ADVANCES IN DIGITAL PHOTOGRAMMETRY AND MAPPING FROM SPACE

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Advances in space sensor technology have radically transformed the capabilities of our cartographic institutions. Space sensors are imaging the Earth's surface with higher resolution year after year. Algorithms for sensor modeling are becoming more accurate. Some researchers even claim that the use of space images instead of traditional aerial photographs reduces the costs of map production on some scales. Additionally, imagery from space has major advantages for the cartography of large countries, the creation of general map products and the automation of cartographic production. Recent evaluations of space photogrammetric techniques indicate the revolution in cartography is just beginning.

Introduction

During the last two decades, large quantities of satellite data were available to the public (Sanchez, 1996). However, only a small percentage of that data has been analyzed and used for mapping purposes. This is probably due to the limited markets for low resolution data, national security restrictions on high-resolution data, and lack of application awareness.

Recent advances in space sensor technology make possible high-resolution satellite systems resulting in the availability of space imagery with 1 to 2m ground resolutions. Rapid global coverage by these recent high-resolution space sensors brings to us the necessary tools for map revision and production particularly essential in areas of the Earth's surface undergoing fast changes.

However, efficient algorithms meeting the increasing demands for new cartographic products must support the new sensor technologies. The automation of most of the cartographic processes involving cartography from space emerges as one of the most important issues in recent developments in the area of space photogrammetry. The integration of satellite multisensor images with spatial base data is becoming a useful and important practice in Geographical Information Systems (GIS) development and maintenance (Seitz, 1995).

From Hardcopy to Digital

From Aerial Photography to High-Resolution Imagery from Space.

In the last few decades, the world of mapping has been experiencing a gradual transition from conventional graphical mapping to numerical, computerized mapping. Digital photogrammetry is rapidly evolving, while there are no foreseen changes in the use of analog aerial photos. The main disadvantage of using analog aerial photos pertains to the generic loss of accuracy during the scanning process. Only image scanners specifically designed for photogrammetric applications guarantee the required accuracy. Further, aerial photography is cheap to obtain, but the two-step process of conversion to digital format and orthorectification can be time-consuming and expensive. Although the start-up costs of new high-resolution imagery space sensors are often mentioned as a drawback for cartography from space, the advantages of digital photogrammetry supersede initial inputs. Once the full chain process is implemented and automated, map production from space digital imagery becomes more cost effective, less time consuming and provides a broader range of data for various map applications.

The Era of Digital and GIS

The boom in high-resolution digital images coincides with the development of low-cost, integrated, high-speed, user-friendly image processing tools. The data volume problems are being solved with data compression techniques, software and optical disks or other storage devices now common in GIS environments (Sanchez, 1996). The availability of digital space imagery expands the data sources used in GIS for analysis and mapping purposes. These data, along with emerging technologies including global navigation satellite systems, are already providing a more effective means for mapping changes over the Earth's surface.

Many users will continue to rely on orthophotographs for the detail needed, for example, in urban and cadastral work, and will continue using it to complement the digital information from space for still some years to come. Meanwhile, it is important to develop the techniques, instrumentation and software necessary to progressively substitute scanned aerial photographs (Williams and Norton, 2000; Han and Bae, 2000). The key to such progressive advances in the area of space photogrammetry and cartography lies in automation. Image matching and digital correlation techniques are the mapping community's main concern, and it is now the focus of the photogrammetric digital processing industry (Abdullah, 1996).

Space Sensor Imagery and Cartographic Applications

The use of space sensor imagery provides previously unavailable, up-to-date land use information as well as a synoptic view of overall extensive areas. The multi-temporal, multi-spectral characteristic of space imagery is becoming more and more important in the production of new map products demanded by research and governmental sectors, as well as from the common citizen (Ehlers, 1993). Whether we consider map production or revision processes, space sensor imagery needs to be referenced to a Datum. Referencing enables analysis and comparison with former map products in order to meet defined map-standards and accuracy of feature location or for integration with remote sensing studies or objectives. Usually the integration of a base map such as a topographic map relies on computer-based digital analysis of the data (Li and Baker, 2000). The digital procedure ensures accuracy, ease and time efficiency.

