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Surface and terrain reconstruction from very high resolution imagery: Where are we now?

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ABSTRACT: 3D Geographic Information and especially Digital Surface or Terrain Models are becoming essential data for many applications, from risk mapping (avalanches, volcanoes, floods, ..) to town and infrastructure planning with virtual and augmented reality. Automatic surface reconstruction from images with shape from stereo techniques has been a subject of constant attention within remote sensing, photogrammetric, image processing and computer vision communities since the 70's. These techniques had reached a limit when addressing scenes with poor textures, discontinuities and occlusions as encountered in urban areas with HR geospatial imagery. These limitations have faded lately with the rise of new technologies (e.g. high quality aerial digital cameras) and techniques (e.g multi-view processing) and consequently expectations of full (or nearly) automation at short term have become a trend again.
Meanwhile, LASER scanning technologies, which provide a reliable description of the imaged scenes in the form of 3D cloud points, have achieved a certain degree of maturity.

1 INTRODUCTION

Until the last decade, surface and terrain models were computed using either aerial stereo pairs, scanned maps or surveying techniques. These terrain or surface models were known to be difficult to calculate through automatic processes. Commercial software often reflects this situation and proposes limited choices to compute terrain or surface models from images. For many years, laser scanning technologies have provided an alternative to these techniques and have reached a certain degree of maturity. Meanwhile photogrammetric surface reconstruction algorithms have tremendously increased the possibilities of automation due to better SNR ratios and multi-image based techniques and is still an area of active research. A state of the art can be found in Scharstein & Szeliski (2002). The aim of this paper is to draw an up-to-date review of these techniques and to stress major advantages, drawbacks and how can they work together in order to satisfy as much as possible the needs of given applications. Other techniques (e.g. interferometer) in order to estimate depth or terrain models well known by the remote sensing community but less common for the aerial imagery community are out of the scope of this paper.

We will sketch a comparison of laser-based and photogrammetry-based techniques to point out distinctive advantages whether they are to be integrated and processed within a common system. The techniques are dependent of the characteristic of the landscapes. In the first part, we will analyse terrain and surface reconstruction techniques in urban areas. Secondly, we will draw a comparison between photogrammetric and laser scanning techniques for rural areas. Finally, we will address the trend in the use of surface models to derive other products, e.g. DTMs, true ortho-images, BRDF classifications and trends in the integration of surface models with images to improve spatial partitioning, understanding and reconstruction of cartographic elements (buildings, road networks, vegetation) over complex scenes.

2 URBAN MODEL

DSM quality requirements depend on the application. In an urban context, relevant morphological details must be preserved (e.g. accurate localization of buildings discontinuities, as well as surface and slope breaks). Classical dense raster DSM computed by stereo matching are not sufficiently adapted to describe correctly surface and slope discontinuities. Several approaches have been developed so far to adapt stereo matching techniques to an urban context (Baillard & Dissard (2000)). An alternative consists in computing directly a DSM under a TIN form by fitting the landscape surface to sparse but reliable low-level 3D features (points, lines, segments, etc) Maillet (2002).

Very high resolution images (<50 cm) are generally required so that the whole set of 3D structure should be enlightened. Working at these resolutions in an urban dense environment makes a considerable amount of hidden parts appear. The description of the scene may become impossible using stereo analysis. The acquisition of multiple views of very high SNR aerial digital cameras solves such problems. In a multi-view context hidden areas are reduced. Moreover, having the high redundancy of feature observations will drastically increase the accuracy and the reliability of the 3D feature extraction Jung (2003).

