Remote sensing satellite imagery and risk management: image based information extraction

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Abstract

The introduction of high and very high resolution multispectral satellite imagery, characterized by ground resolution from one to a few meters, has lead to a new perspective in processes of risk estimation, mitigation and management. In particular, the possibility of obtaining, in a very short time, a wide-scene image of areas subjected to a crisis has become useful both for emergency management and for effective damage estimation. Examples of images in the immediate aftermath of natural disasters such as earthquakes, hurricanes, floods, fires, tsunami, volcanic eruptions, etc, have also been globally distributed through information media and web based image systems such as Google Earth. However, a concrete possibility of extracting quantitative information from such images is subject to several factors: first of all, accessibility in term of timing in image acquisition and in image delivery to stakeholders, followed by image quality (resolution, absence of clouds, geo-location, informative content, etc.), and finally the methodology for the information extraction process. After a review of the problem and of the current situation in terms of available data and applications, this paper focus on an approach for information extraction and quantitative image classification, in particular by object oriented analysis. One of the major objectives is to show the possibility of obtaining the outlines and the count of the buildings for an area affected by a severe disaster, saving human time in image interpretation in procedures of risk management and in estimating rebuilding costs; the integration of information coming from existing building databases is also considered. The experiences show the potential of the method and promising results in the classification accuracy.

Keywords: remote sensing, disasters, damage assessment, segmentation.

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1 Introduction

The use of a remote sensing technology in the context of environmental analysis is growing year by year, as data providers, satellite platforms, images, tools and applications are increasing. In the particular case of disaster applications, remote sensing is becoming an essential instrument in the field of documentation and knowledge for emergency management [11]; image-based information is also provided today by broadcast media and the Internet.

As is well known, in the field of disaster risk management it is possible to distinguish four main phases, to be considered consecutive but inter-dependent: Mitigation, Preparedness, Response and Recovery.

- Mitigation: the mitigation phase consists of all actions made to prevent, or to reduce, effects of occurring disasters. The mitigation measures can be differentiated by the structural, using for example particular building construction criteria in a specific area, and the non-structural, such as measures concern legislation and land-use planning. The use of remote sensing is intended as a non-structural measure, through its capability of rapid mapping and production of extensive information for a particular area.
- Preparedness: In this phase, all actions to respond correctly to a disaster are arranged. They include the communication plan, the coordination measures between agencies and the maintenance of emergency services. In this particular phase, remote sensing images can be used principally to make the emergency managers familiar with this kind of data, and with the problems concerning image acquisition. The capability to coordinate the image supply chain between emergency managers and the satellite imagery providers is crucial. In fact, information provided by remote sensing should be made available as quickly as possible for analysis, in order to perform a rapid delivery of the final product to the emergency teams on the ground. All procedures are generally taken by EOC (Emergency Operation Centers): examples using massively remote sensing information are in [8, 13, 14].
- Response: After an event, the first step is to fulfill the humanitarian needs of the population, the so-called “search and rescue”. One of the most effective roles of remote sensing technology is the capability to acquire the scene of a disaster in an effective and quick way, in order to perform a first evaluation of the zone affected by the event: the products, produced by human and/or automated image analysis procedures, are in the form of maps showing the main affected areas, and numerical estimates of the damage. The capability of rapid map production and the effectiveness of the geographic information delivered to stakeholders are crucial when a disaster strikes.
- Recovery: After an event, it is important to constantly monitor for a long period all the advancements in the reconstruction to arrive at a stable situation, both in terms of structural and infrastructural works and arrangement of the population. In this case, the acquisition of satellite imagery at a constant time interval can constitute a very interesting characteristic.

2 Remote sensing image characterization for emergency management

In this part, geometrical, spectral and temporal aspects of current satellite remote sensing platforms and sensors will be evaluated, in order to better emphasize the opportunity offered by this technology to disaster management. It must in any case be emphasized that for almost every application a ground survey is normally necessary to validate the information collected from the space; new technologies are available to support this process [7].