The digital integration of high spatial resolution images and multi-spectral data into a GIS can provide a highly flexible tool for intuitive and contextual analysis. It also can serve to update large amounts of spatial base data. It is important to keep in mind the limitation of current and future satellite image integration with spatial base data, and to balance the criteria for its use against practical considerations of GIS design and management. The potential applications of this type of data and technology are wide and depend in many cases on how reliable the photogrammetric orientation and rectification software is for each space sensor.

Data Accuracy and Map Scales

Usefulness of Imagery and Scale-image Content Classification

With recent advances in space photogrammetry we also have to reconsider the way we communicate the means for interpreting the contents of an image. The interpretability and content of an aerial photograph is well defined when its scale and camera are given. However, with the advances in sensors and technology, the guidelines relating scale and interpretability no longer hold true. With the proliferation of new systems of different characteristics, a measure of quality is no longer adequate to request or express its utility (Jamison, 2000).

The United States Government's Imagery Resolution and Reporting Standards (IRARS) recently developed a National Imagery Interpretability Rating Scale (NIIRS) system to quantify the usefulness of imagery (Leachtenauer, 1996). The NIIRS ratings serve as a shorthand description of the information that can be extracted from a given image. Different levels are defined by the type of tasks an analyst can perform with imagery of a given level. Separate scales were developed for different types of imagery, namely panchromatic imagery, synthetic aperture radar (SAR), thermal infrared, and multi-spectral imagery.

The accuracy and characteristics of the final photogrammetric product obtained using a space sensor image, or a stereoscopic imagepair, depend on several factors: 1) the geometric characteristics of the sensor and of the platform; 2) the model adopted for its orientation; 3) control distribution; and 4) any initial data used for the orientation process. Despite the potential for significant variation between different approaches, the photogrammetric techniques adopted and algorithms developed tend to give similar accuracy for a data set. Only punctual differences in the mathematical resolutions adopted or numerical functions used were found in the algorithms developed by different institutions. This aspect is assessed in a later section of this paper.

Map Production / Revision and Imagery from Space

Tables 1 presents some of the most common space sensor data used in different mapping applications, for map revision and production at the given scales. There is no agreement in the research community as far as the application scales presented. However, the author found a majority of private, governmental and academic institutions that support these numbers. In some cases, cartographic institutions are actually already producing cartography at those scales for commercial purposes.

platform	altitude	sensor / / system	ground resolution	type of stereo	♠ scale for map.
ADEOS	797 km	AVNIR	8 m (P) 16 m (MS)	ALT	1:50,000
CBERS	778 km	CCD camera	19.5 m	ACT	1:50,000
HIROS	700 km	AVNIR-2 VSAR	2.5 m (P) 10 m (SAR)	ALT	1:25,000
IRS-1C IRS-1D	817 km 817 km	LISS III WiFS	< 10 m (P) 23.5 m (MS) 188 m		1:50,000
SPOT-4	830 km	HRV	10 m	ACT	1:50,000
SPOT-5	830 km	HRV	5 m	ALT+ACT	1:25,000
EOS	700km	ASTER	15 m (VIS)	ALT+ACT	1:100,000
Ikonos-1	750 km	Ikonos	1m		1:10,000
Landsat-7	700 km	HRMSI	5 m (P)		1:25,000

Table 1 – Opto-electronic sensors.

Sensors with a pointable mirror, or linear arrays of CCDs covering different viewing angles permit a three-dimensional modeling of the terrain through stereoscopy. The use of stereoscopic models results in better models of the terrain and contributes to the reduction of production costs. Data that do not allow stereoscopic modeling of the Earth's surface are still used for map production by means of matching with other data, georeferentiation, overlay with DEMs, or other techniques (Toutin, 1992; Baltsavias, 1991). Radar imagery, and SAR in particular have recently experienced great improvement and are also becoming widely used for mapping purposes.

Radar data have been used for many different types of mapping applications over the past years. The capability of radar to "see through" clouds makes it a particularly useful tool in the tropical regions of the world. However, the use of radar for some applications in the past has generally involved radar systems having only a single frequency and polarization. A few studies involving more than one frequency or polarization have indicated that a "multi-spectral" radar capability would have a great potential for mapping forest cover as well as many other forestry applications. Analyses of radar also indicate that variations in topography cause significant differences in backscatter, thereby causing tremendous variations in tone that are not related to the characteristics of the forest cover. Since forests are often in mountainous regions of the world, this topographic effect on radar imagery of forest cover can be a significant limitation of the operational utility of radar data.

