MONITORING URBAN AREAS FOR ENVIRONMENT AND SECURITY THROUGH REMOTE SENSING

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ABSTRACT

This paper aims at providing an introduction to the topic of urban area management through remote sensing. It builds over the experience of the GUS (GMES Urban Service) project, funded by ESA in the framework of GMES Service Elements (GSE). We explore the potential of Earth Observation data for the extraction of aggregated data (maps, indicators, ...) useful to urban planners and managers.
More specific results for land use and sealing area mapping are offered to provide a living example of the outputs of the project and the problems as well as the achievements of current analysis algorithms.

1 INTRODUCTION

Environmental monitoring of urban areas seems to be one of the main requests by the citizens around the world. In Europe the Global Monitoring for Environment and Security initiative (GMES) recognizes this need and addresses this topic by means of a project aimed at producing GMES urban services (GUS, 2004). In USA many projects are considering urban remote sensing (e. g. UEM, 2004) as a result of homeland security programs and/or a renewed interest in environmentally aware urban planning.

Despite the number of cases where the technological and scientific knowledge is successfully incorporated in the urban planning decision-making processes, there are still gaps to be filled, especially in terms of technology. We feel that there ought to be an even more active dialogue between the scientific community and decision-makers if we want to accelerate the process of developing new tools and new techniques to collect and monitor indicators as identified by policy-makers. For instance, there is no unique definition of urban areas that could be applied to different fields and policy implementation. Definitions vary from country to country (UN-HAB, 2004) and are often based on different parameters. Urban areas may be defined by administrative boundaries, or number of inhabitants, or sometimes simply referred to as "urban centers". Remote sensing provides a good tool to define urban areas in a more consistent way and to produce spatially georeferenced urban extents. It also allows analysis of physical and demographic/socioeconomic characteristics of the urban environment that can be incorporated in decision-making processes at all levels.

Some of the major areas of scientific research in urban remote sensing that have a strong interaction with the policy cycle and would improve environment and security monitoring in these areas include therefore:

- characterization of the urban environment (i.e. delineation, land use classification, differentiation of the inner structures of cities);
- measuring and monitoring physical properties of urban areas (i.e. vegetation, air quality, noise, heat);
- impact analysis and vulnerability assessment (including water management issues, contaminated land, monitoring of informal settlements), also by co-analysis of physical and demographic/socioeconomic characteristics of the urban environment;
- monitoring changes and urban growth over time.

2 EU AND URBAN AREA MANAGEMENT

The goal of GMES is to increase the environmental and security levels inside and outside Europe by integrating Earth Observation (EO) and ancillary data. As a matter of fact, there is a strong interest in developing services exploiting the potentials of remote sensing for monitoring the environment and managing the security internal and external to each country. Not only the European Community is funding through different calls the research effort for GMES related fields of applications (Land Cover and Vegetation, Water Resources, Ocean and Marine Applications, Atmosphere, Risk Management, Security), but also the European Space Agency (ESA) is currently funding 10 projects for the implementation of novel services in a framework called GMES Service Elements (GSE). Among the useful fields in which the GMES initiative can effectively improve the day-by-day management of the environment, the management of urban areas is certainly included. This is the main reason why, among the above mentioned ESA-funded services there is one devoted to this topic, the GMES Urban Services (GUS) Consortium, lead by Indra Espacio (ES).

For urban areas, a particularly important framework where to integrate these efforts is the Urban Thematic Strategy (UTS), addressed by the recent Communication by the Commission (COM(2004)60, "Towards a Thematic Strategy on the Urban Environment"). The UTS discusses many of the problems facing Europe's towns and cities, such as meeting demanding European air quality standards or urban sprawl. These are common problems throughout Europe and the UTS recognizes that there are clear opportunities at the European level to develop, share and facilitate the implementation of appropriate solutions.

In this context the UTS approach is to develop a strong framework at the European level to provide this coordinated approach and more systematic support to cities. Specifically the UTS focusses on sustainable urban management and urban transport and proposes the development of an integrated framework for tackling the different complex issues and to establish coherent and coordinated environmental policies within towns and cities. The approach proposed is that the largest towns and cities in the EU 25 (the 500 or so towns and cities over 100,000 inhabitants) are required by law to develop and implement an urban environment management plan and an environmental management system to ensure its implementation.

