Quality evaluation of DEMs

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Abstract—Nowadays, sensors and processing techniques provide for the same site DEMs with different geometric characteristics and accuracies. Each DEM contains intrinsic errors due to the primary data acquisition technology and processing methodology in relation with the particular terrain and landcover type. The accuracy of these datasets is often unknown, inhomogeneous within each dataset, and almost always, only a global measure is given. We present a new concept for the quality characterization of DEMs based on different quality measures.

Keywords: Multi-source data, Integration, Quality Control, Spatio-temporal, Digital Elevation Model

I. INTRODUCTION

Terrain elevation is a key input in numerous applications and its quality plays a critical role in understanding various earth surface processes. DEMs are obtained in many ways, depending on the technology and the methodology employed and, of course, the extents and the resolution of the surface to be modeled.

Given the continuously increasing importance that DEMs are gaining in recent years due to their wide field of applications, it is of great relevance to define and to assess the quality of the information they contain. Moreover, DEMs can be produced nowadays at shorter time intervals and for larger areas, and the production process requires quality controls so that a DEM can be checked and updated properly.

The main objectives of this project are to (1) evaluate the differences between DEMs that have different resolutions and accuracies (but not very dissimilar), and different acquisition dates using a new heuristic approach, (2) examine how geomorphological characteristics and land use properties affect these differences, and (3) investigate how more parameters (i.e. blunders, shadows) can be better used for estimating DEMs quality.

The assumption is that we have two or more DEMs of different resolution and accuracy (but not very dissimilar), of different acquisition dates, derived using possibly different acquisition technologies (photogrammetry, laser scanning radar interferometry, map contour digitization). We assume that for each DEM we know the generation technology, acquisition date (year(s), month), resolution (average point density) and a global measure of accuracy. In addition, we assume that multispectral images of the area under consideration exist, permitting a landcover classification of the area. As a first step, the DEMs will be co-registered to each other with existing methods and Euclidean differences (and their XYZ components) will be calculated and visualized.

The main step is the characterization of each input DEM. This is based on various criteria based on theoretical considerations and also long experience and several empirical tests performed worldwide. Although it is very difficult to formulate mathematically some "constant" relations of DEM accuracy to single parameters like slope etc. that are proposed below, we propose to analyze each DEM separately taking into account a combination of various criteria (geomorphological, landcover, DEM generation technology, DEM differences etc.). The whole decision process will be based on a rule-based system which will also take into account what is expected from theory and the accumulated practice. The major criteria that are used in the DEM quality characterization are listed below:

- geomorphological criteria derived from each DEM like slope, aspect, roughness and DEM edges. These will be correlated to the previously derived Euclidean distances and the generation technology. The aim would be to derive for each generation technology, fuzzy relations for each geomorphological criterion, between this criterion and DEM accuracy.
- acquisition date. This relates more to DEM updating during the fusion process. The aim during the fusion should be the latest DEM information. Such DEM changes occur mostly with vegetation and technical works (particularly buildings). For the detection of such changes the Euclidean distances, landcover, and shape and size information will be used. Thereby, also the DEM resolution will be taken into account, as with coarse DEMs small objects like single trees and buildings can not be detected.
- landcover information. Depending on the generation technology, the landcover clearly influences the DEM error characteristics. A special part of landcover which will be treated separately are homogeneous areas (with a subcase for shadows) in the images, which lead to DEM errors when image matching is used for their generation. Again landcover will be correlated to the previously derived Euclidean distances and the generation technology. The aim would be to derive for each landcover class, fuzzy relations for each class, between this class and DEM accuracy.
- the given resolution and accuracy of each DEM. Nominally, a denser and more accurate DEM will initially
be treated as such. However, it can occur that e.g. a denser DEM is less accurate than a less dense one, and such cases should be taken into account in the single DEM quality characterization and the fusion process.

II. LOCAL QUALITY VS GLOBAL QUALITY

Over the years, several approaches have been proposed for DEM quality assessment. The most widely used error parameter for DEM is the Root Mean Square Error (RMSE), which measures the dispersion of the frequency distribution of differences between the original elevation data and the DEM data. However, the RSME is essentially a single global measure, which means that the error is assumed to be the same everywhere in the area covered by the DEM, but this is of course not necessarily true. In addition, assessing the terrain elevation over large areas using reference data is challenging because it is very time-consuming and costly to acquire high quality elevation data using field equipments such as GPS and total stations.