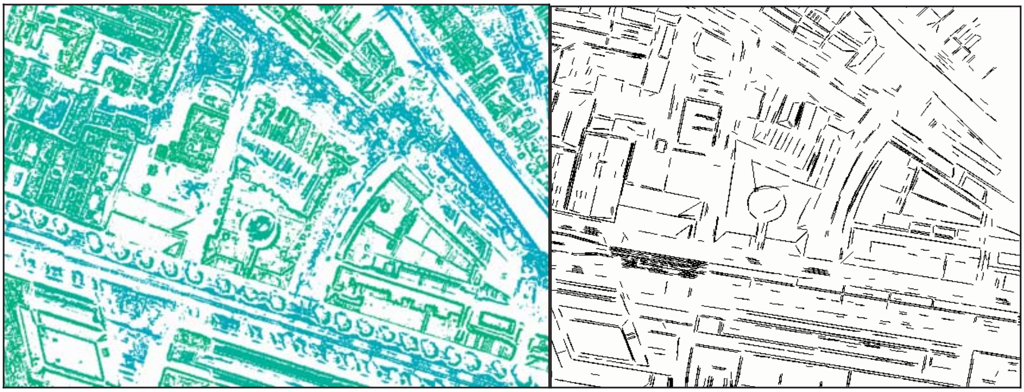

Figure 1. Examples of points (left) and 3D linear features (right) extracted and combined in a TIN model. It is crucial to stress how complementary these features are in order to describe accurately the surface.

Once 3D features have been extracted, the surface reconstruction problem can be considered as a way of interpolating values between the set of these features (Figure 1). The choice of the interpolation function together with the selection of 3D features is oriented depending on the application, but it will be object surface dependent.

The simplest way to build a TIN model is a two step process. The first one is a 2D constraint Delaunay tessellation (using only x and y coordinates of the 3D low level features). Then, the 2D resulting triangles are re-projected in 3D. During this 3D re-projection, triangles almost vertical can be constrained to be vertical in order to preserve real buildings discontinuities.

3 RURAL MODEL

If the urban topology is characterized by abrupt slope gradients around building façades, it is an entirely different geometry when it comes to model rural environment at large scale. Three main items may describe such a rural landscape:

- The gathering of large man-made complex structures (mainly buildings) is missing
- Simple linear structures such as roads or highways are spread over
- Different types of vegetation (forest, isolated trees, agricultural fields) are present

Airborne laser scanner provides tri-dimensional clouds of points. These data are irregularly distributed over the earth surface mainly due to the geometry of sensors. Each point is represented by three coordinates and there is no defined neighbourhood (like a pixel based neighbourhood) within these data.

Airborne laser sensors are of special interest for two major grounds: firstly, the accuracy of such systems is theoretically independent of ground control points, since the geo-coding process is performed directly using INS/GPS measurements as well as the time taken for laser pulses to return to the sensor.

Secondly, the availability of current systems to record multiple laser returns depending on the surveyed object (vegetation) is one of the main assets of airborne laser technology. Whereas a first part of the total energy is reflected by the top tree crown, other pulses are then recorded depending on their penetration rate within the vegetation. The last one is likely to belong to the true ground surface. As a result, a laser survey provides both information concerning the top canopy and above all, concerning true ground, such is the case in a forested area where photogrammetric techniques are unusable to obtain sufficient information about the ground elevation.

Basic techniques for extracting non-ground objects consist of making the difference between two DSMs derived from the first and the last echo (Figure 2,3). It can be sufficient for many applications (e.g. calculating timber volume). However, working directly on the point cloud may provide many more details (see figure 1) that could have been coarsened through the interpolation (resampling) process. The final DSM/DTM accuracy depends on the interpolation function that has been chosen -Smith et al (2003)-.

Many algorithms have been developed for segregating terrain and off-terrain points -Sithole (2003)-, some of them are implemented into commercial software. One of the major difficulties at the time is the large number of parameters required for classifying raw laser data. But once effective, it is possible to work independently on different classes and detect meta structures as mentioned in ii).

As a matter of course, vegetation may be detected by analysing IR images. Such images provide a planimetric classification. We immediately realize how fruitful should be the result of a fusion of both IR/visible images and classified laser data, once perfectly co-registered - Bretar (2003)-. The complementarity of both systems is still of research concern -Rottensteiner and. Briese - explores an automatic generation of buildings with laser and aerial images). But we are not far from a hybrid Laser/Image system similar to laser-platform proposed by constructors.

Depending on the final resolution we want to reach, laser point density may be easily tuned. The higher density the more details (micro-relief or structures) detected (see applications).