It is clear that the UTS generates entirely new policy driven information and intelligence needs based on the urban environmental plan and management system proposed. These information needs are conceptually specified in terms of a cycle of evaluation, target setting and monitoring, based on objective and appropriate data and indicators. The tools and methods essential to deliver this integrated approach to urban management create new demands for higher quality information and intelligence as well as for new concepts of information management.

As an illustration of these new information needs the following listings provide an overview of requirements at both EU and local levels:

- EU Level information needs
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  - Monitor and guide implementation of Urban Thematic Strategy
  - Monitor Directives enforcement of EU legislation
  - Regional Land Use Monitoring
  - EEA "state of the urban environment" report
  - European Topic Centre coordinate information needs
  - New EU level environmental indicators
  - New EU sustainable urban transport indicators
- Local Level information needs
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  - Report on implementation of LA21
  - Harmonization of urban environmental data
  - Plans based on explicit environmental targets, actions and monitoring
  - Need for land use, noise, transport, air quality indicators
  - Data and indicators to be applied according to standards
  - Develop data to indicators for reporting at national and European levels
  - Maximize use of urban management tools and models

3 GUS PRODUCTS

As already recalled GMES Urban Services (GUS) is a project from ESAs GMES Service Element (GSE) aimed to the consolidation of a product portfolio addressed to meet the requirements from urban areas. GUS team is currently made of 11 companies and research teams with the following roles: Service providers (Planetek, Eurosense, Hugin, Indra, SCOT); System Developer (Definiens); Consultants (ControlWare, UWE); Research Partners (Department of Electronics, University of Pavia and Environmental Studies Centre-Vitoria-Gasteiz).

In headlines, GUS portfolio is made of three big components:

- UTS block. Information in support of the UTS, made of different geoinformation layers derived from Earth Observation satellites combined with ancillary information from in-situ measurements including socio-economic data.
- REG block. A set of products at regional scale focused in urban areas and spatial planning.
- DEV block. A set of products for cities in developing countries (collaboration with UN-Hab).

3.1 UTS block

Among the different products addressed by GUS in the UTS block, we would like here to focus on land use mapping. Reason is that this application is extremely more challenging than land cover mapping. Of course, the two tasks have something in common, since they are both classification problems. However, some land use classes are impossible to obtain from remote sensing data only, and land use mapping always requires at least a spatial analysis. As a matter of fact, the use of a land parcel may be different even with the same cover, but may be inferred by its neighborhood.

The problem of land use mapping in urban and periurban areas has been traditionally approached in two ways. The first starts from a detailed land cover map obtained by means of standard or improved classification routines. Then, spatial reclassification by kernel techniques is applied to extract from land cover classifications the land use maps. Alternatively a priori knowledge or external data sets is considered by a human expert or a knowledge system. The second methodology is instead based on a direct approach, which tries to incorporate into the first classification step some kind of spatial (texture) information. Thus, land use maps are directly extracted.

Considering the approach to land use mapping based on extracting first the land cover and then land use classes, an overview of the present methodologies requires first some considerations on land cover mapping in urban areas, and then on the techniques used to provide land use from land cover maps.

Block	GUS Product	Sensor(s)	Spatial res.	Temporal res. (requ.)
UTS	Land Use	Spot 5	1:15.000	2-4 year
	Land change	Spot 5	1:15.000	2-4 year
	Hot-spot monitoring	Spot 5/ Ikonos	1:25.000 (5.000)	6 12 months
	City volume model	Airborne		
	Modelling tool			
	Sealing map	Spot 5	1:15.000	2-4 year
	Noise observatory	Spot 5	1:15.000	2-4 year
	Heating efficiency	Airborne		10 years
REG	Basic Land Use	Landsat/Spot	1:50.000	2 year
Regional sealing	Envisat	1:50.000	2 year	
DEV	Basic urban mapping dev. countries	Spot 5/Ikonos	1:15.000 (5.000)	

Table 1: GUS current portfolio spectral, spatial and temporal specifications.

Land cover mapping in urban areas with the accuracy requested nowadays by the users requires dealing with high or very high spatial resolution satellite sensors. The cost and the acquisition problems of these sensors at the moment allow usually to work on single date, single sensor data sets. Therefore, co-registration problems are usually not considered at this stage and the pre-processing steps are devoted to remove image artifacts, distortions due to the viewing geometry of the sensors, and atmospheric effects. From this point of view, all data providers are quickly adapting to the market, which requires data with all these corrections already. Moreover, models for the viewing geometry of all these sensors have been or are planned to be included in the most widespread COTS software.