Many possible application areas and potential uses of radar data need to be studied further. It would appear that there are far more areas of uncertainty concerning the use of radar for mapping applications than there are areas where operational capabilities have been thoroughly documented. It is also quite likely that commercial organizations involved in obtaining and analyzing radar data have many valuable insights concerning the use and limitations of radar that are not well documented in the literature (that is primarily concerned with research activities as opposed to the operational use of radar technology).

Modeling Digital Imagery from Space

The accuracy to which imagery from space is modeled defines its suitability for cartographic purposes. There are two common approaches to this problem: adopting a physical modeling or a polynomial approach for the description of the platform's position with time and attitude variations (Neto, 1993; Ebner, 1988). The so-called physical description of the sensor's orbit, making use of classical collinearity equations from photogrammetry, is the most commonly adopted. This approach also makes use of the orbital parameters to describe the variation of position with time. Also, the orbital approach reduces the orientation parameters needed to a minimum, requiring less control data for the orientation process. Polynomial approaches are not as stable particularly when applied to describe long arcs of the orbit.

Recent research in modeling algorithms considers the use of Global Positioning Systems (GPS) both for tracking the sensor's position in space and the data directly used in the orientation, and for visiting ground control. The main advantage of GPS is the easy elimination of human biases while selecting error check sites. The use of projection center coordinates derived by kinematic GPS positioning in the bundle block adjustment is becoming standard and reduces the number of required control points. On-flight recorded data about the position and attitude of the sensor platform plays an important role in the automation of image orientation and digital mapping procedures.

Toth (1994) and Schenk (1995) have been conducting tests in the area of aerotriangulation of digital imagery. They consider constrained collinearity equations relating the sensor coordinates of measured pair points to corresponding world coordinates via kinematic orientation. The semi-automatic method developed is an attractive solution for conventional mapping and is a valuable supplement for purely digital approaches yet to come.

The complexity of the many different types of space imagery becoming available requires the development of more widely applicable modeling algorithms. Yet, the algorithms should be robust enough to give the accuracy required for cartographic purposes.

Usually, point selection, point transfer, point measurement and final block adjustment have to be performed sequentially using point mark/transfer instruments and analytical plotters. Digital aerotriangulation can combine these steps into one integral procedure, and thus open new possibilities for the overall performance. One key technique is the application of matching procedures to digitized images, enabling a substantial automation of aerial triangulation (AT) (Heutchel, 1996).

Matching clusters of points is an essential and advantageous strategy in the image matching process. The redundancy can be used for the identification and elimination of mismatches. Also, it improves the results of the block adjustment. Measuring a large number of points does not represent a large additional expenditure for a digital system because the computer can simultaneously access all overlapping photos of a block. Further, optimized algorithms have been developed for point extraction.

Image to map registration is another important function being integrated into mapping procedures with direct application to map revision and change detection. Major research institutions have been assessing flexible and general ways to automate these registration processes. The more promising solutions are generally based on the some method of feature extraction – the main objective is to find a set of common points on the map and the image. Polygons are typically the most used features. As such, research has focused on developing robust algorithms for automatic polygon extraction.

Recent work in automatic feature extraction methods have shown a number of promising algorithms. These algorithms use a method of edge focusing to extract edges and region segmentation based upon minimum line description. Although already developed algorithms give good results, a necessary step in the automation process from digital imagery is to match patches and edges accurately.

The automatic recognition of cloud and snow cover in digital images presents even greater challenges to the mapping community. There is little or no operational experience in developing algorithms for automatic detection and masking of clouds and snow without multi-spectral information. However, as it directly intervenes in the automatic matching functions, the automation of this process requires immediate consideration.