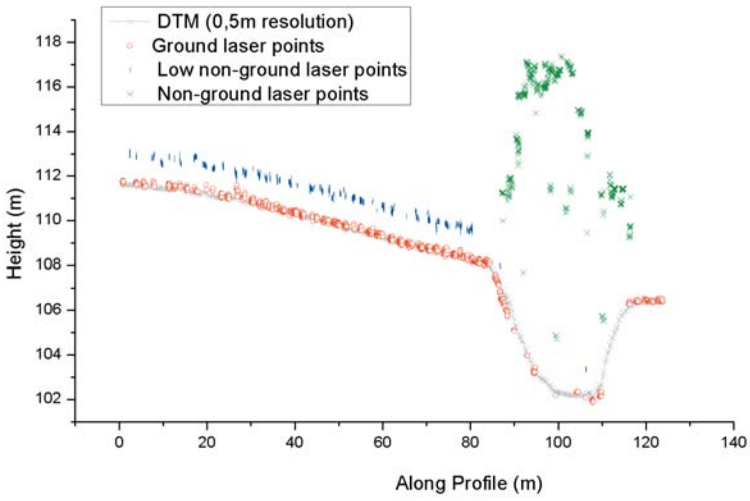

Figure 2. Example of filtering airborne laser data into ground (red) , low non-ground (blue) and non-ground points (green). The reconstructed terrain is represented in grey. This profile has been calculated with an algorithm developed in - Bretar (2004)-

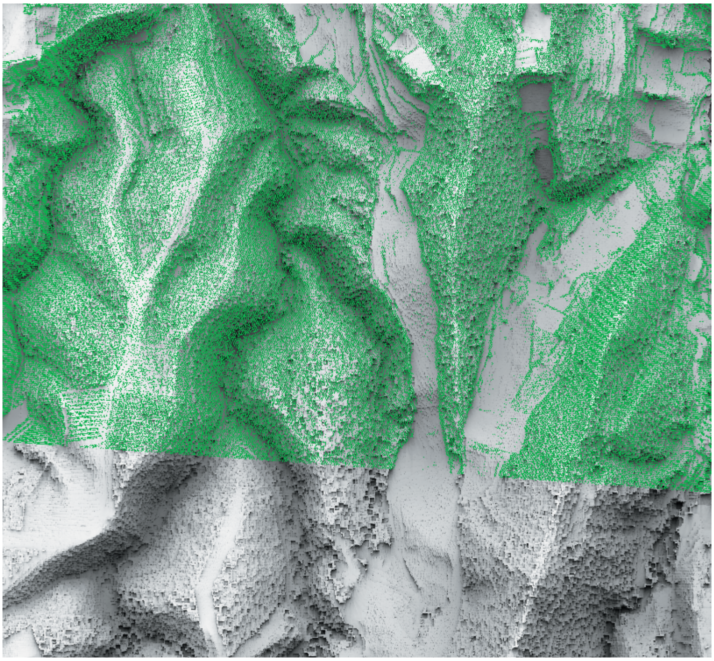

Figure 3. Superimposition of a laser DTM and vegetation extracted using above ground laser points.

4 APPLICATIONS

DTMs and DSMs are essential for many cartographic applications. Among them we can find : true orthoimages generation, virtual reality, risk management, radiometric corrections and even a rough predictor for other applications.

4.1 *True Orthoimages*

Urban true orthoimages are of increasing interest for many users. True ortho-images provide simple and useful geographic information with a metric significance and coherence with cartographic databases. This application requires an accurate knowledge of the topographical surface: the slightest error in the surface model entails disturbing artefacts (Figure 4). DSMs calculated with point and line tessellation seem to fit perfectly these products: altimetric discontinuities will follow edges.

