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Index

HIGH RESOLUTION SATELLITE IMAGERY: The New Tool to Support Urban Monitoring and Mapping

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ABSTRACT

High-resolution (1 to 2-m ground resolution) satellite imagery has high potential to monitor and map urban environment, towards the production of land use statistics. Based on an error estimation analysis, it is concluded that the ortho-rectified products of high-resolution satellite imagery are within the expected accuracy standards for 1:15000 to 1:10000-scale mapping. These images present high potential for land use identification and correct interpretation, similar to the commonly used aerial photographs. Change detection studies could rely on the simultaneous use of high-resolution satellite imagery and aerial photograph acquisitions, since the two data types, provide information at a comparable level of detail. Undoubtedly the high-resolution imagery could complement, and under specific circumstances, replace high altitude aerial photography, in the frame of land use mapping studies.

1. INTRODUCTION

Satellite remote sensing can provide a method for acquiring regular and up to date information on urban areas, which may be particularly useful for monitoring the urban environment and urban expansion (*Foster, B.C.: 1985*). Examples in using Landsat MSS and TM data for urban classification are reported in various studies (*Haac et al: 1987, Khorram et al: 1987*). Other studies investigate the use of multi-spectral SPOT imagery or merged Landsat TM and SPOT P data (*Martin et al: 1989, Harrison et al: 1988, Welch et al: 1987*). Various image pre-processing and image analysis and classification techniques have been tested, in the frame of relevant studies, towards the production of meaningful thematic land use products, (*Khorram et al: 1987, Toll: 1985, Ryherd, S. et al: 1996, Paola, J. et al: 1997, Cushnie, J.L. et al: 1987, Barsnley et al: 1989, Spooner et al: 1991, Harris, P.M. et al: 1995, Moller-Jensen, L.: 1990 Sadler et al: 1990*). However, these experiments have shown no significant improvement in land use class specificity, at the level of detail required by statistical organisations (e.g. EUROSTAT's CLUSTERS nomenclature). This is mainly attributed to the coarse spatial resolution of the satellite data.

The future satellite technology will provide sensors with high spatial resolution and stereopair capabilities. Systems like the upcoming IKONOS, QUICKBIRD, and EARTHWATCH, or existing ones (e.g. IRS-1C P, KOSMOS) are better adapted to studies for urban mapping. It could complement and in some cases replace the high altitude aerial photography. It may be proved especially useful in cases where the use of aerial photographs becomes less cost effective and time consuming procedure.

The remaining of the paper is a summary of the conclusions of the study "Statistical ATLAS for Urban Agglomerations in EUROPE", aiming to identify the extend by which the needs for statistical mapping in urban areas, may be met by very high-resolution satellite imagery. The main aims of the study were:

1. To evaluate and quantify the contribution of very high-resolution optical satellite imagery for urban mapping according to the EUROSTAT's CLUSTERS nomenclature scheme.
2. To clearly identify and utilise the complementary nature of these data sources with conventional aerial photography.
3. To define the necessary data pre-processing procedures, analysis chains and product quality control measures, which permit repeat exercises to be carried out more economically and efficiently in the future for change detection studies.
4. To find and evaluate the needs for new algorithmic approaches to process the very high-resolution satellite imagery.

2. STUDY AREA / INPUT DATA SET / DATA PRE-PROCESSING

The study area is the city of Athens (HELLAS). Athens represents a typical example of a large urban agglomeration in Europe, which has changed significantly through the last decades. Planning actions for the city, require continuous mapping works and change detection studies, at the level of the residential block.

Multi-temporal and multi-spectral IRS-1C LISIII data as well as panchromatic data from the same sensor (IRS-1C P) have been used in the frame of the study. Their ground resolution is 25 meters and 5 meters respectively. In addition an older acquisition of the KVR-1000 camera (ground resolution=2 meters) and several 1:30000-scale aerial photographs, covering the study area have been used, in order to apply change detection. The use of this variety of data, gave the opportunity to evaluate the range of capabilities offered by high resolution satellite imagery for large scale mapping, and land use identification and correct interpretation, as a function of the pixel resolution. The relevant comparison with high altitude aerial photography permits to evaluate the complementary nature of the two data sets.

