DEM automatic extraction on Rio de Janeiro from WV2 stereo pair images

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Abstract. The use of three-dimensional data has become, for a lot of mapping applications, very important. DEM are applied for modelling purposes, i.e. the 3D city model generation, but principally for imagery orthorectification. In aerial photogrammetry is well known the suitable use of stereo imagery to produce an accurate DEM, but the limits of the process (cost, schedule of data collection, highly technical staff) and the new advanced digital image processing algorithms have open the work scenario to the remote sensing data. This research has wanted to investigate the possibility to obtain accurate DEMs by means of automatic terrain extraction algorithms implemented in Leica Photogrammetry Suite (LPS) from stereoscopic remote sensing images collected by DigitalGlobe’s WorldView-2 (WV2) satellite. The DEM of Rio de Janeiro (Brazil) and the correspondent digital orthoimages have been the results.

1. Introduction
Many new technological devices have big performances for the three dimensional data acquisition of the territory. LIDAR, SAR, INSAR and very high resolution optical remote sensing sensors (IKONOS, QuickBird, GeoEye 1-2, WorldView 1-2, and so on) give every day a lot of information related to the natural and artificial relief on the Earth. The fast and accurate data processing by means of new digital image algorithms allow reconstructing Digital Elevation Models (DEMs). A DEM, a 3D representation of the terrain’s surface created from elevation data, nowadays, is an integral part of any geospatial analysis. The suitability of a variety of DEM data depends on the project specifications, concerning for examples: telecommunications, planning, transports, tourism, urban inventory, environmental risk, etc. The achieved three-dimensional representations,metrically correct and with a notable level of detail, can be useful in mapping applications to produce a very accurate orthoimage, particularly in urban zones. There are two types of DEMs: Digital Terrain Model (DTM) and Digital Surface Model (DSM). DTM represent the bare ground surface excluding any man-made features while DSMs represent the earth’s surface including all objects on it. The improvement of these representations provides good 3D city visualization or three-dimensional information, easily GIS ready, which can be used for drawing relative geometric attributes to territorial objects.

This research has investigated the possibility to obtain DEMs by means of an automatic terrain extraction process from stereoscopic images collected by DigitalGlobe’s WorldView-2 (WV2) satellite. The stereo imagery is suitable to produce an accurate DEM, but they are designed for users with advanced image processing capabilities and photogrammetric tools [1]. This experience has tested different algorithms implemented in Leica Photogrammetry Suite (LPS) software to produce the DEM of Rio de Janeiro and the correspondent digital orthoimages. In the next sections every processing will be illustrated step by step, comparing the performances founding on the different accuracy of the results.

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2. World View2 data acquisition
DigitalGlobe\textsuperscript{®} gives much information about WV2 data (www.digitalglobe.com). The satellite, launched in October 2009, first commercial satellite at high-resolution 8 multispectral bands, has improved the capability of the landscape analysis. Operating at an altitude of 770 kilometers, WV2 provides 0.5 meter panchromatic image resolution and 2 meter multispectral image resolution. WV2 has an average revisit time of 1.1 days and it is capable of collecting up to 975,000 square kilometers (376,000 square miles) per day. The multispectral diversity (4 standard colors: blue, green, red, near-IR1 and 4 new colors: coastal, yellow, red edge, and near-IR2) and the increasing of the level of detail improve the understanding of global warming on sustainable land resources, tracking the impact of pollution, improving natural resource management and exploration, and protecting and monitoring agricultural development and sustainability [2]. Furthermore the satellite system has a high capacity to collect different types of scenarios by means of the stereo pair imagery useful for precise change detection or mapping analysis. Stereo images are collected in-track, meaning on the same orbit, and are acquired at angles optimal for stereo viewing and manipulation (figure 1).

Figure 1. World View 2 satellite sensor and its acquisition schema

To test the potentiality of the World View 2 satellite data we used two series of images acquired on January 19, 2010, on Rio de Janeiro (Brazil). The set of data were made up of one series of 5 panchromatic images (0.5 m. ground resolution) and another series of 5 multispectral images (2 m. ground resolution), the pan-sharpened images were not available. In figure 2 a selection of three images of the pan-series: the first (a) and the last one (c) of the strip and the nadir image (b). In figure 3 we have the same configuration for the multispectral series. The basic stereo imagery products have a large image swath collection size: at least 16.4 km wide by 14 km long. Although the satellite imagery has lower resolution than aerial photographs, it offers the advantage which an area can be covered by a single image. Working with fewer images allows faster processing of certain steps of the workflow, such as triangulation. Furthermore, the availability of satellite data overcomes some limits of the aerial photogrammetry (cost, schedule of data collection, highly technical staff, as well as high-end hardware and software), although this last technique provides more accurate products (e.g. sub-meter). Thanks the remote sensing new improvements data collection methods have been steadily evolving to reduce the costs and increasing the high-accuracy of results, which for GIS applications can be significantly less and give reliable products.

