

APPLICATION OF HIGH SPATIAL RESOLUTION SATELLITE IMAGERY FOR URBAN ENVIRONMENT MAPPING

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ABSTRACT:

The aim of the study is to develop automatic procedures for the identification of urbanized and not urbanized areas using high spatial resolution remote sensing data. We examine the potential of panchromatic and multispectral Quickbird images for the classification of different urban areas in the Province of Milan (Italy).

Satellite data were initially pre-processed by using an orthorectification procedure with ground control points in order to achieve a high geometrical accuracy. Geometrical accuracy was evaluated by means of the analysis of the root mean square positioning error that was found to be from 2.5 to 5 m in the different images.

An object-oriented classification based on a multi-resolution segmentation technique was applied by means of the *e.Cognition* software, in order to obtain the classification of urban land cover types.

This methodology allowed the creation of thematic maps with several intra-urban land use classes, which can be used as a cartographic background in urban studies. The results confirm that the classification of Quickbird images is a powerful tool for urban development, environmental protection, policy making, risk assessment and planning.

1. INTRODUCTION

Remote sensing has made enormous progress over the last decades and a variety of sensors now deliver medium and high resolution data on an operational basis. Nevertheless, a vast majority of applications still rely on basic image processing concepts developed in the early seventies, classification of single pixels in a multi-dimensional feature space. The spatial context plays a modest role in pixel-based analysis. Consequently, classical algorithms of pixel based image analysis are becoming less important for high resolution classification (Antunes et al., 2003).

Alternatives to a pixel based classification are being currently developed for instance the object oriented approach that takes into account the form, textures and spectral information. Object-based classification starts with the crucial initial step of grouping neighbouring pixels into meaningful areas, especially for the end-user. This means that the segmentation and object (topology) generation must be set according to the resolution and the scale of the expected objects.

2. QUICKBIRD SENSOR

DigitalGlobe's QuickBird satellite was launched in October 2001 aboard a Boeing Delta II rocket, from Vandenberg Air Force Base, CA. QuickBird provides the highest resolution commercial satellite imagery currently available (0.61-meter black and white and 2.4 meter colour). The multispectral imagery has four bands—red, blue, green and near-infrared—which has a variety of uses, such as vegetation studies, as the near-infrared can be used to differentiate between surfaces. The sensors are based on a “push-broom” scanning array. The push-broom sensor can be pointed on the ground and moved across a specified area of geography to collect pieces of geography many times larger than the sensor projection itself. This method allows for larger pieces of continuous image data to be

collected. The most important QuickBird specifications are illustrated in Table1.

| Features | Description |
|----------------------------|---|
| Orbit Altitude | 450 Km |
| Sensor Resolution at nadir | 0.61 cm panchromatic |
| Panchromatic Bandwidth | 2.44 m multispectral from 445 nm to 900 nm <ul style="list-style-type: none">• blue from 450 to 520 nm• green from 520 to 600 nm |
| Multispectral Bandwidth | <ul style="list-style-type: none">• red from 630 to 690 nm• Near-IR from 760 to 900 nm |
| Metric Accuracy | 23-meter circular error; 17-meter linear error (without ground control) |
| Onboard Storage | 128 Gbits capacity |
| Dynamic Range | 11-bits per pixel |
| Revisit Frequency | 1 to 3.5 days depending on latitude |
| Nominal Swath Width | 16.5-kilometers at nadir |
| Single Area Size | 16.5 Km x 16.5 Km |

Table 1. QuickBird characteristics

Because some QuickBird Imagery Products allow the option to break up imagery into smaller pieces called tiles. Tiles may be defined by pixel based grids or by map based coordinates. A tile map file is delivered with every product to help place the tiles in product coordinates.

Quickbird data are in different formats:

- *Basic Imagery*
- *Standard Imagery*

- *Standard Ortho Ready Imagery*
- *Ortho Imagery*

The first three products can be submitted to a geometrical processing by the user, while the last one has been already orthorectified by DigitalGlobe (DigitalGlobe, 2003).

3. STUDY AREA

This study focused on a specific urban area (Province of Milan) of the Lombardy Region (Italy): the Province of Milan governs the largest metropolitan area in Italy, and it is situated in the middle of one of the most highly populated regions of Europe. Almost four million people live and work in the district administered by the Province, all within an area of less than 2000 square kilometres. This number represents 6.5% of the population of Italy and 41.6% of the population of Lombardy. In addition to the urban cover types, non urban land cover types include water bodies, green vegetation (usually irrigated or agriculture) and bare soil (e.g. constructions sites). The urban area represents different types of land use including residential area with high densities, mixed-use areas, and commercial and industrial districts with various urban built-up cover types such as roof, roads, and parking.

