Semantically Correct 2.5D GIS Data – the Integration of a DTM and Topographic Vector Data

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ABSTRACT:

This paper presents an approach for a semantically correct integration of a 2.5D digital terrain model (DTM) and a 2D topographic GIS data set. The algorithm is based on a constrained Delaunay triangulation. The polygons of the topographic objects are first integrated without considering the semantics of the object. Then, those objects which contain implicit height information are dealt with. Object representations are formulated, the object semantics are considered within an optimization process using equality and inequality constraints. First results are presented using simulated and real data.

1. INTRODUCTION

1.1. Motivation

The most commonly used topographic vector data, the core data of a geographic information system (GIS), are currently two-dimensional. The topography is modelled by different objects which are represented by single points, lines and areas with additional attributes containing information on function and dimension of the object. In contrast, a digital terrain model (DTM) in most cases is a 2.5D representation of the earth's surface. By integrating these data sets the dimension of the topographic objects is augmented, however, inconsistencies between the data may cause a semantically incorrect result of the integration process.

Inconsistencies may be caused by different object modelling and different surveying and production methods. For instance, vector data sets often contain roads modelled as lines or polylines. The attributes contain information on road width, road type etc. If the road is located on a slope, the corresponding part of the DTM often is not modelled correctly. When integrating these data sets, the slope perpendicular to the driving direction is identical to the slope of the DTM which does not correspond to the real slope of the road. Additionally, data are often produced independently. The DTM may be generated by using lidar or aerial photogrammetry. Topographic vector data may be based on digitized topographic maps or orthophotos. These different methods may cause inconsistencies, too. A semantically correct integration leads to consistent data.

By considering the semantics of the objects it is also possible to verify the DTM. In many cases, topographic vector data are almost up-to-date because objects like roads and railways possess major priority in GIS. A DTM, however, may be more than ten years old. It is true that height changes appear less frequently than changes in the horizontal position of objects. Nevertheless, integration of both data sets considering the semantics of objects will show discrepancies, and will allow to draw conclusions on the quality of the DTM.

1.2. Related work

The integration of a DTM and 2D GIS data is an issue that has been tackled for more than ten years. Weibel (1993), Fritsch & Pfannenstein (1992) and Fritsch (1991) establish different forms of DTM integration: In case of *height attributing* each point of the 2D GIS data set contains an attribute "point height". By using *interfaces* it is possible to interact between the DTM program and the GIS system. Either the two systems are independent or DTM methods are introduced into the user interface of the GIS. The total integration or full database integration comprises a common data management within a data base. The terrain data often is stored in the data base in form of a triangular irregular network (TIN) whose vertices contain X,Y and Z coordinates. The DTM is not merged with the data of the GIS. The merging process, i.e. the introduction of the 2D geometry into the TIN, has been investigated later by several authors (Lenk 2001; Klötzer 1997; Pilouk 1996). The approaches differ in the sequence of introducing the 2D geometry, the amount of change of the terrain morphology and the number of vertices after the integration process. Among others, Lenk and Klötzer argue that the shape of the integrated TIN should be identical to the shape of the initial DTM TIN. Lenk developed an approach for the incremental insertion of object points and their connections into the initial DTM TIN. The sequence of insertion is object point, object line, object point etc. The intersection points between the object line and the TIN edges (Steiner points) are considered as new points of the integrated data set. Klötzer, on the other hand, first introduces all object points, then carries out a new preliminary triangulation. Subsequently, he introduces the object lines, determines the Steiner points, adds both to the data set. Since the Delaunay criterion is re-established in the preliminary triangulation, the shape of the integrated TIN may deviate somewhat from the one of the initial DTM. The methods have in common, that inconsistencies between the data are neglected and thus may lead to semantically incorrect results.

Rousseaux & Bonin (2003) focus on the integration of 2D linear data such as roads, dikes and embankments. The linear objects are transformed into 2.5D surfaces by using attributes of the GIS data base and the height information of the DTM. Slopes and regularization constraints are used to check semantic correctness of the objects. However, in case of incorrect results the correctness is not established. A new DTM is computed using the original DTM heights and the 2.5D objects of the GIS data.

