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"Digital surface modeling and its applications in urban areas using high resolution satellite images"

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Table of Contents

List of Tables

List of Figures:

Chapter (1)

INTRODUCTION

Chapter (1)

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1.1 General:

Digital Surface Modeling is being acquired in different application domains ranging from urban planning, archeology and simulation to computer games. The primary focus is placed on 3D objects with a maximum level of detail and a high degree of realism. In others it is placed on spatial context requiring the inclusion of large geospatial data sets. However, all applications relying on reality-based 3D models also have a lot of aspects in common, namely the need for efficient data handling and access and the increasing demand for dynamic contents.

Geographical Information Systems (GIS) shall play an important role in bridging the existing gaps between the different applications domains.

In GIS environments, the third dimension represents fundamental information for efficient disaster simulations (earthquakes, flooding, etc), urban and environmental planning, building monitoring, telecommunication planning, pollution distribution analysis, microclimate investigations, security evaluation, and others. In the field of visualization, the added value provided by a 3D object in comparison to the corresponding 2D plan is incommensurable. By flying through the 3D city models the user can recognize the location and get the true impression of the height of the buildings around him.

1.2 High Resolution Satellite images Planimetric positioning

In many respects a prerequisite to the application of approaches such as affine projection and the DLT is that the imagery itself has to be of high metric integrity. It should be recalled that the Geo product is "a geometrically corrected product that has been rectified to a pre-specified ellipsoid and map projection” (Space Imaging 2001). Moreover, the imagery is re-sampled by cubic convolution to 1m pixels and in the case of a stereopair it is epipolar resampleawza tosbory 3la d. As a means of both ascertaining the planimetric positioning accuracy of 1m Ikonos imagery and of evaluating ‘sensor linearity’, a number of 3D transformations from image to object space were performed.

The aim was to examine the accuracy in XYZ coordinates resulting from mapping the image data to height-corrected ‘planes of control’ using various Ground Control Points(GCPs) configurations.

The results of this 2D accuracy analysis, which are reported in Hanley & Fraser (2001), were very encouraging. For three configurations of six GCPs and 20-25 independent checkpoints, RMS positioning accuracies of 0.3-0.5m were obtained. When a best-fit mapping was carried out using all 32 GCPs, the XY discrepancies displayed RMS values ranging from 0.27m to 0.38m, i.e. from about 0.3 to 0.4 pixels. In the absence of any camera model information, it was felt that this straightforward analysis gave a strong indication of the metric integrity of Ikonos Geo imagery, which augured well for the use of linear models in 3D geopositioning. Moreover, the tests demonstrated that in the presence of good quality control and DTM data (or moderately flat terrain) Ikonos imagery readily yields XY positioning accuracies to 0.5 pixels

Open GIS Consortium (OGC) has developed the Rational function model by the Abstract specification (OGC, 1999) Space Imaging (Grodecki and Dial, 2001).It refers to the camera model as the ‘Rational Polynomial Camera (RPC) model, they also refer to the RPC model coefficients.

RPC can also stand for rational polynomial coefficients, a terminology which is also used by Fraser et al (2002a). In the OGC document (OGC, 1999), the polynomial coefficients are also called Rapid Positioning Capability (PRC) data. Tao in all his publications refers to the rational function model (RFM). The term rational function model will be used and also the term rational polynomial coefficients (RPCs). Rational function model will be used as a generic term, to include the Universal Sensor Model.

An important use of RFM during the past 7 years has been to restitute Ikonos data. Ikonos images can be set up using these RPC's in digital photogrammetric systems such as LPS, SOCET Set and Z/I Imaging and this use will be reported.

These methods allow one to use RFM for 3D reconstruction and stereo measurements. There have been a number of tests carried out to determine the accuracy of the RFM. These break down into those using sensors for which the model is known, such as aerial frame cameras or SPOT, and those using Ikonos data for which the sensor model is not known, and for which the tests must compare only results from the RFM, with ground control points (GCPs).The former are better indicators of the accuracy of the model, although the latter are of more interest.

Tao ha carried out extensive tests on different formulations of the RFM, mainly on SPOT and aerial photography, Hu and Tao (2001),Tao and Hu (2001a,2001b, 2001c).They conclude that the RFM can give very high accuracy for aerial photography and SPOT data in the terrain-independent case. The high order RFM is favorable sometimes, for example, for SPOT data. The normal equations are usually well conditioned. In the terrain dependent case the solution is very sensitive to the GCP distribution, and its design matrix is almost rank-deficient.

Yang (2000) also reports on using the rational function model with aerial photography and SPOT and achieved negligible errors 'when proper polynomial order is used' (under the terrain-independent case). In the case reported, functions lower than third order was used and the correct order can be chosen, based on Root Mean Square Error(RMSE) threshold.

The RPCs provided with Ikonos imagery allow the object to- image transformation to be performed. This gives accuracy in the 3D object space which is consistent with the specifications for the different Ikonos products such as GEO or Precision. The RPCs for the GEO product, which are expected to produce a RMS positioning accuracy of about 25m (www.spaceimaging.com), are derived solely from satellite ephemeris and attitude data, whereas those for Precision products are computed with the additional aid of ground control.

