Very Advanced 3D Landscape Models

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ABSTRACT

At present web-mapping applications, earth viewer, and geo-localized information undergo an enormous boom in the internet. Many people use the internet to obtain information about favorite holiday spots and tourist attractions. New technologies are now emerging to display large scale aerial and satellite image mosaics in very high resolution 3D and not only in the form of two-dimensional maps. This article describes the technologies necessary to produce very high resolution digital terrain models from digital aerial imagery and how to display 3D landscape models smoothly via the internet. 3D RealityMaps GmbH developed a proprietary, extremely powerful software that allows internet users to interactively explore photorealistic 3D landscape models in real-time. Tourist regions are the main target market for this advanced, high-precision 3D application called 3D RealityMaps™.

1. INTRODUCTION

With the development of novel digital cameras and high precision Global Positioning System (GPS) GPS and Inertial Measurement Units (IMU), photogrammetric stereo image processing can now be automatized. Especially, the Semi Global Matching (SGM) algorithm yields very good results in calculating high-precision surface models on the basis of digital aerial photographs (HIRSCHMÜLLER, 2005; HIRSCHMÜLLER, 2008). To date, digital surface models (DSM) are generated by means of LiDAR (Light Detection And Ranging) laser data or by using satellite data, such as the SRTM (Shuttle Radar Topography Mission) and TanDEM-X, which will be available in the coming years. However, compared to digital cameras these technologies have constraints. The widely used SRTM landscape model has a low resolution of only 30 or 90 meters (RABUS, 2003). LiDAR systems have a very high resolution and accuracy in the range of centimeters to decimeters but recording per day is limited in size and data acquisition and processing is costly (LIU, 2008). Gehrke et al. (2010) have shown that SGM-derived digital surface models are an effective alternative to LiDAR, especially when high resolution is a requirement. While both data sets can generally be used for the purpose of ortho image rectification, SGM is the preferred choice as it is based on the same data set and saves the additional acquisition costs of LiDAR.

The reduced production costs of DSM's from digital aerial imagery and SGM processing now make applications possible, where the production with LiDAR data is too expensive, e.g. large-scale 3D visualization of landscapes for applications in the internet. Aiming at the tourism sector as main target, 3D RealityMaps GmbH has developed a method which allows interactive 3D visualization of very advanced, high-resolution landscapes in the internet. Similar products are Microsoft Bing Maps and Google Earth which both enjoy great popularity. However, compared to these the 3D RealityMaps™ have a terrain resolution that is more than 1000 times higher. 3D RealityMaps™ have a height measurement grid cell size of 1 meter and a vertical resolution of 50 cm, whereas Google Earth Maps are based on 30 and 90 meters SRTM terrain data with 5 to 20 vertical resolution. Only very advanced landscape models correctly display all topographic details e.g. of mountain ranges and give a photorealistic impression. A comparison of 3D RealityMaps™ with a real photograph clearly shows, that the landscape is correctly represented in all its spatial detail (Fig. 1).

Figure 1: A comparison between a screenshot of 3D RealityMaps (Ötztal Alps, upper image) and a photography of the same area (lower image) clearly shows the highly detailed accuracy of the aerial imagery and the digital surface model. www.realitymaps.de

True ortho imagery and very advanced 3D landscape models have a wide range of applications. 3D RealityMaps GmbH focuses on the tourism sector. Vacation planning should not only be efficient, it should generate a pleasant anticipation, too. To make the decision for the upcoming vacation we want to get a real picture of our destination in combination with links to services and activities. Beside the photorealistic representation of the landscape destinations can determine what data they

wish to include in their 3D RealityMap™ and what design is best suited for their homepage. The 3D RealityMaps™ are a good example how science and technology can be transferred into commercial products and help customers in the decision making process. 3D RealityMaps GmbH provides customers with a complete one-stop service: from the acquisition of aerial imagery with the digital 3D stereo camera, development of terrain models and production of 3D landscapes and cities to augmented reality products and 3D visualization in intra- and internet.

2. 3D TECHNOLOGY

2.1. Stereo processing of digital aerial imagery

Prerequisite for stereo processing of digital aerial imagery is the acquisition of images with a minimum side overlap of at least 35% and a forward overlap of at least 60%. Results become better with more overlap. Furthermore, DSM generation from digital aerial cameras data requires that position of the aircraft during acquisition is exactly known. This can be achieved by using an Internal Measurement Unit (IMU), an electronic device that measures and reports on the aircraft's velocity, orientation, and gravitational forces, using a combination of accelerometers and gyroscopes.