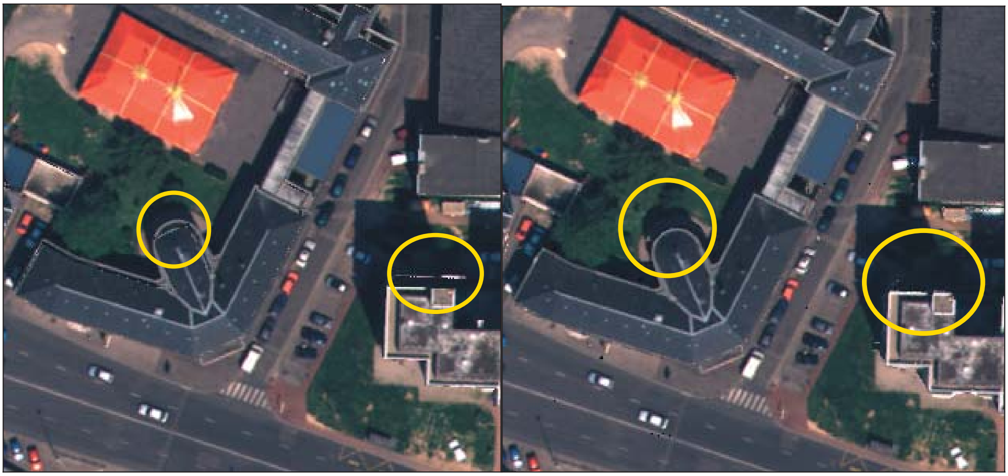

Figure 4. Two examples of orthoimages. Left figure shows the artifacts due to a 3D model without refining the slope contours. Right figure shows the same scene computed wit a DSM using accurate line and point tessellation.

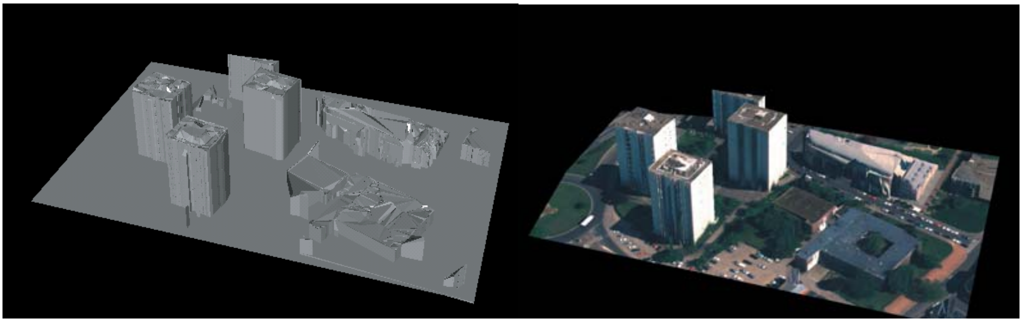

Figure 5. Fully automatic DEM computed using a line and point tessellation (Left). Building Discontinuities are well described using this technique. Textured model (Right)

4.2 *Virtual Reality*

Virtual reality consists of projecting textures onto a known surface model. TIN models may be obtained through a fully automatic process (Figure 5). The major drawbacks of such techniques are the large number of triangles required to describe the scene. On the contrary, CAD models are certainly more concise but they would require much more interactions for a human operator.

4.3 *Risk Management, Inter-visibility maps, navigation systems assistance*

Reliable 3D information can be used in order to predict the damage of floods, noise, etc. Risk management needs completely reliable 3D information. Hence the choice between manual and automatic photogrammetry or laser scanning has to be made judiciously.

4.4 *Radiometric corrections*

Hot Spot correction using a DTM is a well-known problem in the satellite community -Le Men and Boldo (2000)-.But new radiometric corrections can also be applied to HR images acquired by means of either new satellites (Pleiades, QuickBird, Ikonos, etc.) or airborne platforms. For instance, given an accurate 3D model of a scene and a radiometric model it is possible to detect and perform radiometric corrections of shadows inside images -Martinoty (2004)- (Figure 6).