The satellite data pre-processing comprised the following works:

- *DTM production.* Two DTMs were used, which differ in spatial and height accuracy. The one has been produced by contour digitisation using 1:50000-scale maps. The height accuracy of this product was of the order of ±10m. Another more detailed DTM has been produced by a pure photogrammetric approach, based on the use of 1:30000-scale aerial photographs. The locational and height accuracy of the second DTM was of the order of ±2.5m.

- *Ortho-rectification of IRS-1C P and KVR-1000 scenes.* The two satellite scenes were ortho-rectified by using the DTMs described before. The fine resolution of the KVR-1000 scene, required the use of the more precise DTM, in order to get a properly geo-referenced image. The mean residual errors, in X and Y directions, resulted from the IRS-1C P image ortho-rectification, were σ_X=3.29 m (0.66 pixels), σ_Y=3.4 m (0.68 pixels) and σ_{XY}=4.73 m (0.94 pixels). The same error estimations for the ortho-rectified KVR-1000 scene, were σ_X= 0.69 m (0.35 pixels), σ_Y= 0.46 m (0.23 pixels), σ_{XY}= 0.83 m (0.41 pixels).
- *Geometric registration of the two-date multi-spectral IRS-1C LISS III scenes,* using as reference:
  - (A) the panchromatic IRS-1C P image and
  - (B) the KVR-1000 scene

The mean residual errors, in X and Y directions, were:

(a) σ_X= 2.68m (0.53 pixels), σ_Y= 2.94m (0.59 pixels) and σ_{XY}= 3.98m (0.80 pixels), and,

(b) σ_X= 1.89m (0.38 pixels), σ_Y= 2.52m (0.50 pixels) and σ_{XY}= 3.15m (0.63 pixels), in case (A) above and,

(c) σ_X=0.50 m (0.25 pixels), σ_Y= 0.44 m (0.22 pixels), and σ_{XY}= 0.67 m (0.33 pixels), and,

(d) σ_X= 0.56 m (0.28 pixels), σ_Y=0.69 m (0.35 pixels) and σ_{XY}= 0.89 m (0.45 pixels), in case (B).

Other data pre-processing steps relate to:

- *Photogrammetric block adjustment and ortho-photo map production,* for a 10x10 km2 area, seen also by IRS-1C P and KVR-1000 sensors.
- *Satellite data fusion.* Merging of the IRS-1C LISSIII coarser resolution scenes with the high resolution IRS-1C P and KVR-1000 ones. These enhanced multi-spectral thematic products have been proved as being significant input for land use photo-interpretation and automatic classification.

3. TESTING THE POTENTIAL OF VERY HIGH RESOLUTION SATELLITE IMAGERY FOR URBAN MAPPING

The study of the potential of high-resolution satellite imagery (KVR-1000 and IRS-1C P), has been based on the examination of parameters, which have essential impact in urban mapping. Therefore,

(a) the geometric accuracy of the ortho-rectified imagery in comparison with the accuracy inherent to ortho-photo maps produced from high altitude aerial photography, and,

(b) the capabilities offered for single object representation and identification, as well as extraction of land cover/land use information, at the required level of specificity,

have been examined in the frame of the study.

The study of the geometric accuracy of the ortho-rectified imagery was based on a set of independent checkpoints. The co-ordinates of these points were derived from the 1:5000-scale topographic maps. The map co-ordinates of the checkpoints (reference), have been compared with the co-ordinates of the same points extracted from the ortho-rectified imagery (KVR-

1000, IRS-1C P), and the ortho-photo map. From the accuracy assessment carried out, it may be resulted that:

1. Around 90% of the examined points, are identified within the expected accuracy for the 1:10000-scale maps, when 1:30000-scale aerial photography, adequately ortho-rectified, are used. The mean errors, calculated out of the total number of checkpoints, were ó$_x$=1.55m, ó$_y$=1.30m and ó$_{xy}$=2.02m.
2. Seventy five per cent (75%) of the checkpoints were identified onto the ortho-rectified KVR-1000 scene, within the expected accuracy for 1:15000-scale mapping (nominal accuracy for 1:15000 maps = ±3.75m). In this case the mean errors reported are ó$_x$=2.86m, ó$_y$=1.81m and ó$_{xy}$=3.38m.

In both cases (1) and (2) above, the ortho-rectification was based on the use of a very detailed DTM produced by aerial photo stereo-pair correlation.