Global quality parameters have the advantage to describe the whole area of interest with few parameters only. On the other hand, local ones describe the quality of a DEM at a higher level of detail. Therefore much effort should be put in the definition of adequate local quality parameters which can be used.

III. BREAKLINES DETECTION

The accuracy analysis of DEMs can be complemented by additional terrain observations such as breaklines. Breaklines (or called as structure lines or skeleton lines), such as ridge lines and valley lines, are important terrain features as they describe changes in terrain surface. Breaklines not only provide the elevation information, but also implicitly represent terrain information about their surroundings. They describe terrain surface with more significant information than other points.

The detection of breaklines can help to describe the surface geometry along these linear discontinuities in more detail and can therefore support the quality characterization of DEMs. Furthermore, breaklines contribute to the fusion of DEMs since the fusion process should be conducted in such a way that the breaklines are kept. Their preservation and integration in the generation of the new fused DEM significantly contribute to obtaining a reliable, morphological correct DEM.

Traditionally, breaklines were derived either by manually digitizing existing maps or by photogrammetric processing. In our case, breaklines detection in a DEM is similar to the edge detection in image processing. We treat the DEMs as images and we apply three edge detection algorithms: the Sobel operator [3], the Canny operator and the Line Segment Detector.

In vegetation areas breaklines are not useful for the fusion process. Therefore, a detection of those features is not necessary. In contrast, in other regions, e.g. bare earth and areas with man made objects; breaklines are used to improve the fusion process. In the case of DEMs generated using lidar technology breaklines are narrower and sharper.

In Fig. 1 we see the results of edge detection on a lidar DEM. The line segment detector is more suitable for our investigation because it detects only the building breaklines. The Canny and Sobel operators detect also many “noise” breaklines and an additional filtering is needed in order to extract the useful edges.

![Canny operator](image1)

![Line Segment Detector](image2)

Figure 1. Breaklines detection on a lidar DEM, 2m grid spacing. Abbreviations and Acronyms

IV. A CASE STUDY

As a study case we chose the region of Thun in Switzerland, located in a mountainous area where the River Aare flows out of Lake Thun (Thunersee) (Figure 5). The major land covers are water, forest, crops, and urban areas. We investigated the case of quality analysis of three DEMs, produced with image matching (IKONOS satellite images and PRISM satellite images) and lidar technology.

Prism DEM: 5m grid spacing. Imaging acquisition date: 21.09.2006. Number of PRISM images: 1 scene with forward, nadir & backward images, the lakes are defined as water area with a given fixed height. The RMS errors for three test areas are for alpine areas: 6.7m – 7.2m, for open areas: 4.7m, for tree areas: 7.9m/12.8m and for city areas: 5.0m-5.6m. The image matching has been done with the SAT-PP software. This software includes a set of algorithms for processing of high resolution imagery (HRSI) that has been developed by our group at ETH Zurich.

IKonos DEM: 4m grid spacing. Imaging acquisition date: December 2003. Images: two IKONOS image triplets, the image matching has been done with the SAT-PP software and the estimated accuracy (RMS) is ±2m in open ar eas, about 3m on the average in the whole area, excluding vegetation and 8m in vegetated areas.

Lidar DEM: Swisstopo, 2m grid spacing and estimated accuracy (1 sigma) of 0.5m and 1.5m for vegetation and
buildings. The acquisition date is spring 2000. The initial raw point density is about 1 point per 2m2.

A. Co-Registration

First, the DEMs are aligned to a common reference system through co-registration (using at most three translations, three rotations and one scale), the 3D differences between the aligned surfaces are computed and the corresponding X, Y, Z residual maps are generated. Generally, co-registration performs a 7-parameter similarity transformation but in most cases three translations suffice.

Table 1 shows the results of the co-registration of the Prism and IKONOS DEMs to the lidar DEM. Fig. 2 shows the colored residuals between the Lidar DEM and the transformed Ikonos DEM after the co-registration. Fig. 3 shows the distribution of the residuals between the Lidar DEM and the transformed Ikonos DEM after the co-registration.

