hamburg:

4 reference stations (→ realising ETRS89 in HH, permanent maintenance, 112 points for saving the network)

Transmitting of correction terms

Connection of neighbour states

Available in the metropolitan area of Hamburg

www.sapos.de
Central station
Reference stations 1-4
SAPOS (4)

Saving the network:
112 points (RS, TP, RF & UF)
After 3 years → repeating the measurement!
SAPOS (5)

Regional networking
SAPOS (6)

- High-precise GPS surveys in real-time
  → Differential GPS (DGPS)

- Increasing of positional accuracy by making differences
  (Comparison of target and actual results) → Use of reference stations

- Transmitting of DGPS correction terms (format RTCM) for users by 2 transmitter stations → 2m-band GSM (SAPOS®) → mobile phone

  → Accuracy in the range of few centimeters in real-time!
Why ETRS89 in Hamburg?

- Unification and homogenisation of all geodata resources for an overall use
- Efficient use of satellite-based measurement techniques (no "back-transformations")
- Durable availability of the reference system (without marked points) – extensive economies for maintenance
- Resolution of the Arbeitsgemeinschaft der Vermessungsverwaltungen der Länder der Bundesrepublik Deutschland (AdV)

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Basic Conditions (2)

► Why ETRS89 in Hamburg?

► Resolution of the AdV in 1991:

► …European integration

► …introduction of an uniform, pan-European …reference system

► …also for geodetic survey and cadastral surveying…

► …providing and processing of spatial data all over …the European countries

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Objective:
Transfer large cadastre point fields referencing different local frames into a unique reference frame → ETRS89 with UTM projection

LS = status of location

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Basic Conditions (4)

- **Different local frames:**

- **Hamburg (old):** Origin → Bowl of the Church Michael („Soldner“)  
  LS 220 (status of location = 220)

- **Hamburg (new):** Origin → Bowl of the Church Michael („Soldner“)  
  (after reconstruction of the tower)  
  LS 210 (status of location = 210)

- **DHDN, „Potsdam Datum“,**  
  Ellipsoid Bessel, central point Rauenberg  
  LS 100 (status of location = 100)

**Characteristics:**

- Inhomogeneities
- Multiple storage
- Principle of neighbourhood
- Connection between the cadastre point field and the conventional higher-order point field

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Basic Conditions (5)

Special feature in Hamburg:

► In the cadastre point field only the transferred coordinates in the locality represent the course of boundary (of land parcels)!

► Boundary marks are not mandatory!
Basic Conditions (6)

Point of departure:

Local „Hamburg“ frames
¼ of the coordinated points

20 % of the area of Hamburg →
without coordinated points!

Frame DHDN, „Potsdam Datum“ (G-K-projection)
¾ of the coordinated points

Cadastre point field ... approx. 1 million points
Basic Conditions (7)

Cadastre point field Hamburg-Nord

LS 100 status of location (DHDN, G-K-projection) approx. 42,000 points
Basic Conditions (8)

Cadastre point field Hamburg-Nord

LS 210 status of location
(New Hamburg coordinates)
approx. 76,000 points
Basic Conditions (9)

Cadastre point field Hamburg-Nord

LS 220 status of location
(Old Hamburg coordinates)
approx. 8,400 points
Basic Conditions (10)

Requirements

- Transfer the conventional higher-order point field into ETRS89
- Possibility to work also with conventional terrestrial procedures of measurement in ETRS89
- Break-up of the conventional higher-order point field (continuous process over a long period)
- Realisation with maintainable financial strain
- Free choice about the time for using satellite-based techniques of measurement
Approach (1)

▶ Grouping blocks of local systems

▶ Why?