The classification approach to these images aims at fully exploiting their spatial resolution, and therefore to integrate pixel-by-pixel classification with spatial analysis. Its of course impossible to refer here of all the methods that have been proposed. However, from the research viewpoint, land cover classification using satellite data have been recently discussed in the September 2003 Issue of the IEEE Transactions on Geoscience and Remote Sensing, devote to “Urban Remote Sensing by Satellite” (Gamba *et al.*, 2003) , which is therefore a good introduction to the topic. Once land cover maps are obtained, land use can be extracted, tough only to some extent, by means of automatic or semi-automatic ways. A final manual reclassification is always required, at least at the moment, to reach the accuracy required by the final user. Kernel-based reclassification (Kontoes *et al.*, 2000) is based on the evaluation of the patterns of vegetation and built areas, for instance, to provide information about residential and industrial areas. Similarly, a much more complex, graph-based approach has been proposed (Barr and Barnsley, 2000) to discriminate among building districts built in different centuries, with different spatial patterns of man-made features. It requires the extraction of each building, the characterization of a graph connecting it to its neighborhood, and a strategy to compare graphs to match the given residential model.

An example of knowledge-based integration of GIS data into the classifier is found in Stefanov *et al.* (2001), where ASTER data have been used to analyze a large urban area in Arizona, and coordinated with many different layers of information. Results are encouraging, and have been recently proposed in a second paper on the same area using LANDSAT data, which proves the robustness of the system. Re-classification by knowledge-based classifiers is also used, since it is currently available in COTS like E-cognition by Definiens (Definiens, 2004) and Erdas Expert Classifier by Leyca Geosystems (Erdas, 2004). They incorporate spectral and spatial information at different scales and provide very good land cover classification accuracy at an affordable price. For land use mapping (Kressler *et al.*, 2001) problems arise from class definition and support the above mentioned consideration that remote sensing data alone are not able to provide all the information required for accurate land use mapping.

A different approach to land use mapping tries and takes into account directly spatial statistics, represented mainly by texture measures, to provide a land use map, or at least a map with classes other than “buildings”, “roads”, “trees”, “meadows” and “water”. The basic idea is that if we incorporate texture measures or statistical measures as a supplementary band, we may recognize the different textural appearance of urban environments. The process is driven, for instance, by studies that show that census data is correlated with texture statistics in Landsat TM images (Chen, 2002). So, in Gong and Howarth (1990) the authors combine edge-density image with the two principal component (PC) bands to obtain a better overall accuracy with SPOT imagery. They also observe that the edge-density image eliminates the confusion between the rural and urban land use that have similar spectral characteristics. Similarly, in Gong *et al.* (1992) the authors compare gray level co-occurrence matrix (GLCM), simple statistical transformations (SST) and texture statistics (TS) approaches for SPOT image of urban area. Their results indicate that some spatial features derived using GLCM and the SST methods could improve the classification accuracies obtained by the use of spectral images only. On the contrary, TS method makes limited accuracy improvements.

Despite the large number of land cover classifiers, the need of extracting information from very high resolution satellite sensors in urban areas has not been fulfilled yet. Thus, also land use mapping is still in the process to become a “mature” application. At the moment the best approach remains strictly connected with human intervention, mainly in the final stage.

We stress however that the approach currently followed by GUS service providers, which heavily relies on manual interpretation (approximately half of the total production effort), is the most suitable to obtain the accuracies required by the users. The methods that we have highlighted are indeed a way to reduce the final manual re-classification step and therefore the time-to-market and the cost of land use mapping products, and this is available and used by some of GUS service providers using COTS software.

Among the classification approaches, it is our opinion that morphological analysis, which is currently pursued by many authors, is able to provide in the short term some kind of improvement in this field. Similarly, methods aimed to integrate texture measures may be useful to provide semi-land use class, i.e. something that is not a land use map, but more than a land cover one. These features are already used in standard software: what lacks now is a clear definition of which nomenclature is possible to extract with textures. More far in the future is, to our knowledge, the possibility to integrate GIS information with remote sensing data, at least at the European level.

Summing up, limitations of the present version of land use mapping product are the limited use of spatial information in the images to improve land use mapping, the lack in definition of nomenclature, the problems in integrating GIS layers and remote sensed data, the large percentage of the work still done manually. Research lines that should be addressed to improve them are therefore:

- criteria for the selection of simple spatial feature to improve land use mapping;
- realization of simple procedures for incorporating GIS data into classification tools exploiting their characteristics;
- definition of the land use nomenclature that it is possible to extract from each sensor or, on the contrary, of the requirements of sensors for extracting a given nomenclature.