4. DATA PRE-PROCESSING

4.1 Orthorectification process through RPCs

In this study we used *Standard Ortho Ready Imagery*, and we applied an orthorectification process in order to remove the effects of topographic relief displacement and distortions induced by the variation in altitude, speed, and attitude of the platform. The output of orthorectification is a planimetrically true image.

The most used methods for the rectification are based on sensor-related information, by using a sensor model that can be of two types: physical or generic. The main difference is that the physical models are rigorous, and require the knowledge of the specific sensor for which they have been designed; each parameter involved has a physical meaning. The generic sensor models, on the other side, are sensor-independent, that is the knowledge of the sensor and of the physical meaning of the image collection process are not required (Volpe, 2003).

A rigorous model enables an accurate three-dimensional description and orthorectification of the imagery. A generic sensor model supplies the relationship existing between the three-dimensional coordinates of an object, and the corresponding image coordinates in a generic mathematical form. The RFM (Rational Function Model) can be considered one of the generalised models used by more than ten years (Hu et al., 2004) instead of rigorous models. It expresses the relationship between object and image coordinates through the use of ratio of polynomial expressions. The coefficients of the polynomial are the Rational Polynomial Coefficients or Rapid Positioning Capability (RPCs).

Satellite images have been orthorectified by using the generic (Rational Function sensor model). QuickBird images are supplied with their RPCs file: the accuracy precision of the final products can be improved by using one or more GCPs (Ground Control Points). In order to use the RPC approach, it was necessary to use DEM (Digital Elevation Model), otherwise the processing must be carried out with a constant value elevation, for example for totally flat areas.

4.2 Data Processing

All satellite images have been orthorectified by using ENVI 4.2 software. The RPC orthorectification process combines several input data to place each pixel in the correct ground location:

1) The images to rectify. We processed 33 panchromatic and 33 multispectral images: the satellite data covered about an 1836 square kilometres area, and they were acquired from 2003 to 2004 (Figure 1).

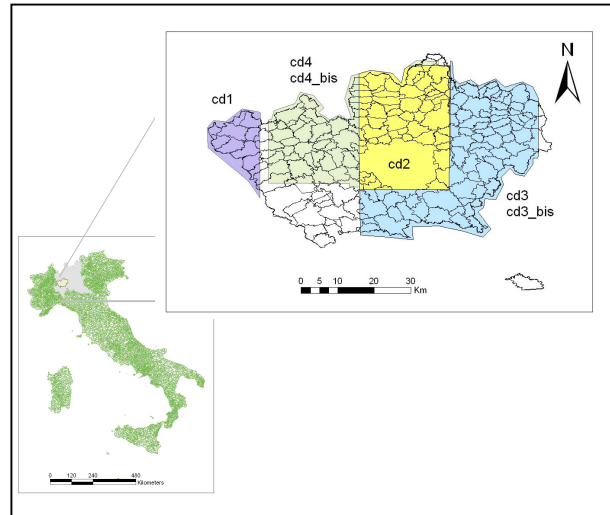


Figure 1. Investigated area and satellite imagery coverage

2) Digital Elevation Model data were provided by the Regione Lombardia with a spatial resolution of 20 meters (Figure 2).

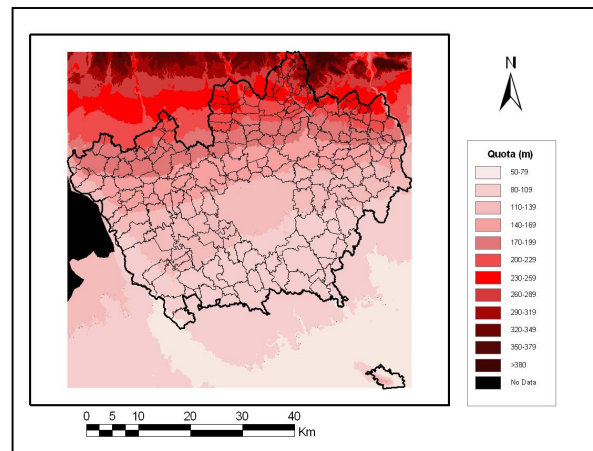


Figure 2. DEM data of the Province of Milan

3) Ground Control Points to enhance the accuracy of the RPC orthorectification process: the GCPs were collected on a mosaic of topographic maps of the Region Lombardia: scale map 1:10000 resample to 0.85 m spatial resolution.