Using a common algorithm as those of Lenk (2001) and Klötzer (1997) may lead to a semantically incorrect integrated data set. We not only check constraints which are derived from the semantics of the objects as Rousseaux & Bonin (2003) but the heights of the integrated data set are changed to fulfill predefined constraints. Such approach is comparable to the homogenization of different data sets. Hettwer (2003) and Scholz (1992) have investigated the homogenization of 2D cartographic data which possibly stem from different data sources and refer to different coordinate systems. As well as we do they use a least squares adjustment: coordinates are introduced as direct observations and regularization constraints are formulated as pseudo observations. However, the investigations are restricted to 2D data and no inequation constraints are introduced.

2. SEMANTIC CORRECTNESS

2.1. Consequences of non-semantic integration

A digital terrain model (DTM) is composed of points with its coordinates X,Y,Z and an interpolation function to derive Z values at arbitrary positions X,Y. Mostly the DTM is a 2.5D representation of the topography, i.e. bridges, vertical walls and hang overs are not modelled correctly. Against this, the topographic vector data we consider are two-dimensional. The topography is modelled by different objects which are represented by single points, lines and areas.

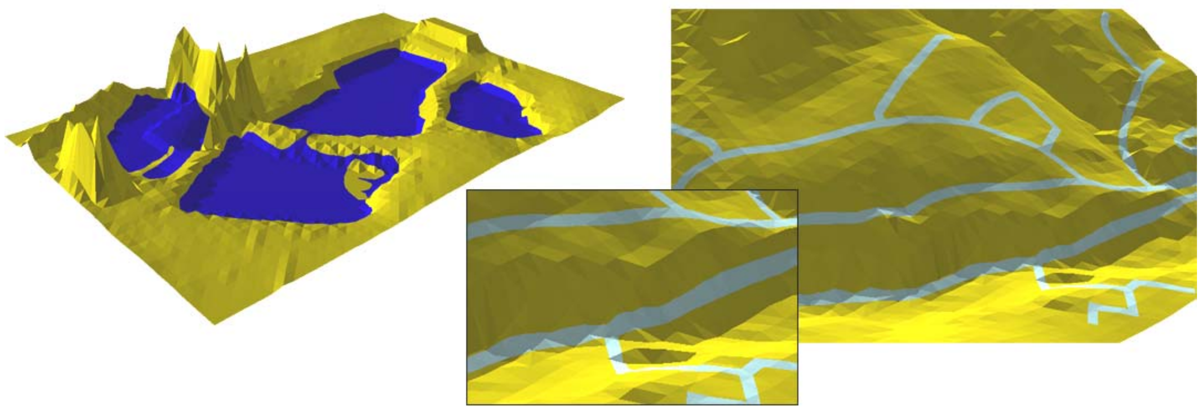

Figure 1: The integration of a DTM and 2D topographic vector data without considering the semantics of the objects; left: lakes, right: road network, exaggerated terrain

Figure 1 shows two examples of an integration of a DTM and 2D topographic vector data without considering the semantics of the topographic objects lake and road. The integrated data set is represented by an irregular triangular network (TIN).
The height values of the lakes do not show a constant height level. Several heights of the lakes near the bank are higher than the mean lake height. At the right side of figure 1 the roads are not correctly modelled in the corresponding part of the DTM. The slopes of the cross sections are identical to the mean slope of the hills. There are no breaklines at the left and right borders of the roads. Also, neighbouring triangles of the DTM TIN show extremly different orientations.

2.2. Correct integration

If we have a look at the topography and divide the topography into different topographic objects (road, river, lake, building, etc.), like the data of a GIS, there are several objects which have a direct relation to the third dimension. These objects contain implicit height information. For example, a lake can be described as a horizontal plane with increasing terrain at the bank outside the lake. Even if we do not know the real lake height, we have an idea of the representation of a lake in relation to the neighbouring terrain. To give another example, roads are usually non-horizontal objects. We certainly do not know the mathematical function representing the road height, but we know from experience and from road construction manuals that roads do not exceed maximum slope and curvature values in road direction. Also, the slope perpendicular to the driving direction is limited.

Object	**Representation**
Sports field Race track Runway Dock Canal Lake, pool	Horizontal plane
Road Path Railway, tramway River	Tilted subplanes
Bridge Undercrossing, crossover	Height relation

Table 1: Some topographic objects and their representation in the corresponding part of the terrain

Of course, all other objects are related to the third dimension, too. But it is difficult and often impossible to define general characteristics of their three-dimensional shape. For example, an agricultural field can be very hilly. But it is not possible in general to define maximum slope and curvature values because these values vary from area to area.