Accurate dense stereo matching is an important requirement for 3D reconstruction of landscape details or buildings. For stereo processing the digital aerial imagery has first to be placed into a coordinate system. The GPS and IMU recordings of the flight tracks might not be accurate enough to identify similar features in overlapping, multiple images. Sup-pixel matching of overlapping images can be achieved via triangulation using hundreds and thousands of automatically detected tie points. The technology for producing digital terrain models from aerial photographs presented here was initially developed by the Institute of Robotics and Mechatronics of the German Aerospace Center (DLR) in Oberpfaffenhofen and Berlin. As an industry partner of the DLR, 3D RealityMaps GmbH played a decisive role in the development of this technology to the application stage.

The Semi Global Matching (SGM) algorithm allows the calculation of high-precision digital surface models on the basis of aerial photographs from digital camera systems. The method is based on a pixel wise matching of mutual Information and approximating a global, 2D smoothness constraint by combining many 1D constraints. This opens the way for robust, illumination insensitive stereo matching in a broad range of applications. The Semi-Global Matching (SGM) method performs much better matching than local methods and is almost as accurate as global methods (HIRSCHMÜLLER, 2005). In the past three years the 3D processing algorithm was adapted to various recent digital aerial cameras, such as Vexel's UltraCam, Zeiss DMC and Leica ADS camera or the newly developed Multicam of the DLR. Most difficult are often the boundaries of objects and fine structures, which can appear blurred. Additional practical problems originate from recording and illumination differences of reflections, because matching is often directly based on intensities that can have quite different values for corresponding pixels. Furthermore, fast calculations are often required, either because of real-time application or because of large images or many images that have to be processed efficiently.

A comparison with LIDAR systems shows that the aerial image technology has several practical advantages. LIDAR systems usually produce 1-4 height measurements per m^2, while with photo flights up to 16-200 measurements per m^2 are possible. Another advantage of the photo flight technology is that ortho image generation is based on the same data set, representing the same point

in time, identical geometry and resolution. The resulting image mosaics are so called true or nearly true ortho images. Because the high-resolution surface model is used for ortho rectification the true ortho imagery shows no tilted buildings. In addition, in mountainous terrains up to 1500 km² per day can be flown with an UltraCAM Xp system with a ground resolution of 25 cm (resulting in 16 height measurements per m²). With LIDAR only 100-150 km² could be achieved under the same conditions, because the aircraft has to fly much lower and acquires data in different height levels. Thus, laser DSM generation requires more expensive acquisition tasking and complicated processing technology. Own studies showed that the accuracy of SGM derived digital surface models in urban areas is only slightly lower than LIDAR derived DSM's. Gehrke et al. showed that SGM-derived DSM's are an effective alternative to LiDAR, especially when high resolution is a requirement. SGM is the preferred choice as it is based on the same data set and saves the additional acquisition cost of LiDAR (GEHRKE et al., 2010).

2.2. 3D visualization – 3D RealityMaps software

To be able to interactively visualize very advanced landscape models and superimposed aerial imagery, 3D Realit298yMaps GmbH developed high-performance software which enables users to navigate in 3D landscapes in real time and display all sorts of geo-information from databases or the internet. Road, villages, topographic names, hiking routes, ski lifts and maps can be superimposed on the landscape and photographs, videos and webcams can be linked to their true position in the landscape. Special functions allow users to calculate distances and slopes and thus to estimate the duration of hiking tours, ski runs or bike rides.

In order to achieve a realistic or even photorealistic impression of a 3d terrain, several preconditions have to be fulfilled. The first and foremost criterion is generally the detail of the model, as this defines how close and at which perspectives the user may observe the model without noticing deficiencies. But even the most detailed model does not render a realistic experience, if the observer camera cannot be moved around freely and with fluid frame-rates. This restriction leads to the basic problem of computer graphics as the size and detail of the model seem directly limited by the memory and computing capabilities of the target platform. The key to solving this issue lies in the observation, that the amount of data necessary to render one photo-realistic frame from a fixed camera-perspective is very limited, as the necessary detail decreases linearly with the distance to the camera. The solution therefore consists of a pre-computed 3D model which allows extracting the necessary portions of the scene quickly and with the required level-of-detail. With an update of the camera, then also the active model is updated to adapt to the new perspective.

Since very advanced landscape models with 30 cm or less spatial resolution of the image *and* the DSM are generally by far too large to fit into the system memory, out-of-core techniques have to be applied, i.e. techniques to efficiently fetch the data from external memory (WAHL et al., 2004). Key technical characteristics of the 3D RealityMaps software include 1.) a quadtree hierarchy instead of a mere tiling, a very large range of LODs can be covered without significant computational overheads, 2.) pixel-true geometric LODs based on guaranteed Hausdorff-distance. This leads to very detailed contours and perfect-fit texture imagery. 3.) details do not just pop in at a certain distance but are always represented adequately. This greatly enhances realism as changes in the LOD become virtually unnoticeable and the illusion of a static full-detailed model is maintained. 4.) efficient geometry compression and generation of a triangular irregular networks by simplification which represents the DSM at a very low polygon count as opposed to regular grids or semi-regular approximation models.