2.1 Geometric accuracy

In this paper, the geometric accuracy of information is intended not only as the ground pixel size and the georeferencing accuracy of the maps produced, but also as the level of the extraction of detail, or otherwise as the minimum object of interest; this concept is quite similar to the MMU (Minimum Mapping Unit) in thematic cartography. Different scales of analysis can be identified, in particular:

- Large: the object of interest is of morphological type, e.g. coastline modification, or a flooded region, etc. Satellite platforms such as Landsat or ASTER should be well suited for this kind of analysis. The ground resolution of the images should be around 100 m cell size.
- Medium: it is possible to study the morphological characteristics but also the texture, for instance it is possible to distinguish between densely and sparsely populated areas, and it is possible to delineate large buildings or blocks of buildings. In this case, the image resolution should be from 5 to 30 m and Landsat, IRS, ASTER, SPOT are examples of suitable platforms.
- Small: the objects of interest are the single buildings or specific features, and it is also possible to delineate characteristics such as roofs and, in the case of oblique imagery, the façade (for aerial acquisition an interesting example is the Pictometry application, [12]). The image resolution should be 1 m or less, requiring Very High Resolution (VHR) satellite sensors such as Ikonos or QuickBird, but digital aerial imagery can be also necessary.

Satellite platforms have the capability to collect images in different portions of the electromagnetic spectrum: of particular interest for these applications are panchromatic, visible, near infra-red, far infrared data, to be processed with different algorithms. Spectral characteristics impact on image interpretation, as information extraction capacity depends on the perceived information (Fig. 1).

2.2 Information temporal accuracy

There are at least two different aspects to be considered regarding the information temporal accuracy: the temporal resolution and the up-dating quality of information.

The temporal resolution concerns the capability to have a basic product within hours after an event, in order to be effective on the search and rescue effort. Temporal resolution of the most common platforms is nowadays mainly linked to revolution orbits completion and capabilities of some telescopes to rotate and provide higher frequency acquisitions. The possibility of having in the next future all-time acquisition by new satellite constellations could better satisfy the requirements for disaster mapping.

The up-dating quality of geographic databases is an issue also applicable to remote sensing imagery, where one of the most common methodologies of performing a change detection analysis is to compare two remote sensing images, one taken before and one taken after an event, and analyze the modifications that have occurred between the two acquisition dates: of course, the two dates must be as close as possible to the event. As it is important to have a representation of the situation of an area just after a disaster, it is also important to have an up-to-date knowledge of the previous situation, coming from cartographic databases or from satellite imagery. In emergency management and also during the mitigation processes, the availability of up-to-date and well documented geographical datasets is generally an essential requirement. The development of initiatives such as the INSPIRE [10] directive, the use of standards (ISO/TC11, OGC) are providing a general framework for the interchange of geographical data, and constitute an effective way to distribute and use data and metadata. Unfortunately, minimum data requirements for emergency management are very often unsatisfied in developing countries, and therefore the only high resolution and up to date information available comes from satellite imagery.

From 1972, the start of the first mission Landsat (still the system providing the longest temporal coverage), several satellite platforms were launched for environmental monitoring, and many others are in development.

Commercial platforms became the major source of civilian satellite information, since the launch of Orbview 1 in 1996; use of Ikonos (from 1999) and Quickbird (from 2001) for disaster response and mitigation are well documented in literature. Modern platforms, also thanks to the capability of rotating the telescopes to the zone of interest (agile platforms), allow acquisition of every part of the Earth surface with a temporal resolution spanning from 1 to 7 days. Table 1 shows the temporal and geometric resolution of the main satellite platforms (optic and radar). Note that the spatial resolution is becoming comparable to aerial imagery (about half a meter for the satellites GeoEye and WorldView); the temporal resolution is about 3 to 7 days for commercial

Table 1: Common satellite platforms currently used in emergency management: (*) planned; (g) governmental agency; (r) radar.