The objects containing implicit height information which need to be used for the semantically correct integration can be divided into three different classes (see Table 1). The first class contains objects which can be represented by a horizontal plane. The second class describes objects which can be composed of several tilted planes. The extent of the planes depends on the curvature of the terrain; the planes should be able to adequately approximate the corresponding part of the original DTM. The last class shown in Table 1 describes objects which have a height relation to other objects. Bridges, undercrossings and crossovers may contain a certain height relation to the terrain or water above or beneath.

To integrate a DTM and a 2D topographic GIS data set in a semantically correct sense, the implicit height information of the mentioned topographic objects has to be considered. That means, after the integration the integrated data set must be consistent with our view of the topography. E.g. all height values of points of the bounding polygon of a lake and all heights situated inside the bounding polygon must have the same height level. The DTM points at the bank outside the lake must be higher than the lake height. In case of roads, the slope and curvature values in road direction should not exceed maximum values, the slope across the road must be nearly zero. This means, that points of a road cross section should have nearly the same height value.

3. AN ALGORITHM FOR THE SEMANTICALLY CORRECT INTEGRATION

The aim of the integration is a consistent data set with respect to the underlying data model which needs to take care of the semantics of the topographic objects.
Topographic objects which are modelled by lines but which have a certain width, are first buffered. The buffer width is taken from the attribute "width" if available, otherwise a default value is used. Thus, the lines are transformed into elongated areas, the borders of which are further considered. The next step of the algorithm is an integration of the data sets without considering the semantics of the topographic objects. It is based on a constrained Delaunay triangulation (Lee & Lin, 1986) using all points of the DTM (mass points and structure elements) and the points of the topographic objects of the 2D GIS data (section 3.1). The linear structure elements from the DTM and the object borders are introduced as edges of the triangulation, the result is an irregular triangular network (TIN) – an integrated DTM TIN.
Then, certain constraints are formulated and are taken care of in an optimization process (section 3.2). In this way, the topographic objects of the integrated data set are made to fulfill predefined conditions related to their semantics. The constraints are expressed in terms of mathematical equations and inequations. The algorithm results in improved height values and in a semantically correct integrated 2.5D topographic data set.
A basic assumption of our approach is that the general terrain morphology as reflected in the DTM is correct and has to be preserved also in the neighbourhood of objects carrying implicit height information. Therefore, any changes must be as small as possible. A second assumption is that inconsistencies between DTM and topographic object stem from inaccurate DTM heights and not from planimetric errors of the topographic objects.

3.1. Non-semantic data integration

There are several approaches for the integration of a DTM and 2D topographic GIS data based on a triangulation. Among others, Lenk (2001) and Klötzer (1997) argue that the shape of the integrated TIN should be identical to the shape of the initial DTM TIN. Lenk developed an approach for the incremental insertion of object points and their connections into the initial DTM TIN. The sequence of insertion is object point, object line, object point, etc.: after having inserted the first object point Lenk introduces the object line between this point and the following one. The intersection points between the object line and the TIN edges are considered as new points of the integrated data set (Steiner points). Subsequently, Lenk inserts the next object point, and so on, until the data set is complete.
Klötzer, on the other hand, first introduces all object points, then carries out a new preliminary triangulation. Subsequently, he introduces the object lines, determines the Steiner points, adds both to the data set. Since the Delaunay criterion is re-established in the preliminary triangualtion, the shape of the integrated TIN may deviate somewhat from the one of the initial DTM.
The advantage of Lenk's approach compared to that of Klötzer is that the shape of the integrated TIN is identical to the shape of the initial DTM TIN. The disadvantage is that the approach results in a large amount of