– Big number of points → approx. 1 million points !!! (cadastre point field)
– Introduction of ETRS 89 step-by-step / district-wise
– Working parallel
– Discontinuities of the cadastre point field, e.g. along railways, watercourses or administrative boundaries (proximity fitting cross lines of discontinuity → falsification of results !)
Approach (2)

7 blocks of local systems $\cong$ 7 districts of Hamburg

One block can contain up to 200,000 points!
Approach (3)

Fixing block boundaries

– Block boundaries are stable and independent of the internal area of the block

– After fixing all the block boundaries → unique blocks are transformed separately

– No later change of border area necessary when merging the blocks
Approach (4)

Fixing block boundaries

- Block A
- Block B
- Unknotted block boundary
- Knotted block boundary
Fixing block boundaries (principle)

- Determination of identical points (with GPS measurements) along the district boundaries
- Calculation of boundary points of the district boundary
- Boundary points become identical points to transform cadastre point fields inside the districts

Identical points

Boundary points

Overlapping area

District 1

District 2

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Determination of identical points (aided by GPS measurements)

Important for a high-quality:

1) ...accuracy of the identical points
2) ...how good can identical points represent the systematic distortions of the cadastre point field

Density of identical points depends on the quality of the existing cadastre point field

Immense distortions ➔ many identical points !!!
Approach (7)

- **Determination of identical points (principles)**

- **Points of the conventional higher-order (control) point field must…**
  1) have a direct neighbourhood relationship to the cadastre point field!
  2) have a clear identity!
  3) allow GPS measurements!

- **Checked points of the cadastre point field must…**
  allow GPS measurements!
Approach (8)

Determination of identical points of the conventional higher-order (control) point field by measurement:

- **Category I**
  - free stationing inside a group of points
  - forced centering
    GPS measurements with SA POS and RTK

- **Category II**
  - centric / excentric on a higher-order survey point
    GPS measurements with SA POS and RTK

Area of connection points
Approach (9)

District Hamburg-Nord

480 measured identical points
(conventional higher-order points)

280 measured control points
(boundary points)

Using of RTK-equipment
(Real-Time-Kinematic) GPS surveying
Transformation by using the adjustment program SYSTRA of technet GmbH

Principle:

- Interconnected transformation of local frames with following
- Proximity fitting as adjustment problem
- According to least squares adjustment
Process of transformation

2-dimensional-transformation is sufficient:
- limited area extension
- coordinates of the cadastre point field are 2-dimensional

Fixing the system borderlines and features (stochastic model, type of transformation, points for interconnecting the systems, e.g. HH-coordinates and GK-coordinates)

Adjustment of the first type: Calculation of the approximated coordinates

Adjustment of the second type: Strict Adjustment

Adjustment of the third type: Proximity Fitting
Approach (12)

Process of transformation

Adjustment of the first type:

- Calculation of the approximated coordinates for non-linear observations (junction points)

- Detection of outliers (confusion of points, configuration defects)
Approach (13)

Process of transformation

Adjustment of the second type:

- Strict adjustment

- Estimation of the unknown parameters via functional and stochastic model according to the method of least squares adjustment

- Adjusted coordinates of the new points; sets of parameters
Approach (14)

Process of transformation

Adjustment of the third type:

- Neighbourhood relationships via meshes of triangles according to Delauney

- Transfer remnant discrepancies of the identical points to the new points
Approach (15)

* Meshing of triangles
* cadastral district Uhlenhorst
* approx. 5000 points
Approach (16)

* Interpolation of remnant discrepancies
* cadastral district Farmsen
Basic approach for „transformation Hamburg“

Transformation of the state and district boundaries
  - Fixed boundaries in ETRS89
  - Getting a skeleton

7 further transformations (districts)
  - Every district with many local systems and all border points as identical points
  - Like a total adjustment
Execution of control measurements

Consistency between measured and adjusted coordinates of boundary points…?
Approach (19)

Analysis of control measurements → Verifying the reproduction accuracy estimated by the adjustment
Virtual identical points (1)

► **Virtual identical points:**

► "Relict" of district-wise transformation (adjustment)

► Via transformation from LS 100 into LS 310 or LS 320

► Arranged in a regular grid (point distance: 250 m)

