FUSION OF LIDAR AND PHOTOGRAMMETRIC GENERATED DIGITAL ELEVATION MODELS

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ABSTRACT:

The fusion of digital surfaces, their optimal combination into a new single dataset, is a crucial topic in the geomatic sciences. Nowadays, sensors and processing techniques provide for the same site Digital Elevation Models (DEMs) with different geometric characteristics and accuracy. Each DEM contains intrinsic errors due to the primary data acquisition technology and processing methodology software in relations with the particular terrain, and additional errors like blunders. In order to overcome the limitations of each surface model and create a better DEM, an intelligent fusion is required. Examples of situations where fusion is crucial are: merging of DEMs with similar accuracy generated by different techniques (for example, Lidar and image-based matching), update of a DEM with a more recent one, improvement of a global DEM (like SRTM) in areas where other DEMs are available for validation and elimination of erroneous points, and removing systematic errors between DEMs.

Although in technical literature some papers report DEMs fusion strategies, there is still not a consistent and global applicable solution on the topic of DEM fusion. The basic idea of our approach is to integrate different available height data according to their accuracy, which is a result of the geomorphological characteristics (i.e. slope, aspect, roughness) of the DEMs, the calculated differences between the DEMs, the land coverage, and the DEM production technique. The goal of our fusion is to generate automatically a new DEM surface which is geometrically accurate by depicting the correct height information of the area, clean by eliminating blunders and errors which are present in the initial data and complete by modelling all the area in the highest possible resolution.

To perform the fusion of multiple DEMs, the procedure shown in Figure 1 is proposed. The assumption is that we fuse two DEMs, called DEM1 and DEM2, with grid spacing $s1$ and $s2$, where $s1 > s2$, and we produce a new DEM, called DEM3, with grid spacing $s3 = s2$. The only a priori information that we have for the DEMs is their technology (i.e. laser, photogrammetry, SAR) and one global measure of accuracy. If the input surface models are available as point clouds, a regular grid is generated with grid size equal to the average point distance.

First, the DEMs are aligned to a common reference system through co-registration (using translations, rotations and one scale). After the co-registration, the Euclidean distances (E) between the two DEMs are computed point-wise, together with the X, Y, Z components. The Euclidean, X, Y, and Z components provide the so-called "residual maps". In order to fuse the DEMs and generate a new surface model with better accuracy, it is fundamental to have a complete knowledge of the characteristics and accuracy of the initial DEMs. Each individual DEM is precisely evaluated by calculating a variety of quality measures. To this purpose slope, aspect and roughness are used. In the following step the fusion is conducted. The two DEMs are merged into DEM3 applying a mathematical approach using weights from the accuracy analysis step. An active surface model is used to merge the two DEMs. It is a generalisation of snakes or active contours. Each time we attract the less accurate DEM (active surface) towards the most accurate DEM (reference surface). The active surface is attracted to the reference surface while being constrained by rigidity terms. Its shape is controlled by internal forces which constrain the surface to be piecewise smooth, and external forces which drive the surface to coincide with geomorphological feature throughout the reference DEM. Fusing DEMs is a complex issue. Differences between them can be due to the acquisition dates, the resolution, or the production technology. We define different cases according to (a) the residual maps, (b) the geomorphological characteristics, (c) the DEM production technology and its inherent advantages and disadvantages and optionally (d) the land cover map, if available, and perform an adaptive thersholding for the automatic detection of the areas to be fused on each case. The accuracy information is also used to calculate the weights for the mathematical part of the fusion. The fusion is applied in "problematic areas" where the differences between the two DEMs are significant with respect to their nominal accuracy. The internal force E_{int} depends from the nominal accuracy of the DEM, the production technique and the land cover while thenal force E_{ext} depends is calculated according the geomorphological characteristics. If we know a priori that one DEM is wrong (i.e. blunders, artifacts) instead of using the active surface mode we select the values of the most correct DEM on this "problematic area" and we interpolate with the neighbourhood values of the DEM we wish to improve using biharmonic spline interpolation.

The study site is an area around the town of Thun, Switzerland, characterized by steep mountains, smooth hilly regions and flat areas, both rural and urban. The elevation range is more than 1600m, varying from 530m to 2190m. The land cover is extremely variable with both dense and isolated buildings, open areas, forests, rivers and a lake. Over this test area, two IKONOS image triplets were acquired in October 2003 and a DEM was produced using image matching techniques with the ETH-IGP software Sat-PP at 4m grid. The estimated accuracy is $1 - 2$m in open areas and about 3m on the average in the whole area, excluding vegetation. Another DEM was available from airborne lidar scanning. It is a 2m regular spacing DEM, with an accuracy of 0.5m (1σ) for bare ground areas and 1.5m for vegetation and buildings. The lidar data were acquired in 2000 by the Swiss Federal Office of Topography, Bern (Swisstopo). The size of the overlapping area between the two DEMs is approximately $10\mathrm{km} \times 12\mathrm{km}$.

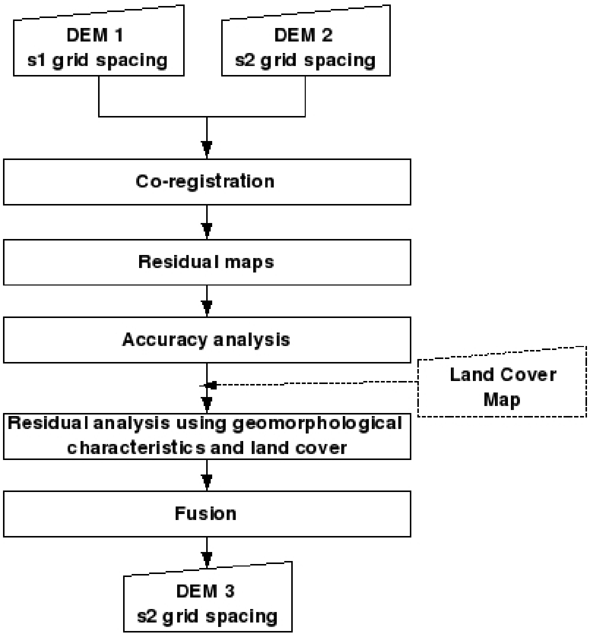

Figure 1: Workflow of the DEM fusion approach.