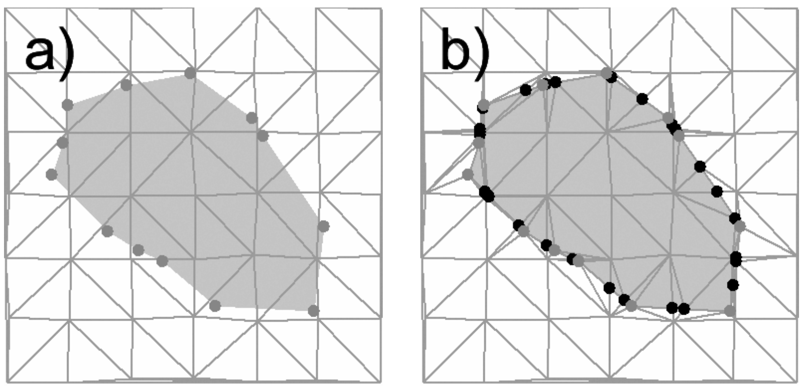

Figure 2: Integration of a DTM and a topographic object "lake", a) original DTM TIN and object "lake", b) integrated data set

Steiner points which lead to additional observation equations and/or inequation constraints (see section 3.2). Because computational aspects are not subject of this paper and because the height changes of the original heights have to be as small as possible the prementioned condition has to be fulfilled. Thus, we use a variant of Lenk's method. First, a DTM TIN is created using the mass points and the structure elements in a constrained Delaunay triangulation. Second, the heights for the topographic objects are derived using the height information of the TIN by interpolating a height value for each object point. Then, the points and their connections are inserted into the initial DTM TIN: After insertion of the first object point the connection between this point and the following one is inserted. This is done in such a way, that the intersection points between the object line and the edges of the DTM TIN are introduced as new points (Steiner points). The edges of the DTM TIN and the lines of the object polygon are splitted. Here, the Delaunay criterion may locally be not fulfilled.

Figure 2 shows an example of the integration of a DTM and an object "lake" of a 2D GIS data set. The original points of the bounding polygon of the lake are shown in grey. After the integration, the intersection points between the DTM TIN and the object polygon are new points of the integrated data set (coloured by black).

Another example is given in figure 3. A road is an object modelled by lines which is buffered using an attribute "road width" (figure 3a). First, the middle axis of the road (black line) is introduced using a constrained Delaunay triangulation. All intersection points between the middle axis and the DTM TIN are introduced as new points. This is done because every triangle has a different inclination and the middle axis should be best fitted to the terrain represented by the DTM TIN. The left and right side of the buffered road, which contain as much points as the middle axis, are then introduced using another constrained Delaunay triangulation (figure 3b).

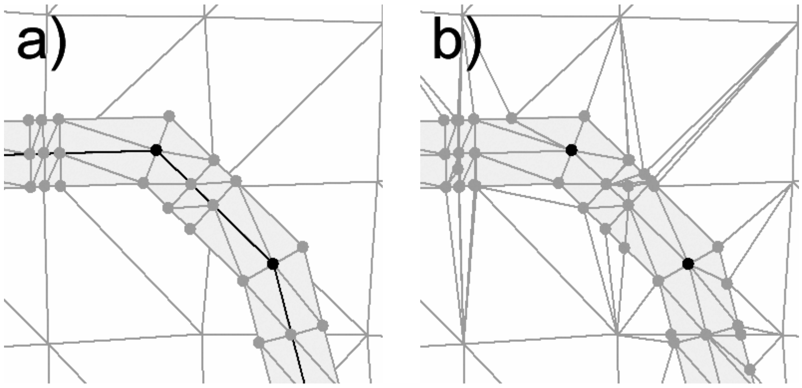

Figure 3: Integration of a DTM and a topographic object "road", a) original DTM TIN and object "road", b) intersection between DTM TIN and object, c) buffered object, d) integrated data set

3.2. Optimization process

As mentioned, there are topographic objects of the 2D GIS data which contain implicit height information. Within the integrated data set these objects have to fulfill certain constraints which can be expressed in terms of mathematical equations and inequations. To fulfill these constraints or to achieve semantic correctness, the heights of the DTM are changed. Up to now the horizontal coordinates of the polygons of the topographic objects are introduced as error-free.

The heights of the topographic objects are estimated within an optimization process which is based on a least squares adjustment; these values are the unknown parameters. The heights of the corresponding part of the DTM are introduced as direct observations for the unknown heights at the same planimetric position. Equality constraints are introduced using pseudo observations. Thus, a Gauss-Markov adjustment model is used and the adherence to the constraints is controlled via weights for the pseudo observations. Furthermore, inequality constraints are introduced. The optimization process is solved using the linear complementary problem (LCP) (Lawson & Hanson, 1995; Fritsch, 1985; Schaffrin, 1981).