► Number of virtual identical points: approx. 26,000

► High density of identical points → true neighbourhood transfer

► Accuracy of transformation → in the range of the absolute reproducibility of the conventional higher-order point field and the connected boundary points

► **Data delivery on CD:** with district-wise introduction of ETRS89

► **Price:** 1.400 €

Landesbetrieb Geoinformation und Vermessung
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<thead>
<tr>
<th>Punktnummer</th>
<th>Punktname</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
<th>ASCII-Datei mit virtual identical points (in extracts)</th>
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</table>

ASCII file with virtual identical points (in extracts)
Virtual identical points (3)

- **Applications:**
  - Georeferencing of
    - GIS projects
    - CAD applications
    - digital maps
    - measuring points

- Clear assignment of identical points to data resources
- Repeatability of transformation in both transformation directions!
Virtual identical points (4)

Virtual identical points in the district Hamburg-Nord
Virtual identical points (5)

Example: Transformation of a CAD drawing
Virtual identical points (6)

Example:
Coordinate differences between transformed points via measured identical points and transformed points via virtual identical points

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</table>

Extract (ds \rightarrow \text{descending sorted}) :
\[
d_{\text{max}} = 5,4 \text{ cm (maximum point offset)}
\]
\[
\text{deviation} \equiv 0,003 \text{ m (by approx. 100.000 points)}
\]
## Economic aspects (1)

### Cost calculation

<table>
<thead>
<tr>
<th>Georeferencing with higher-order (control) point field</th>
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<tbody>
<tr>
<td>2.5 Mio € per year 10 years</td>
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<tr>
<td>Maintenance of the conventional higher-order point field</td>
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<tr>
<td>2.0 Mio € per year 5 years</td>
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<tr>
<td>Investment for complete upgrading the conventional higher-order point field</td>
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<tr>
<td>0.2 Mio € per year 10 years</td>
</tr>
<tr>
<td>Gains by data delivery</td>
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</table>

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## Economic aspects (2)

### Cost calculation

#### Georeferencing without higher-order (control) point field

<table>
<thead>
<tr>
<th>Cost</th>
<th>Duration</th>
<th>Description</th>
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<tbody>
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<td>0.4 Mio € per year</td>
<td>10 years</td>
<td>Maintenance of the reference stations</td>
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<td>0.1 Mio € per year</td>
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<td>Maintenance and saving the network</td>
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<td>0.6 Mio € per year</td>
<td>3 years</td>
<td>Investment for SAPOS + saving the network</td>
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<td>1.4 Mio € per year</td>
<td>5 years</td>
<td>Investment for change-over the official information of boundary determination</td>
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<tr>
<td>0.2 Mio € per year</td>
<td>10 years</td>
<td>Gains by data delivery</td>
</tr>
</tbody>
</table>

Landesbetrieb Geoinformation und Vermessung
Transforming cadastre point fields - referencing different local systems - into ETRS89

- **Hamburg-Nord**
  - July 2003: 117,168 points

- **Eimsbüttel**
  - October 2004: 102,725 points

- **Wandsbek**
  - December 2003: 227,462 points

- **Altona**
  - March 2005: 118,302 points

- **Hamburg-Mitte**
  - June 2004: 110,357 points

- **Bergedorf**
  - Midyear 2006: approx. 150,000 points

- **Harburg**
  - Year-end 2005: approx. 150,000 points

- **Wilhelmsburger Insel**
  - March 2003: 32,204 points
Experiences, Problems, Look-out

► Accuracy of the transformation < ± 2 cm!
  (average standard deviation over all calculated points)

► Neighbourhood relationships are not necessary anymore!

► Data management is very extensive!

► Exact fixing of system boundaries and connected points!

► In transformed areas → No conventional higher-order (control) point field is necessary!

► Transformed areas are homogeneous!

► Areas with bigger problems (Areas with Inhomogenities in old data) factoring out, later!
  (surrounding area = identical points)

► Geologic, tectonic changes!
  (selected points; actual-required-determination)

Landesbetrieb Geoinformation und Vermessung
Many thanks for your attention!