**TABLE I. CO-REGISTRATION RESULTS**

<table>
<thead>
<tr>
<th>Master DEM</th>
<th>Slave DEM</th>
<th>(s_3) (m)</th>
<th>(T_x) (m)</th>
<th>(T_y) (m)</th>
<th>(T_z) (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lidar, 2m</td>
<td>Ikonos, 4m</td>
<td>5.04</td>
<td>1.72</td>
<td>-3.95</td>
<td>0.65</td>
</tr>
<tr>
<td>Lidar, 2m</td>
<td>Prism, 5m</td>
<td>5.08</td>
<td>0.81</td>
<td>-9.02</td>
<td>-1.07</td>
</tr>
</tbody>
</table>

![Figure 2](image1.png)

Figure 2. The colored euclidean residuals between the Lidar DEM and the transformed IKONOS DEM after the co-registration. The residuals bar unit is in meters.

B. Tile Co-Registration

Tiling is an optional way to co-register the given DEMs. We divide the geographic region into equal size rectangles in order to perform the co-registration progress. After the tile co-registration we analyze and plot the residuals for each tile.

On Fig. 4 we observe that the co-registration parameters differ significantly from one tile to the other so we have to define a different strategy for the co-registration process. Furthermore, we see that the geomorphology and the land cover influence the co-registration results. There is a need for the development of a robust co-registration method that it will take into account additional information (i.e. land cover, slope).

![Figure 3](image2.png)

Figure 3. The colored residuals between the Lidar DEM and the transformed IKONOS DEM after the co-registration.

![Figure 4](image3.png)

Figure 4. The results of the tile co-registration between the Lidar DEM and the transformed PRISM DEMs respectively.

V. GEOMORPHOLOGICAL CHARACTERISTICS ANALYSIS

Some measures relating to DEM quality are derived by using the geomorphological characteristics of the surface model. Geomorphological terrain parameters are those that can be derived directly from the DEM using some local operations such as slope, aspect, roughness, curvature, etc.

The calculation and relation to co-registration residuals of three geomorphological indices (slope, aspect and roughness) are analyzed. The residuals between the DEMs are studied in relation to the mentioned geomorphological characteristics of the terrain. The terrain parameters' slope, aspect, profile curvature and plan curvature are extracted according to Wood, 1996. He uses a multi-scale approach by fitting a bivariate quadratic polynomial to a given window size using least squares.

Bearing in mind the initial assumptions results show that the proposed quality analysis can be successfully performed between two heterogeneous datasets acquired at different resolutions and with different data acquiring techniques. Aspect, slope and entropy seem to be the most useful geomorphological characteristics. According the graphs of
Fig. 5 we notice that the co-registration residuals vary (increase or decrease) in a non-random pattern in relation to these three geomorphological characteristics. The other geomorphological characteristics which we examined we consider that they are not useful for further research since they do not relate on a prominent way with the co-registration residuals. The land cover analysis needs further research. The Fig. 6 reveals, as expected, that the DEM quality is related to the land classes.

![Graphs showing Euclidean distances vs aspect, slope, and texture entropy.](image)

**Figure 5.** Geomorphological characteristics vs Euclidean residuals between the Ikonos and the Lidar DEM.

**Figure 6.** Plots of the 3D residuals between the Ikonos and the Lidar DEM as a function of the landcover. The euclidean residuals are represented in absolute values.

**VI. DISCUSSION**

In the previous paragraphs several quality parameters for DEM have been presented. Due to the continuously growing importance of DEMs and their related applications it is desirable that future DEMs will be provided not only in terms of height models, but also with adequate quality information. It will pertain to the user to employ the quality information, depending on the application. It must be noted that it still remains an open question which quality measures must be eventually chosen and how they will influence the decisions based on them.

After having a relation between the various quality measures and the DEM quality, which will be expressed in numerical terms, the aim should be to combine these criteria and derive final overall quality values. This should be done not only for each DEM point, but should also take into consideration the points (and their quality) in a local neighbourhood. The derivation of these final quality values is the most difficult part.

Local update or enhancement operations, restricted to some portions of a dataset only, or integration of heterogeneous DEMs represent another field of research where no definitive solutions have been found yet, and new investigations are required.

**REFERENCES**