3.2.1. Basic observation equations

The heights of the DTM which correspond to the topographic objects of the 2D GIS data are introduced as:

$$0+\hat{v}_i=\hat{Z}_i-Z_i \qquad \text{Equation 1}$$

The height Z_i refers to the original height of the DTM, the value $\hat{Z}_i$ denotes the unknown height which has to be estimated, $\hat{v}_i$ ist the residual of the observation i.

In order to be able to preserve the slope of an edge connecting two neighbouring points P_j and P_k of the DTM TIN (and thus to control the general shape of the integrated DTM TIN) additional equations are formulated. One of the two points is part of the polygon describing the object, the other one is a neighbouring point outside the object:

$$Z_j-Z_k+\hat{v}_{jk}=\hat{Z}_j-\hat{Z}_k \qquad \text{Equation 2}$$

3.2.2. Equality and inequality constraints

Each class of object representation (see table 1) has its own constraints which can be expressed in terms of mathematical equality and inequality constraints. These constraints will be derived in the following for each class of representation.

Horizontal plane

Heights of objects which represent a horizontal plane must be identical everywhere. This means, that points P_l with height Z_l and planimetric coordinates X_l, Y_l situated inside the object boundary (see Figure 4a, grey points) must all have the same value $\hat{Z}_{HP}$ which has to be estimated in the optimization process. These height values lead to the following observation equation:

$$0+\hat{v}_l=\hat{Z}_{HP}-Z_l \qquad \text{Equation 3}$$

The points of the bounding polygon of the topographic objects do not contain any height information, i.e. the heights have to be derived from the DTM. We use the mean height value of all points inside the object. Again, the height difference between the unknown object height and the calculated or measured original height is used to formulate an additional pseudo observation (see figure 4a, black points):

$$0+\hat{v}_m=\hat{Z}_{HP}-Z_m\left(Z_1,Z_2,...,Z_n\right) \qquad \text{Equation 4}$$

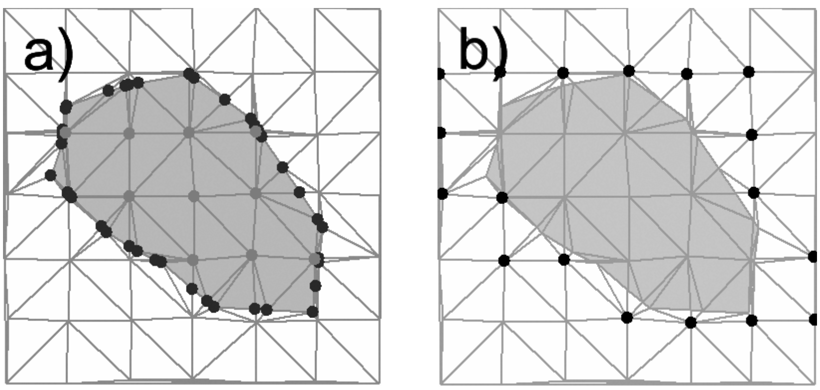

Figure 4: Equality and inequality constraints of a horizontal plane, topographic object “lake“, a) points inside the lake and points of the waterline, b) points of the neighbouring terrain

The neighbouring terrain of the horizontal plane is considered using the basic observations 1 and 2 (see 3.2.1). If the object represents a lake it is necessary to use a further constraint which represents the relation between the lake in terms of a horizontal plane and the bank of the lake whose height values $\hat{Z}_i$ have to be higher than the height level of the lake $\hat{Z}_{HP}$:

$$0 > \hat{Z}_{HP} - \hat{Z}_i \qquad \text{Inequation 1}$$

In figure 4b the points $\hat{Z}_i$ of inequation 1 which are points of the neighbouring terrain are shown in black.

Tilted planes

The objects treated in this paper which can be composed of serveral tilted planes are elongated objects. In longitudinal direction these objects are not allowed to exceed a predefined maximum slope value s_{Max}:

$$s_{Max} \geq \left| \frac{\hat{Z}_n - \hat{Z}_o}{D_{no}} \right| \qquad \text{Inequation 2}$$

The example in figure 5 shows a road which is modelled by lines and then buffered using the attribute “road width” of the GIS data base. Here, $\hat{Z}_n$ and $\hat{Z}_o$ are the unknown height values of successive points P_n and P_o in driving direction of the road (figure 5a). D_{no} is the horizontal distance between these points.