3. APPLICATIONS

3.1. Interactive 3D landcape models for applications in tourism

Very advanced 3D landscape models together with a powerful software to display these data sets via the internet make highly topical applications possible, for example in the tourism sector. Current statistics show that 84% of all travelers plan their vacation beforehand on the Internet (BITKOM, 2009) and this number is still growing. Interactive applications are among the most popular. The internet user experiences a perfect 3D representation of a holiday destination at his computer (or smartphone in the near future) and gets all kinds of information on demand for planning the next holiday trip or vacation.

With just one click users are able to search for accommodation in different categories and find their favorite location for a stay in the photorealistic landscape. Another click displays all hotels available during a specific holiday period and links directly to a hotel booking portal. Yet another click and the user finds the perfect hiking track for the day. The search of services based on long lists of text was yesterday, the search in a geographic context is now.

More and more vacation spots are interested in 3D products and decide in favor of 3D RealityMaps™, especially in mountain regions which are famous for their scenery. An example is the visualization of the tourism region Alta Badia located in the Dolomites in South Tyrol (Fig. 2A). Besides sport attractions like hiking and mountainbiking tours, regional information of tourist offices, parking, webcams, shops, rentals, bus stops etc. are integrated within the 3D landscape. Furthermore, all accommodations are displayed and listed. This allows the user to search for the hotel, B&B or apartment with e.g. the best panoramic view or nearby village facilities. Hoteliers can book ads to distinguish their accommodation with photo, address and website. By linking to a booking system accommodations with vacancies are indicated in their spatial context and can be directly booked.

3D RealityMaps™ have been produced also for winter destinations in Germany, Austria and Italy. A good example is 3D Dolomiti Superski", an area of more than 5500 km² of impressive winter landscape with 12 ski areas, 422 ski lifts and 713 slopes or the Stubaier Gletscher Bahnen in Tyrol (Fig. 2B). High resolution winter landscapes are unique of 3D RealityMaps™. With this freely accessible online 3D maps tourists can easily explore skiing areas and find the slopes which best suits to his skills. After a skiing day the user can calculate and visualize the covered distance using the "Check Ski Performance" tool. Furthermore, regional information as well as sledge and cross country slopes are displayed.

"3D Mount Everest" is the first ever published very advanced landscape model of the highest peak on Earth created from high resolution WorldView-1 satellite imagery (Fig. 3). The 3D model was created in cooperation with DLR and DigitalGlobe, a leading global provider of high-resolution earth imagery solutions. The resolution of the digital terrain model is about 400 times better than that available in other 3D views of the mountain. It is a breakthrough in satellite imagery based 3D modeling and real time 3D rendering. The extreme level of detail achieved in 3D Mount Everest gives crews supporting the climb capabilities never before possible. The application was used to support a 12-climber expedition of the climbing enthusiast and expedition management company Peak Freaks. The climbers set out to summit Mount Everest in late March 2011. Using a newly developed live-tracking function internet users were able to monitor the progress of the expedition in real-time. More information is on the dedicated website www.everest3d.de.

Figure 2A: Lodging in Alta Badia, South Tyrol. 2B: Skiing slopes in Stubaier Gletscher, Tyrol. www.realitymaps.de

There are many other applications for very advanced landscape models beyond tourism and mountaineering. One example are the German Armed Forces, who are using the 3D RealityMaps technology of for resource planning in conflict areas.

3.2. Automated Reconstruction of buildings

Very high resolution digital terrain models can also be used to extract building geometries. The quality and the automation have been very much improved in recent years. This has resulted in a significant cost reduction that makes the usage of 3D city models very attractive for a wide range of new applications such as real estate marketing, navigation, tourism and the visualization of urban planning. High resolution and geo-referenced DSM's are used by 3D RealityMaps in an largely automated process to extract building geometries. Different Levels of Detail (LOD) can be derived from digital surface models with different spatial resolution. For a detailed building reconstruction aerial images with a resolution of at least 10 cm or better are needed, having a forward overlap of 80% and side overlap of 70%. Real textures of facades are automatically extracted from angular views of the stereo images or with images from oblique cameras. This enables the fast creation of 3D city models without needing any terrestrial photography (Fig. 4). Alternatively or additionally, photographs of facades can be used to create extra high quality views.