3.2 REG block

Among the REG block a particular interest is in sealing mapping products. This point is confirmed by the realization of a very recent symposium promoted by one of the European Environmental Agency Technical Committees, for the definition of what “sealing” really means or should mean.

As a matter of fact, sealed area maps are of particular value in relation to increasing urbanization, increases in surface run off and increasing concern with the unpredictability of weather patterns in the context of global warming. The map of sealed areas offers a means of addressing issues which are on the foreground on the political agenda and are therefore matters for which positive remedies are sought throughout the European context.

A first way to provide sealing maps with different sealing factor comes from an accurate characterization of the cover classes in the urban area of interest. For instance, after determining the built up area with precision we may compute the percentage of coverage to provide the sealing map. Therefore, a first group of methods for the proposed task is made by procedures starting from high resolution data, typically SPOT or IRS-1 at 5 m spatial sampling, and classify these images with very high precision with respect to urban cover classes.

The largest part of these procedures adds one or more bands to the original data. In Shaban and Dikshit (2001), for instance, textural features extracted from grey level co-occurrence matrix, grey level difference histogram and sum and difference histogram are compared and used to improve the urban classification accuracy. It was found that the best results are obtained by combining spectral and textural features, without any advantage by a conventional Principal Component Transform before the combination. Moreover, usual separability criteria (like transformed divergence) are not useful to select the best combination. A similar approach is proposed in Chen *et al.* (1997), where a fractal measure is used to improve the classification. The paper shows that the use of this information improves the accuracy values for heterogeneous classes, slightly degrading homogeneous areas, e.g. water.

A different approach is presented in Zhang (1999), where the textural measures are used to filter out the classification results to improve the accuracy of the built up classes. The homogeneity of the class map is computed in a 3×3 window and in the four diagonal directions, and then filtered to discard uninteresting areas and improve by some sort of majority voting the initial guess based only on spectral characteristics.

The complementary approach to those in previous paragraphs is to compute information about the sealing density by means of a more direct approach. To this aim, we may define two major methodologies. The first one, exemplified in Karathanassi *et al.* (2000), refers to the use of textural features to directly decompose the urban environment into areas with different urban density. In this work the classes are defined by setting up thresholds in built up to overall area ratios (< 0.3, low density, 0.3 to 0.7 medium density, > 0.7 high density). It is found that significantly larger window size than in [1] should be used, because we are not looking for buildings, but for blocks. Instead of 3×3 co-occurrence measures, 11×11 or wider windows are used. Large improvements were obtained with respect to spectral features alone.

Finally, the so-called Vegetation - Impervious surface Soil (VIS) model may be used to discriminate among different degree of impervious surface. This is done for instance in Phinn *et al.* (2002), where samples from these three classes are extracted using a first simple classifier, and then a manual analysis of the model allows finding end members for a refined segmentation. The paper shows that this method enables distinctive densities of commercial, industrial and residential zones to be clearly defined, mainly based on the relative amount of vegetation cover.

Presently the sealed area in urban areas can be mapped to a sufficient degree of accuracy by using textural features in conjunction with spectral information. It is still to be investigated what the critical issues are when this approach is applied on a large scale project, on more than one or few test sites. Moreover, automatic choice of the optimal window size for the measures as well as of the measure set need to be related to the scale of the "objects" we are looking for in the urban environment. These may be the lines for future research on this matter. In the meantime, current methods combining spectral and textural features may be sufficient, or even only spectral features like those that allow to calculate the NDVI, on which the method by the GUS service provider is based, followed by correction by a remote sensing expert.

In conclusion, main limitations of the current algorithms for sealing mapping are that the estimation of the sealing degree based on very few sensed quantities, where textural information is not considered, while, where textural information is considered, there is actually a lack of extensive testing. Research lines that should be addressed to solve these problems are therefore:

- automatic definition of the window size where textural features are used;
- extensive testing of techniques combining spectral and textural features over a number of different sites with different characteristics.