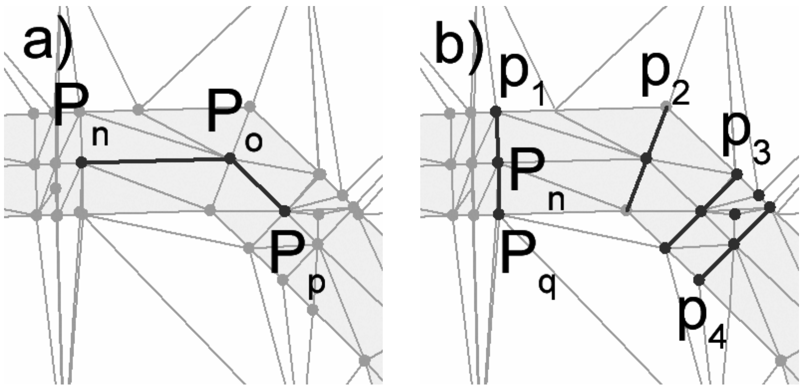

Figure 5: Equation and inequation constraints, a) maximum slope and maximum slope difference, b) horizontal profile and points belonging to a plane

In addition, the difference between two successive slope values which is comparable to the curvature of the object is restricted to the maximum value ds_{Max}:

$$ds_{Max} \geq \left| \frac{\hat{Z}_n - \hat{Z}_o}{D_{no}} - \frac{\hat{Z}_o - \hat{Z}_p}{D_{op}} \right| \qquad \text{Inequation 3}$$

In case of a road, the points P_n, P_o and P_p are successive points of the middle axis of the object, D_{no} and D_{op} are the corresponding horizontal distances.

Assuming a horizontal road profile in the direction perpendicular to the middle axis the height values of corresponding points must be identical:

$$0 + \hat{v}_{nq} = \hat{Z}_n - \hat{Z}_q \qquad \text{Equation 5}$$

The values $\hat{Z}_n$ and $\hat{Z}_q$ represent point heights of the centre axis and the left or the centre axis and the right side of the buffered object (figure 5b). These constraints are introduced for all cross sections whose centre point results from the intersection between the DTM TIN and the original object line. In figure 5b these cross sections are p_1, p_3 and p_4. Those cross sections whose centre points are original points of the object middle axis are not used to form this kind of constraint because in the original points the road may show a change in horizontal direction and slope (cross section p_2). Consequently the cross section is not horizontal.

Finally, the points of any two neighbouring cross sections and the points in between have to represent a plane:

$$0 + \hat{v}_r = \hat{a}_0 + \hat{a}_1 X_r + \hat{a}_2 Y_r - \hat{Z}_r \qquad \text{Equation 6}$$

In figure 5b the points of the neighbouring profiles p_3 and p_4 as well as the points in between represent a point P_r of equation 6. These points have to represent a plane with the unknown coefficients $\hat{a}_0, \hat{a}_1, \hat{a}_2$. X_r, Y_r are the planimetric coordinates of point P_r, $\hat{Z}_r$ is the height of P_r which has to be estimated. A special case is the treatment of the points of a cross section involving an original object point of the 2D road centre axis. Equation 6 is set up twice, once for the points of the horizontal profile p_1 and the centre point of profile p_2 (and any point in between), and again for the points of the horizontal profile p_3 and the centre point of profile p_2 (and any point in between). After the optimization process the intersection straight line of the two neighbouring planes can be calculated. This straight line represents the non-horizontal profile p_2 and the left and right point of the profile can be calculated, too.

Height relation

Bridges, undercrossings and crossovers have a certain height relation to other objects (for example roads, railways, rivers, etc.). The height values of these objects must be higher or lower than the one of related objects. The height difference *d* is identical to the height of the bridge or the crossover or the depth of the undercrossing.

$$d \geq \hat{Z}_s - \hat{Z}_t \qquad \text{Inequation 4}$$

$\hat{Z}_s$ is the unknown height of the higher point, $\hat{Z}_t$ the one of the lower point.