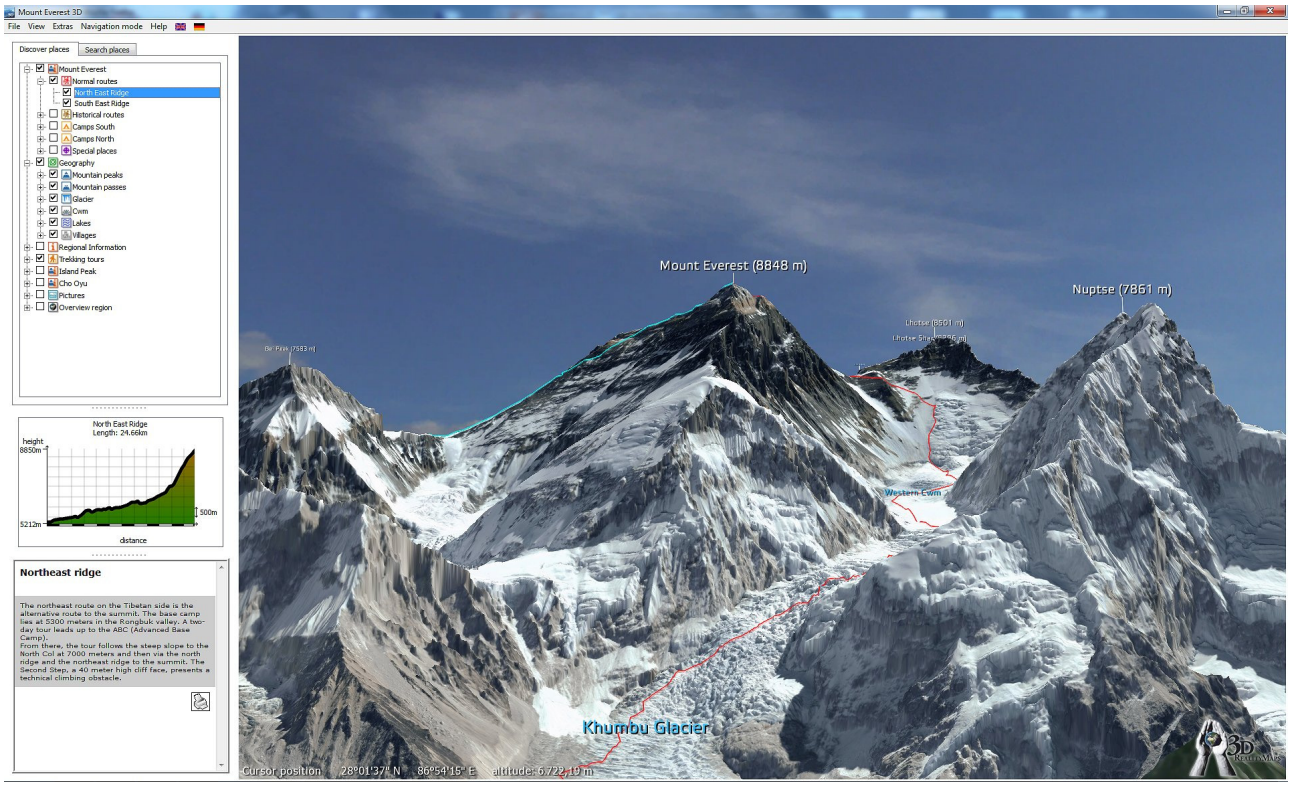

Figure 3: “3D Mount Everest” shows a unique satellite based landscape model. www.everest3d.de

In the same way as landscape modeling becomes more important in the tourism market, the demand for the city models is also fast growing. Hotel managers can give potential customers a good impression about a holiday resort via virtual 3D models in the web. The most recent 3D RealityMaps™ application was the planning visualization of the Olympic Games 2018 in Munich, an integration of a winter 3D landscape model of Munich and the Bavarian Alps and CAD models of existing and planned competition venues.

Figure 4: Interactive 3D model of an alpine village based on aerial imagery with 10 cm resolution.

4. CONCLUSION

Latest technologies allow new applications based on 3D landscape models in the internet that were too complex and expensive to produce with previous technologies. Novel digital cameras can be navigated with high precision which is a prerequisite for the generation of high-resolution digital surface models. The Semi Global Matching algorithm was specifically adapted to stereo processing of aerial imagery from most recent camera systems. 3D Reality Maps developed a powerful software to visualize photorealistic 3D landscape models and 3D cities in the internet. The 3D RealityMaps™ software is freely available for internet users. As online vacation planning becomes more and more popular and common, the award winning 3D RealityMaps™ software is an attractive and forward-looking new development.

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