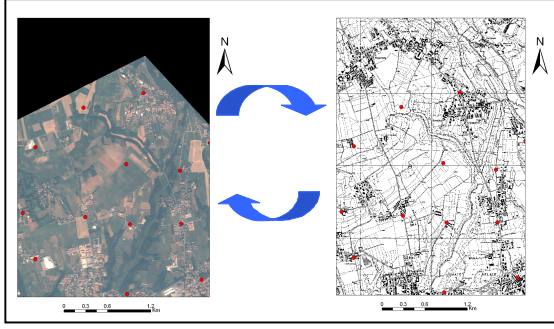


Figure 3. Collection of GCPs

We selected a nearest neighbour resampling method for the image and the bilinear method for the DEM. The orthoimages have been georeferenced in Gauss Boaga, Zone 1.

4.3 Accuracy evaluation

We examined the accuracy in XY coordinates, resulting from the orthorectification process, using new GCPs. We collected 10 random GCPs from orthoimages (points not used in the orthorectification process) and the conjugate check points (CPs) from topographic maps and we calculated the Root Mean Square Error (*RMSE*) as a Euclidean distance from the points:

$$RMSE = \sqrt{\frac{e_1^2 + e_2^2 + \dots + e_n^2}{n}} \quad (1)$$

where e is the error distance for each points:

$$e = \sqrt{(X_t - X_d)^2 + (Y_t - Y_d)^2} \quad (2)$$

where X_t , Y_t are the true coordinates and X_d , Y_d are the data coordinate (Figure 4).

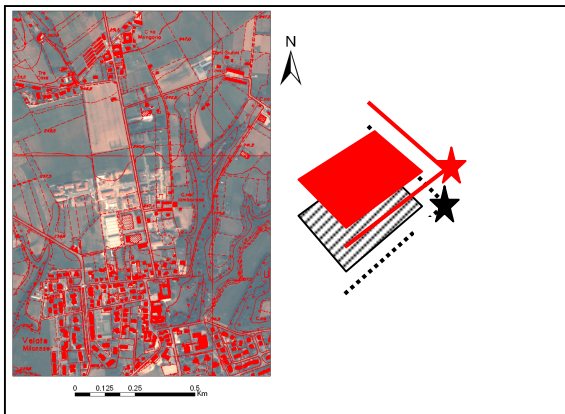


Figure 4. Collection of GCPs and CPs

The *RMSE* varied from 2.41 m to 4.96 m with an average value of about 3.67 m.

5. OBJECT-ORIENTED CLASSIFICATION

The concept behind object oriented classification is that important semantic information necessary to interpret an image is not represented in single pixels, but in meaningful image objects and their mutual relationships. The basic difference, especially when compared to pixel-based procedures, is that the algorithm does not classify single pixel, but rather image objects, which are extracted in a previous image segmentation step.

We used the eCognition 2.1 software that allows for a multi-resolution segmentation. It was developed to extract image objects at different optional resolutions (fine or coarse structures) in high quality (UserGuide eCognition, 2001).

Advantages of object-oriented analysis are meaningful statistic and texture calculation, an increased uncorrelated feature space using shape (e.g. length, number of edges, etc.) and topological features (neighbour, super-object, etc.), and the close relation between real-world objects and image objects (Antunes et al., 2003).

5.1 Classification Strategy

The strategy for the classification was a multi-resolution segmentation, which uses information provided by small object primitives to label large scale objects (Table 2).

| Segmentation Level | Scale | Color | Shape | Shape settings | |
|--------------------|-------|-------|-------|----------------|-------------|
| | | | | Smoothness | Compactness |
| Level 1 | 10 | 0.8 | 0.2 | 0.9 | 0.1 |
| Level 2 | 30 | 0.7 | 0.3 | 0.7 | 0.3 |
| Level 3 | 100 | 0.7 | 0.3 | 0.7 | 0.3 |

Table 2. Segmentation parameters used for the analysis

In particular, in this study we present preliminary results in a test area located on the urban area of Milan. We processed a multispectral image of about 9.5 square kilometres acquired on 19 August 2003 (Figure 5).