3.2.3. Inequality constrained least squares adjustment

The basic observation equations (section 3.2.1) and the equation and inequation constraints (section 3.2.2) have to be introduced in the optimization process which is based on an inequality constrained least squares adjustment. The stochastic model of the observations (basic observations and equation constraints) consists of the covariance matrix which can be transformed into the weight matrix. Assuming that the observations are independent of each other, in general the diagonal of the weight matrix contains the reciprocal accuracies of the observations. To fulfill the equation constraints the corresponding pseudo observation has to get a very high accuracy and the corresponding diagonal element of the weight matrix has to be very large. The solvability of the optimization process, i.e. the semantic correctness of the resulting integrated data set depends on the choice of the individual weights. Because of this the next section 4 deals with investigations on weighting the observations.
The algorithm is formulated as the linear complementary problem (LCP) which is solved using the Lemke algorithm (Lemke, 1968). For more details see Koch (2003), the LCP is explained in detail in Lawson & Hanson, 1995; Fritsch, 1985 and Schaffrin, 1981.

4. RESULTS

The results presented here were determined by using simulated and real data sets. Two different objects were used – a lake which can be represented by a horizontal plane and a road which can be composed of several tilted planes. The simulated data consist of a DTM with about 100 height values containing one topographic object. The heights are nearly distributed in a regular grid with a grid size of about 25 meters.
The real data were made available by the surveying authority of Lower Saxony “Landesvermessung und Geobasisinformation Niedersachsen LGN”. The data consist of the DTM ATKIS® DGM5, a hybrid data set containing regularly distributed points with a grid size of 12,5 m and additional structure elements. The 2D topographic vector data are objects of the German ATKIS® Basis-DLM. Three different lakes were used bordered by polygons. The objects are shown on the left side of figure 1.

4.1. Simulated data

In case of a lake, the unknown lake height is identical to the mean value of the heights inside the lake. This is true if the neighbouring heights outside the lake are higher than the mean height value, i.e. if the inequation constraints (inequation 1) are fulfilled before the optimization begins. It is also true if neighbouring heights outside the lake are somewhat lower than the mean height value and the equations 3 and 4 have a very high weight. Here, equations 3 and 4 have a weight of 10^6 times higher than all other observations.
After the optimization process the equation and inequation constraints are fulfilled, and thus the neighbouring heights outside the lake are higher than the estimated lake height. All heights inside the lake and at the waterline have the same height level; the integrated data set is consistent with our view of a lake.
If the heights of the bank outside the lake have a high weight, the lake height is pushed down. Then, the heights outside are nearly unchanged but the original height difference between the lake and the point outside has changed.

The second simulated data set represents a road with five initial polyline points. The maximum height difference is 6 m, the road length is 160 m and the width is 4 m.
The investigations were carried out by using different weights for the basic observation equations and the equality constraints. Equation 1 was used for all points of the bordering polygon and the points outside the object which are connected to the polygon points. Equation 2 represents the connections to the neighbouring terrain. Using the same weight for all observations results in a road with non-horizontal cross sections and differences to the tilted planes. The inequation constraints are fulfilled and the maximum differences between the initial DTM heights and the heights of the integrated data set are in an order of half a meter.
Using higher weights (10^6 times higher than other weights) for the basic equation 2 and the equation constraints 5 and 6 leads to horizontal cross sections and nearly no differences to the tilted planes. The maximum differences between the initial DTM heights and the heights of the integrated data set are somewhat bigger than the differences before.
If the equation constraints 5 and 6 have a high weight, the equation and inequation constraints are fulfilled exactly. Compared to the results before, the terrain morphology has changed considerably.
The results show, that a compromise has to be found between fulfilling the equation constraints and changing the terrain morphology. Using a higher weight of 10^6 leads to fixed observations, i.e. the equation constraints are fulfilled exactly. But, the terrain morphology is not the same as before.

4.2. Real data

The real data sets representing lakes consists of three ATKIS® Basis-DLM objects with 294 planimetric polygon points. The DTM contains 1.961 grid points with additional 1.047 points representing structure elements (break lines). The semantically correct integration was carried out by using high weights for the equation constraints 3 and 4 and for the basic observation equation 1 (10^6 times higher than other weights).