Our starting idea was to verify the performances of the stereo imagery products by means of advanced image processing photogrammetric tools to produce DEMs. We used the Leica Photogrammetry Suite software (LPS), one of the last releases that use both the ATE algorithm and the new algorithm eATE. The software can automatically generate digital terrain models, which can be reviewed and edited in stereo. Once an accurate 3D surface is derived the images can be orthorectified and a mosaicking can be produced. The project has been ambitious because the area is not flat or countryside but it is completely human made, with high buildings, an airport and a seaport.
3. Stereo imagery data processing
The workflow described below is for an urban project area without ground control points. In this case we cannot achieve sub-meter accuracy but at the same time it is possible to create relative stereo pairs.
with comparable accuracy to the original images. This increase the benefits of the satellite images for mapping, and can dramatically reduce costs when meter-level accuracy is sufficient for project requirements.

The processing steps involved: set up of the project, automatic point measurement, refinement of the analytical triangulation and evaluation, generation and editing of 3D terrain model.

3.1. Automatic bundle adjustment

The data processing, first of all, has required the set up image block triangulation step. All the data have been delivered with some support data files needed for radiometric and geometric calibration processing, including a stereo file that identifies the images in the pair. The metadata provided the RPC sensor parameters for the use of the geometric model of the rational function and the selection of the reference coordinate system (WGS84 Lat, Long) [3]. After the image pyramid generation, the automatic tie point measurement has been run to provide an automatic selection of tie points to make the relative orientation. This process involves a bundle adjustment, a review of the results and, if it is necessary, a refinement of the performances to improve the quality of the solution. In our case the presence of the buildings, placed side by side, has produced some lack of data or blunders. This is a critical step and it needs that an operator measure new tie points and delete the mistakes, but it is also a time-consuming stage (figure 4).

![Figure 4. Tie point refinement (sx) and block triangulation (dx)](image)

The triangulation iteration convergence has given, after the new measurement, an RMSE of 0.166 m. about the panchromatic imagery block; the multispectral imagery block solution was fallen proportionally the ground resolution. Good oriented stereo pair images are crucial for 3D product generation, because XYZ measurements come from them.

3.2. DEM generation

The next step is to generate a Digital Elevation Model (DEM), used as source during the orthorectification process. LPS allows using different algorithms: the Automatic Terrain Extraction tool (ATE) and the eATE, the new LPS module for generating high resolution terrain information from multi-stereo imagery.

The automatic collection of 3D terrain data is performed by sophisticated correlation algorithms, improved in eATE by means of dense pixel-wise matching. eATE should give more reliability and accuracy because uses a multi-ray matching with a simultaneous use of multiband stereo-images.

The workflow has involved the two block of stereo imagery (pan and multi) in two different stages, setting the grid respectively 0.5 m and 2 m. Initially was used a complete automatic process but the default parameters not allowing a sufficient control of the procedure and the results have been consequently bad, in both case. We choose to display in figure 5 only the ATE tool processing results that are not a very good products because the building contours are not well defined. The produced TIN, visualized by imagery in 3D with associated RGB values, shows uncertain definition of the elevations. The multispectral images with 2 m. of ground grid spacing have given a smoothed DEM, with not well defined contours of man-made objects.
Continuing the processing we focused our attention only on the use of the panchromatic stereo pairs with high ground resolution although in gray scale. In fact the color bands of the multispectral imagery could be a gain if their ground resolution was improved with a pan sharpened process.

So we performed the automatic extraction of cloud points setting some parameters: the overlapping over 90%, the area with min and max altitude (0-200 meter) and the “high urban” strategy, suitable for the built area. It’s quite that the processing needs always a quality check and a detailed monitoring of automatic extraction output. The final result was successful with a “General Mass Point Quality Excellent” of 93.59% and the rest “Good”; the DEM “Vertical Accuracy”, based on the comparison with tie points used in the block triangulation, had a RMSE of 3.7 m. (figure 6).

3.3. Orthoimages production

The orthophoto digital generation requires an accurate DEM [4]. The last product was better but must be improved by means of an editing phase in stereoscopic mode, which can help to define the meaningful elevation points, eliminate blunders or preserve objects for a more realistic model. In the case of an urban area with high buildings there is the necessity to define the ground cloud points (DTM) respect the 3D surface model of the objects (figure 7).
The orthoimages in comparison before and after the editing phase and the new processing of data are showed in figure 8; the yellow circles show like errors in the terrain can introduce horizontal error into orthoimage.

![Figure 8. Othoimage pre (sx) and post (dx) DEM editing processing](image)

4. Conclusions
Starting from a stereo automatic terrain extraction a variety of 3D geospatial data products can be derived that have value in a number of different applications. While orthorectified imagery is used as a base layer in many GIS applications, the additional 3D vector and 3D terrain information allow for analysis that goes beyond traditional 2D geospatial applications.

The future improvement will be the possibility to extract 3D features such as buildings and then to export the 3D model to KML file for display the urban environment in Google Earth. Another way to add a level of realism that enhances the 3D scene will be collect the buildings by the automatic stereo processing and use them as a 3D shapefile with texture applied. In summary, the process for creating value-added geospatial data products from sensors such as WorldView-2 imagery can be accomplished by following steps identified above.

References
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