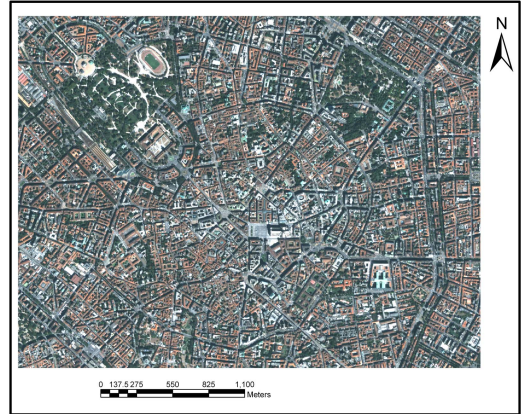


Figure 5. Quickbird multispectral image of urban

The area is characterized by different urban surfaces with similar spectral properties. This work was focused on the possibility to evaluate the separability among several intra-urban land use classes. Class descriptions were performed using a fuzzy approach of nearest neighbour or by combinations of fuzzy sets on object features, defined by membership functions. In this work, the classification was conducted by fuzzy logic (Figure 6).

First the image objects extracted from segmentation Level 1 have been distinguished in two classes using a membership function based on the *NDVI* index: vegetation and urban area.

Secondly, on Level 2, we discriminated three building roofs classes characterized by different materials and spectral reflectance; we used a combination of object features as mean layers values and shape properties. Asphalt roads have been classified by using TeleAtlas vector data while water bodies presented low reflectance value of the blue band. Additional rule-set definitions were introduced, such as relationships with neighbour objects, in order to classify the other classes.

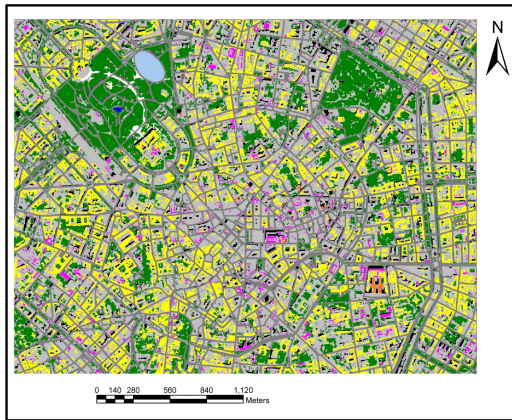


Figure 6. Object-oriented classification of the QuickBird image

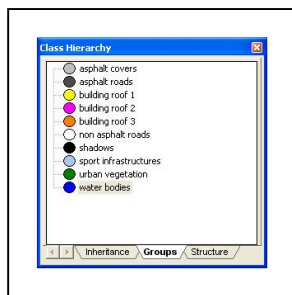


Figure 7. Class Hierarchy Legend

5.2 Results

The presented classification results show the ability of the so far developed rule-sets to distinguish between objects and to generate semantic classes. This is demonstrated with the high value of the overall accuracy – 0.827 of the classification (Figure 8).

| User Class \ Sample | urban vegetation | sport infrastructures | building roof 2 | building roof 3 | shadows | non asphalt roads | water bodies | Sum |
|-------------------------|------------------|-----------------------|-----------------|-----------------|---------|-------------------|--------------|-----|
| urban vegetation | 18 | 0 | 0 | 0 | 0 | 0 | 0 | 18 |
| sport infrastructures | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 3 |
| building roof 2 | 0 | 0 | 17 | 0 | 0 | 0 | 0 | 17 |
| building roof 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| shadows | 1 | 0 | 0 | 0 | 10 | 0 | 0 | 11 |
| non asphalt roads | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 5 |
| water bodies | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 |
| unclassified | 1 | 0 | 0 | 5 | 1 | 4 | 0 | 11 |
| Sum | 20 | 3 | 18 | 11 | 9 | 3 | 3 | |
| Accuracy | | | | | | | | |
| Producer | 0.9 | 1 | 0.944 | 0.545 | 0.889 | 0.556 | 1 | |
| User | 0.947 | 1 | 1 | 1 | 0.909 | 1 | 1 | |
| Hidden | 0.923 | 1 | 0.971 | 0.706 | 0.909 | 0.714 | 1 | |
| Short | 0.927 | 1 | 0.944 | 0.545 | 0.833 | 0.556 | 1 | |
| YIA Per Class | 0.866 | 1 | 0.926 | 0.506 | 0.893 | 0.524 | 1 | |
| Overall Accuracy | 0.827 | | | | | | | |
| KIA | 0.752 | | | | | | | |

Figure 8. Error matrix and statistics

6. CONCLUSIONS

The orthorectification process through RPCs allowed the creation of orthoimages with high positional accuracy (from 2.41 m to 4.96 m). The object-oriented classification based on a multi-resolution segmentation technique enabled us to analyze high resolution data with high values of overall accuracy.

The object-oriented classification performed by eCognition allowed the creation of thematic maps with several intra-urban land use classes, which can be used as a cartographic background in urban studies.

The next step will be the assignment of the deduced classification rules on the whole Province of Milan.

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