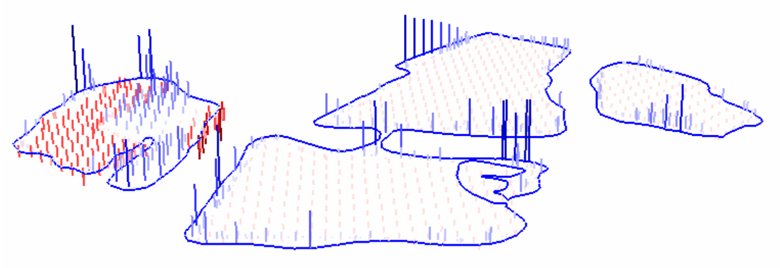

Figure 6: Height differences between the original heights of the DTM and the estimated heights of the optimization process (vertical exaggeration factor: 30), object: lake

The number of basic observations and equation constraints is 2.754; 533 parameters had to be estimated and the number of inequation constraints is 530. The results show, that all constraints were fulfilled after applying the optimization. The differences between the estimated lake heights and the initial mean height values are very small. The first mean height value is reduced by 2 mm and the second one by 4 mm. The third lake is 3,7 cm lower than the original mean height value which is caused by a higher number of heights at the bank which did not fulfill the inequation constraint (inequation 1).
Figure 6 shows the residuals after the optimization process. The blue vectors correspond to height values which are lower than the original heights after the optimization. Red coloured vectors refer to heights which became higher. The figure shows that most of the heights inside the lakes became higher. Most of the points which became lower are situated at the border of the lakes. Against this, a big part of the differences of the left lake became lower, too. Here, the corresponding part of the DTM seems to be coarse erroneous. The maximum differences between the original heights and the estimated heights are -1,84 m and +0,88 m, respectively. Figure 7 shows the result of the semantically correct integration (right side) with respect of the results without considering the semantics of the lakes (left side). The semantically correct integrated data set shows that all constraints are fulfilled. The height values inside the lake and at the water line have the same level. The terrain outside the lake arises.

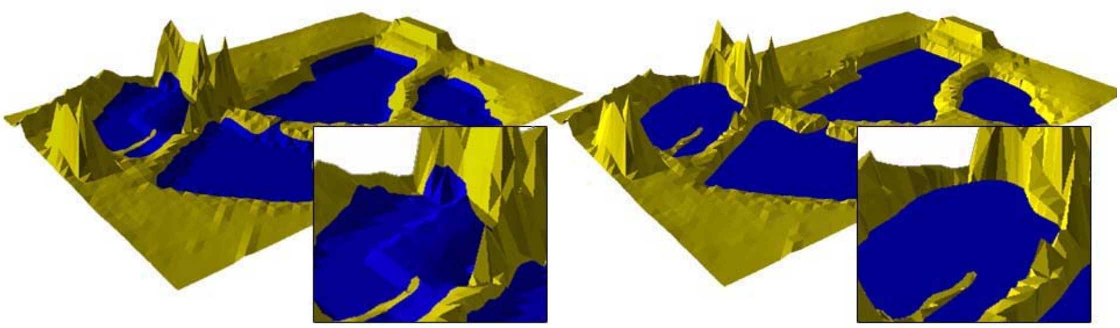

Figure 7: Results of the integration, left: without considering the semantics of the topographic objects, right: semantically correct integration

5. OUTLOOK

This paper presents an approach for the semantically correct integration of a DTM and 2D topographic GIS data. The algorithm is based on a Delaunay triangulation and a least squares adjustment taken into account inequality constraints.

First investigations were carried out using simulated and real data sets. The objects used are lakes represented by a horizontal plane with increasing terrain outside the lake and roads which can be composed of several tilted planes. The results which are based on the use of different weights for the basic equations and equation constraints are satisfying. Height blunders or big differences to the equality and inequality constraints may cause a non-realistic improvement of the original height information of the DTM. Thus, blunders have to be detected and corrected prior to the overall adjustment in the future.
Furthermore, the planimetric coordinates of the topographic objects were introduced as error-free. This may cause a erroneous height level of the topographic objects.
In addition, planimetric coordinates of structure elements have to be considered in the adjustment algorithm. Otherwise, structure elements inside the object polygon will be deleted and the morphology can be erroneous, too.

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