Automation of Cartography

In recent years, the scientific community has been monitoring the evolution of Digital Photogrammetry as a promising field for the qualitative and quantitative representation of data coming from digital imagery. In analog and analytical photogrammetry, human operators have the task of measuring image points and identifying conjugate points in a block of photographs (aerotriangulation). Recently, digital photogrammetry approached the above tasks and its variants automatically or semi-automatically, where only human operators control the processing chain (Weidner, 1999).

The introduction of thresholding parameters and rules of thumb in automatic procedures usually restricts algorithm's wide applicability. Area-based matching techniques require the availability of very good approximations. Consequently, they become time consuming operations as they are embedded inside pyramidal structures.

Some of the image matching techniques fail due to different exposure set-ups. Scaling and rotation effects are introduced and the simultaneous variability of illumination conditions make conjugate image patches differ significantly. In order to move to higher-level vision processes such as image interpretation, it is better to apply an algorithmic framework. This type of framework deals with high level primitives such as lines, edges, regions. By introducing knowledge of topological and relational types we accommodate the mapping process and move towards image understanding (Agouris and Stefanidis, 1996).

Object extraction is one of the most important photogrammetric analysis processes. The resulting information (spatial position of objects) is essential to a wide variety of applications, especially GIS-related ones. Monoplotting strategies have been adopted, which do not necessarily imply monoscopic measurements, even though this is the case in most methods. It is common to associate a DEM to a single image to get survey coordinate reference. The use of a least squares based matching methodology is supportive of such an extension. It has been shown to be very suitable for multiphoto application (Baltsavias, 1991). It is foreseen that monoplotting will allow us to perform in the near future stereo or even multi-stage measurements without dedicated and complicated optical measuring instruments.

An automatic detection of the initial positions of all image patches at a low resolution is the key to the automation of the AT procedure. Automatic point cluster measurement in multiple images leads to a stable block geometry and to very good results of the block adjustment (Tsingas, 1995). Research shows that this strategy can be applied successfully to all image pyramids. Feature extraction has proved difficult to treat, and robust tools, which enhance productivity by automatically extracting and measuring features, are not yet in widespread use (Hoffmann et al., 2000).

The Future of Space Photogrammetry

The recent advancements in digital photogrammetry and in automation allow us to reach the accuracy levels traditionally associated with photogrammetric applications. Additionally, these advancements improve the performance of photogrammetric processes by eliminating human errors and allowing simultaneous access to multiple images rather than the traditional stereo (Id.).

SAR is becoming a competitive type of data, mostly due to improvements in the referencing methods and in data quality. SAR's capability of taking information of the Earth's surface in bad weather conditions makes it appropriate for a wide range of mapping applications.

The implementation of the point cluster strategy in a digital AT is expected to bring in the near future a distinct improvement in accuracy compared to the conventional AT with analytical plotters. It is also expected that the accuracy of a high precision AT will be reached although the precision of a single matched point in a digital image may be less accurate compared with the transfer and measuring accuracy of analytical plotters. Automation is in all cases the priority of any future development in space photogrammetry.

Conclusion

In general, the costs of spaceborne data are higher than classical aerial photography. However, there is still much contention about the costs of mapping with space digital data versus with aerial photography. The procedures of digital photogrammetry are less expensive than classical approaches and will compensate for the more expensive space data. On this fact alone, digital photogrammetry is the future of mapping from space.

Within the next ten years, public and private operators plan to launch over 30 land remote sensing satellites for civil applications. This imminent expansion of the quantity and reliability of raw data from space combined with competitive pressures among suppliers and the availability of cheaper tools for data distribution and exploitation will lead to the improvement of existing applications and the development of new ones. Given the proliferation of systems, users must begin to rethink the ways in which they can use satellite remote sensing of the land for both commercial and scientific purposes.

Considering the computing time per image. It is without a doubt that the development of computer software and hardware will definitely increase the performance of any digital AT, not to mention the economic advantages of faster instrumentation. While software is generally extremely robust, successful use requires a significant level of computer and photogrammetric skills. Some users have expressed a wish for more friendly, intuitive and productive user interfaces and better recovery from user errors. Future software and hardware development must take this into account.

The mapping community is recognizing a general need to reorient and invest institutional, academic and industrial resources into a cost efficient and effective network for providing information. Recent attention to commercial use, management and assessment of the environment creates an opportunity for new and more diverse, theme-oriented map products.

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