Grodecki and Dial (2001) report that tests with 140 ground control points gave horizontal accuracy of the order of 1m while vertical accuracy was of the order of 2m from a controlled stereo pair over San Diego. Hanley and Fraser (2001) tested Ikonos Geo product by first projecting the control points onto 'planes of control', to minimize the effect of terrain, and then transform the image to these points using affine and projective transformations.

The results show that 0.3-0.5m geopositioning accuracy is achievable from the Geo product without using the rational function solution. Fraser et al (2002a) have extended this work in two dimensions into three, using similar techniques. The true relative accuracy is shown when the stereo pair is transformed by a translation, in the first case using 1 single ground control point (repeated with 4 single GCPs), and in the second case using 4 ground control points (repeated with four sets of 4 GCPs).

As with the Planimetric test, this does not give a true test of the accuracy of the RPCs because they were computed only using the camera model and

sensor position and attitude recorded by on-board GPS receivers and star trackers.
It does however clearly indicate that the RPCs can give good results with Ikonos data. Similar test results were shown in Baltsavias et al (2001).

1.2.1 Building Extraction from High Resolution Imagery

Building extraction from high resolution satellite images has been an important research topic for the last decade. Particularly, the extraction of 3-D building information from very high resolution imagery, mainly aerial photos (C. Baillard.,1997) or IKONOS (Fraser, et al., 2001.)and Quickbird satellite images (N. Chehata, et al,2003).
In most of the previous studies, black and white aerial images have been used as a single data source due to its high resolution (Huertas and Nevatia, 1988; Kim and Nevatia, 1999; Lin and Nevatia, 1998). These methods were mainly based on edge detection, line extraction, and building polygon generation. Since, the height data appear to be an important source for building extraction in the last few years, Digital Surface Models(DSMs)generated from LASER/LIDAR data have been used in several studies (Alharthy and Bethel, 2002; Priestnall et al, 2000).
Building extraction algorithm was tested on high-resolution aerial photography and resulted in the detection of 87% of the buildings; however the accuracy of the extracted buildings was not reported. A technique based on extracting buildings from high-resolution PAN aerial photography by first identifying their cast shadows was developed by Irvin and McKeown (1989). Building hypotheses are initially generated by grouping detected edges and corners into polygons. Shaded regions are then identified using a variety of image processing techniques, followed by identification and simplification of the shadow edge. The shadow edges are then combined with the building

hypotheses to identify buildings. Building extraction accuracy measures for this approach were not reported.

The availability of high spatial resolution satellite images has provided a new data source for building extraction. When compared with the aerial photographs, the high resolution satellite images provide several advantages that include the low cost, accessibility and repeatability.

1.2.2 Building Extraction from IKONOS Satellite Images:

IKONOS can acquire two (stereo) or more images of the same region simultaneously by agile pointing of the sensor through rotation of the satellite body, reducing thus the differences between these images and facilitating automated processes. This fact, together with the high spatial resolution of the images, the 11-bit quantization and the narrow field-of-view allows and requires an extension of the "classical" satellite image processing methods for the full exploitation of the potential of this data.
Building extraction from IKONO is a complex work . Sohn and Dowman (2001) proposed an automatic method of extracting buildings in densely urban areas from IKONOS images. They used large detached buildings without analysis of accuracy and structure details. Ortner (2002) implemented optimization and destruction approaches concurrently for building extraction. A point process technique is developed to extract well-structured buildings. Fraser et al. (2002) compared buildings extracted from IKONOS imagery with those obtained using black and white aerial photographs to evaluate the potential of high-resolution images. Haverkamp (2003) implemented a linking edge chain to extract buildings from IKONOS images. Thomas et al (2003) concluded that high-resolution imagery is a

valuable tool for mapping urban areas in extracting land cover information from high-resolution images.

Height maps in the form of DEMs (Digital Elevation Models) or DTMs (Digital Terrain Models) have proven quite useful for building extraction. Gamba, Dell'Aqua, and Houshmand (2002) use SRTM (Shuttle Radar Topography Mission) data to identify buildings. A lower-resolution DEM is created to estimate the underlying terrain and then subtracted from the SRTM. Areas of sufficient residual height are the buildings. It continues on to model the area buildings and extract the planes of roof sections. Hug (1997) uses laser altimeter data. The method combines the height information with surface reflectance, height texture, and surface gradient to distinguish between buildings and elevated vegetation (trees). Huertas, Kim, and Nevatia (2000) supplement elevation data derived from IFSAR with panchromatic aerial data to confirm the presence of individual buildings.

Investigations on DSM generation from high-resolution imagery include the following. Ridley et al. (1997) evaluated the potential of generating a national mapping database of maximum building heights for buildings at least 5 x 10 m in planimetry by using DSMs extracted by matching of 1m aerial imagery. They report that matching has a potential to provide the requested information if the DSM had a spacing of 1-3 m but with lower accuracy (1.5 – 3 m RMS(Root Mean Square Error)) and completeness compared to manual measurements. Muller et al. (2001) use simulated 1m-resolution and IKONOS data for DSM generation and landuse determination to estimate effective aerodynamic roughness for air pollution modelling and determine position of trees close to buildings that may cause soil subsidence for insurance risk assessment. Dial (2000) also reports the expected mapping accuracy of IKONOS. There are no published investigations on the other two operational high-resolution spaceborne systems (EROS-A1 and