4 RESULTS AND MAPS

As an example of the above mentioned products, we offer in this section the results of a recently developed methodology for the extraction of urban area information from medium resolution SAR satellite data. We focus in particular on RADARSAT data, as a suitable mean to understand to which extent this mapping approach may be useful with the finest spatial data now available. This, in turn, may be a first guess of what we may expect from finer resolution, Low Earth Orbit satellites, like Cosmo/Skymed, TerraSAR.x And SARLupe, as well as RADARSAT-2.

It has been shown in Dell'Acqua and Gamba (2003) that interesting results on urban land use discrimination may be obtained by using a combination of co-occurrence texture measures. In particular, this procedure exploits the spatial disposition of the man-made features, which have a peculiar response in radar images. Co-occurrence features highlight the spatial patterns of backscatterers. A supervised clustering of these features reveals where buildings and other man-made objects gather in a are way. So, residential areas with isolated scattering elements are quite different from town centers with many crowded backscatterers or even financial areas. The methodology proposed for exploiting these information consists of three subsequent steps: first, compute the co-occurrence matrix and extract textural features, applying *a priori* knowledge, if any, on the *optimal* scale or the *best range* of scales; second, determine which feature set is the most useful to discriminate the classes in the training set; third, classify the chosen feature set using the same training areas as seeds for a supervised clustering procedure. Classification maps for two RADARSAT-1 images of the area of Pavia, Northern Italy, are shown in fig.1, and show the dependence of the class accuracy to the incidence (beam) angle. It is indeed interesting to observe that the accuracy of the map increases with more nadir-looking views, but this is due mainly to the "water" and "sparse buildings" classes, while the behavior of the areas where many strong scatterers are present is less various.

5 CONCLUSIONS AND PERSPECTIVES

This work presented some of the recent efforts for the exploitation of EO data for the realization of GMES urban service products. We highlighted for a couple of products which are the methodologies available in technical literature and which are their weaknesses. Moreover, we introduced an approach suitable for exploiting data from SAR sensors, usually neglected in urban remote sensing applications.

The interest to urban products from EO data is increasing, in parallel with the availability of more refined algorithms for data interpretation. Moreover, the requirements by EU and especially the UTS are driving the need for these information, especially as aggregated indicators of urban quality and environmental characteristics. More work is therefore needed to integrate new data sources as well as to connect more tightly the users with the producers via a suitable application-oriented research and development effort.

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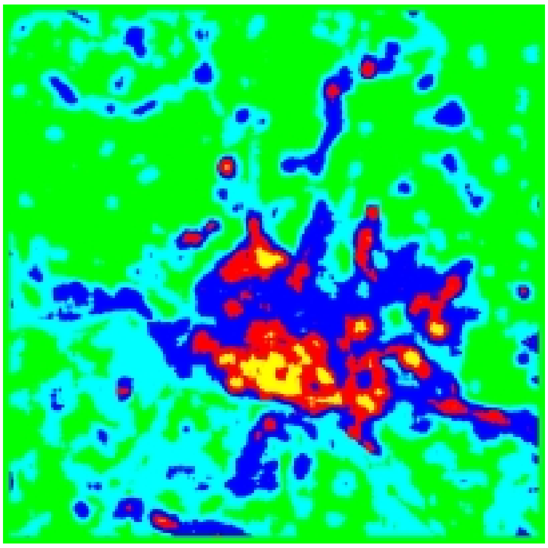
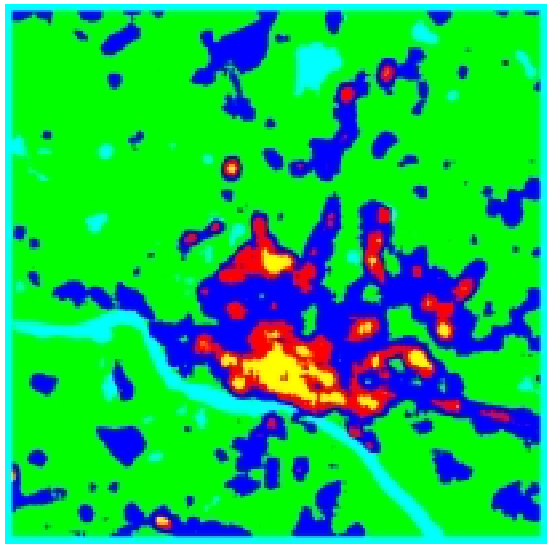


(a)



(b)

Figure 1: Classification maps from RADARSAT-1 data: yellow is city center, red are residential areas, blue are sparse buildings, light blue water and green vegetation): (a) February, 21st, 2003; (b) November 22nd, 2001.

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