The accuracy assessment study, concerning the ortho-rectified IRS-1C P image, showed that 73% of the points could be identified within the expected accuracy for 1:20000-scale mapping. The pixel resolution of the ortho-rectified IRS-1C P image was 5 meters. The mean errors calculated out of the total number of checkpoints, were ó$_x$=3.71m, ó$_y$=2.98m and ó$_{xy}$=4.76m.

The results of the study for feature identification and correct interpretation, based on the use of ortho-rectified KVR-1000 and IRS 1C P images, show that exactly the same potential, as for high altitude aerial photography, was reported, when general land use classes, like "continuous and dense residential", "discontinuous residential of moderate density", "isolated residential areas", "industrial and commercial zones", etc, were subject of interpretation. This is because the photo-interpreter, is capable to recognise, onto the ortho-rectified KVR-1000 and IRS-1C P scenes, the existing land cover classes (e.g. houses, roads, gardens, leisure areas, sport facilities, etc), and group them into discrete land use categories on the basis of their spatial frequency (see section 4). However, the potential in recognising single features depended mainly on the size of the studied objects and the resolution of the input satellite image. Therefore on the ortho-rectified KVR-1000 scene, single objects were identified and interpreted correctly at a relatively high percentage (89.72%). The same value was much lower when the 5 meter resolution ortho-rectified IRS-1C P image was used as input. The corresponding percentage for correctly interpreted single objects was around 50%. Therefore, the 5 meter resolution imagery, although not providing the detail that helps to identify successfully single feature elements, yet returns meaningful information on the existing land use patterns (see fig.1). In both tests the reference image used, was the 1:30000-scale aerial photography scanned at the resolution of 22.5 ìm per pixel (=0.675 m).

4. TESTING THE POTENTIAL OF KERNEL BASED IMAGE CLASSIFICATION TECHNIQUES

The extraction of reliable signatures for urban land use classes, requires algorithms which measure the spatial distribution of the spectral and texture properties in the pixel context and produce significant features to introduce into the classification procedure. Two Kernel Based Classification Approaches have been considered, for the purposes of the study: (a) a combination of a supervised and unsupervised Artificial Neural Network (ANN) approach, and (b) the Kernel Reclassification Algorithm.

The application of an unsupervised neural network based on a topological map (Kohonen map, *Kohonen, T.: 1987*) permitted to decide about the optimal kernel size and input image information content (*Paola, J.D. et al: 1995 and Wilkinson et al: 1995*). Best clustering results were returned by the application of a 7x7 kernel on multi-temporal and enhanced (merged) satellite data. The results of this investigation, were used to feed appropriately the back-propagation neural network, consisted of one input layer, two hidden layers and an output layer. The dimension of the network has been defined in an iterative approach in order to avoid over-learning of the network. The input and output layers of the network comprise of six nodes. This means that the number of input satellite layers is six (two dates IRS-1C LISSIII images) and the number of the output land use classes is also six. The two hidden layers comprise of 26 and 14 nodes respectively, which were completely linked with each other. The classification has been achieved in three steps: the training phase, the pre-reclassification phase to verify the success of the learning phase and the classification phase.

The Kernel Based Reclassification Algorithm attempted to derive information on urban land use based on the frequency and the spatial arrangement of the land cover labels within a square kernel. The assumption underlying this approach is that individual categories of land use have characteristic spatial mixtures of spectrally distinct land cover types that enable their recognition in high spatial resolution images (*Wharton: 1982, Barnsley et al: 1992*). The algorithm operates in two stages: The first involves labelling of the image pixels into single land cover classes by the application of a supervised or unsupervised clustering. In a second stage, the pixel labels are grouped into discrete land use categories on the basis of their frequency and spatial arrangement within a square kernel. A pure mathematical description of the algorithm is given in *Barnsley, M. et al: 1996.*

Compared with a pure statistical approach like the maximum likelihood classifier, neural networks or reclassification approaches can offer some advantages. This is especially the case, when insensitivity against noise and redundant information, as well as independence from normal distribution and introduction of texture information is required. Four different experiments have been conducted in the frame of the study. Two of them were using as input the two enhanced (merged with IRS-1C P image) multi-spectral IRS-1C LISSIII satellite scenes resampled to 5 meters. The two experiments were using different classification approaches, that is the ANN and the Kernel Reclassification Algorithm. They showed that meaningful land use information on urban classes might be extracted by the use of the ANN and Kernel Reclassification Algorithm. Four residential classes, with different housing density characteristics, have been returned. These classes are "Continuous dense residential", "Continuous residential of moderate density", "Discontinuous residential of moderate density", "Isolated building areas". The classes “Industrial and Commercial” were recognised as one mixed class. Further distinction between the two was not possible with this image resolution. The remaining land use classes, according to the used nomenclature (EUROSTAT’s CLUSTERS scheme) are functional classes. These classes would never be possible to be returned by pure automatic techniques, unless hybrid approaches integrating existing knowledge or human logic were applied. The classification accuracy level achieved in both experiments was of the order of 72%.