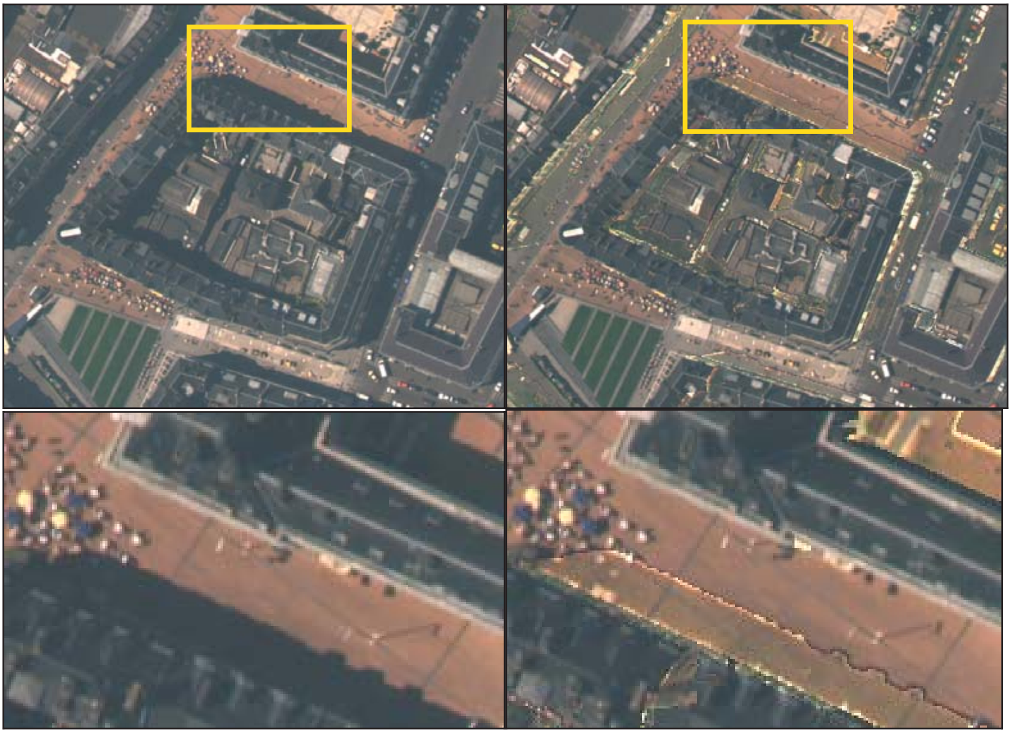

Figure 6. Example of shadow correction. An accurate 3D model of the scene is needed in order to correct shadows. The remaining shadows are due to a lack of precision of the 3D model.

This technique can be useful in order to mosaic multi-date images or to simulate a different sun position and enlightenment.

4.5 *Estimation of a DTM from a DEM / Object detection and classification*

Many applications need the use of both a DSM and a DTM. In urban areas, either photogrammetric or laser scanning techniques can provide reliable DSM. Extracting a DTM can sometimes be a very challenging task (Figure 7). The need of higher level knowledge is often unavoidable.

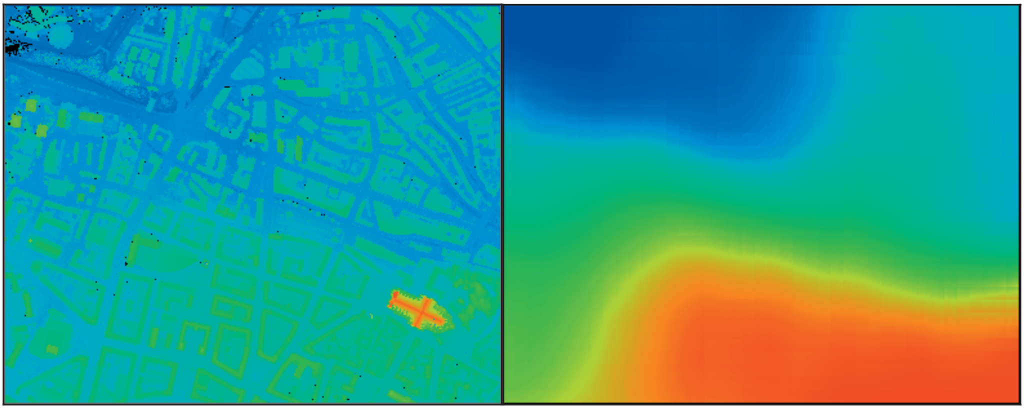

Figure 7. Example of an automatic DTM computation based on a DEM.

4.6 *Building reconstruction*

Building reconstruction for an entire scene is still a challenging problem. In order to reduce the combinatory many approaches segment the scene into focusing areas, each of them containing just one building or a building block. This step can be performed using a ground/above ground classification using the DSM. For each focusing area the DSM can be used in order to extract features close to the surface.

5 CONCLUSION AND FUTURE TRENDS

Surface Models using correlation techniques as well as laser scanning have made tremendous progress over these last years. Some intrinsic limitations and advantages of both techniques have been stressed. Depending on the application, a user must decide which material, which flight condition, data acquisition and which algorithm to use in order to dedicate the surface model reconstruction to the desired application.

Many industrial systems try to combine this information. Cooperation between these sources of data can still trigger many researches and increase performance (reliability as well as accuracy) for many applications. For instance, registration between images and laser data has to be performed accurately. Moreover quality assessment associated to the surface model is still a challenging area of research. Different quality indexes can be studied: geometric accuracy, reliability. Moreover, a better understanding and description of the scene would probably help to provide quality assessment.

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