The next two classification experiments, have used as input the enhanced multi-spectral IRS-1C LISSIII scenes, merged with a KVR-1000 image, producing thus layers with pixel resolution of 2 meters. With the exception of the Kernel Reclassification Algorithm, the application of the back-propagation neural network gave rather similar results. This technique succeeded to classify the urban area into the previously mentioned residential land use classes, with relatively good accuracy. The overall classification accuracy achieved was of the order of 72.77%. Thus, using the artificial neural network approach, improving the geometric resolution from 5 meters (IRS-Pan) to 2 meters (KVR-1000) does not give additional benefit for achievement of more land use classes. However, the back-propagation neural network is a valid alternative for automatic classification of high spatial resolution satellite imagery. In contrary, the Kernel Reclassification Algorithm although it returned a rather acceptable level of statistical accuracy, it produced classification maps which may not be accepted from a thematic point of view. This is due to the big size of the kernel required (45x45 pixels or bigger) to extract representative land use classes within the urban area, which in its turn resulted in large smoothing effects on the classification map. A detailed presentation of the above-described works is illustrated in *Kontoes et al: 1998.*

5. Conclusions

The study shows that high-resolution satellite imagery is recommended to map extended areas in larger scales (1:15000 to 1:10000), especially when map update is often required. The use of 2-meter resolution data, appropriately ortho-rectified, could be used for the production of 1:15000-scale maps. The future sensor technology providing stereo-pair capabilities and higher resolutions (less than 1 meter) will have high potential for 1:10000 or larger (1:5000) scale mapping.

The use of satellite imagery is a preferable solution to cover and monitor changes within urban zones for various reasons. First much larger image footprints are provided, in comparison with aerial photographs. Image acquisition is not restricted and may be repeated in regular time periods and at lower cost rates. In addition, the processing of the satellite data is less time consuming and man effort requiring approach. However, special effort should be given by HW and SW developers to provide tools, which can better handle and process the new high resolution satellite imagery. Tools for enhanced processing of highly tilted stereo-pairs of images, as well as storage models to better handle bigger volumes of image data on the disk, should be developed. Regarding the use of automatic image analysis techniques, it becomes evident that special effort should be placed on further development and refinement of kernel and region based approaches, as well as on techniques accounting for the geometric and structure properties of the objects on the image plane. The development and testing of hybrid techniques which make use of human reasoning for feature recognition, is one of the important issues to be studied, in order to perform automatic classification of the satellite data. Automatic approaches still need a lot of training and post-classification refinement to produce meaningful thematic map products.

Finally change detection studies are highly supported by high-resolution images; due to the fact that they are acquired on a regular basis and can be registered precisely one another. It is expected that the future sensor technology, with spatial resolution of 1m or less, will enable the user to identify little changes at the level of the single feature mapped (e.g. house, street, building, etc).

(a)

(b)

Figure 1: Examples of the ortho-rectified (a) IRS-1C P image, (b) 1:30000-scale aerial photograph and (c) KVR-1000 image.

The covered area is about 2 km^2 located at the north-eastern part of the city of Athens. Single features may not easily being seen on the IRS-1C P image (compared to aerial photography or KVR-1000 scene). However this image shows well enough the existing land use patterns in the city environment. High altitude aerial photographs and KVR-1000 scene provide almost the same information on the city complexity. The three data sets may be undoubtedly used for change detection studies within the urban area. The dark blue arrow indicates an entire city block which is free of houses the date of aerial photo acquisition (May 1987). Five years later (May 1992), the KVR-1000 scene shows that the same block is totally covered by houses. Similarly the light yellow arrow indicates the construction of a new small road in the time lag between aerial photo and KVR-1000 image acquisitions. The same land cover changes may also be reported on the IRS-1C P scene, acquired ten years later (April 1997).

(c)

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