MMU Update	*Large 5-15 m*	*Medium < 5 m*	*Small ≤ 1 m*
>15 days	Landsat-7 (g) ASTER (g)		
2 – 15 days	IRS 1C; SPOT4	EROS-A SPOT-5 RADARSAT-2 (*)	EROS-B (*); Cartosat-2; Orbview-3; Ikonos; Quickbird; TerraSAR-X (r); WorldView 1-2 (*); GeoEye-1 (*)
< 2 days			COSMO-SkyMed (gr*); Pleiades (g*)

satellites, adequate for cartographic up-dating, while new satellite constellations, mainly developed by public spatial agencies, will provide a temporal resolution down to hours, optimal for crisis and disaster management. Note besides that weather conditions (cloud cover) are a limitation for all optical platforms: the integration between optic and high resolution radar information, which is not concerned by clouds, will become an issue for the development of future applications.

3 An approach to information extraction from satellite imagery

The possibility of extracting descriptive and quantitative information in terms of man-made objects and features (buildings, streets…) from high resolution satellite images and GIS databases is precious, and can be pursued using manual, automatic or semi-automatic procedures. The latter are of particular interest in a crisis context, when the rapidity in the extraction of information can effectively save lives and facilitate the search and rescue operations.

It is possible to use different processing technologies for image segmentation and classification, and it is necessary to also consider the multi/hyper-spectrality and the accuracy in geometric geocoding of the images. These aspects will be further discussed in the next section.

The ability to automatically recognize objects in digital imagery is one of the most interesting challenges in computer vision technology. While the capability to distinguish the number plate or a road sign from digital camera images in an automatic way is an effective procedure, the ability to fully perform the photo-interpretation of a satellite image is far from complete. In this section, current capabilities of image analysis technology for the interpretation of remote sensing imagery will be taken into account.

The conventional method applied in the remote sensing community is the pixel-oriented approach, but in recent years an object oriented approach has been successfully adopted: the idea is to perform image segmentation, then automatically/manually carry out the classification of the delineated objects. Object analysis constitutes in some way a hybrid between vector and raster analysis.

In a first step the image is segmented, in order to individuate a database of objects as aggregate of contiguous pixels sharing common features. All the analysis will be done on this database, and the parameters extracted are referred to this archive. Pixel characteristics, like reflectance, texture, ID, are referring to a single object rather than a single pixel; also shape can be considered, for example whether the object is elongate like a road or compact like a building. Compared with pixel-based analysis, these additional attributes have the potential to produce more homogenous and accurate mapping of real-world features [8]. The segmentation analysis conducted here is a bottom-up merging technique, starting with the single pixel object (Baatz and Schäpe [1]): two objects are fused together when a heterogeneity criterion (scale) is reached:

$$scale = w_{color} \cdot h_{spectral} + (1 - w_{color}) \cdot h_{shape} \quad (1)$$

This scale parameter is a weighted (w_{color} is a weight in the range 0.1÷1) mean of a spectral heterogeneity factor ($h_{spectral}$), essentially the standard deviation of pixel values included in the object, and a shape heterogeneity factor (h_{shape}). The shape heterogeneity factor is used to produce a more compact or smoother object, deriving from the following equation:

$$h_{shape} = w_{shaoe} \cdot h_{compact} + (1 - w_{shape}) \cdot h_{smooth} \quad (2)$$

The two heterogeneity factors $h_{compact}$ and h_{smooth} are defined using geometrical parameters like area and perimeter ratios.

For the adoption of these techniques in the management of disasters, a lot of problems must be considered in view of the required application [2, 3]: examples related to two case studies are presented afterwards in relation to different phases of risk management.

3.1 Application to the mitigation phase

The application presented is about the role of remote sensing in cartography updating, simulating a process of the establishment of an image derived geographic database, useful in the mitigation phase. The images are part of a data set distributed by the ISPRS WG VIII/2 for research purposes, representing the upper part of the Susa Valley (Italian Western Alps); its composition is shown in Table 2. Pre-processing steps included data fusion between Quickbird Panchromatic (PAN) channel and Multi-spectral (MS) channels (R, G, B, NIR), using Principal Component and ortho-projection by Rational Polynomial Coefficients. All other data were registered to the Quickbird channel in order to compare the informative content of different image types.

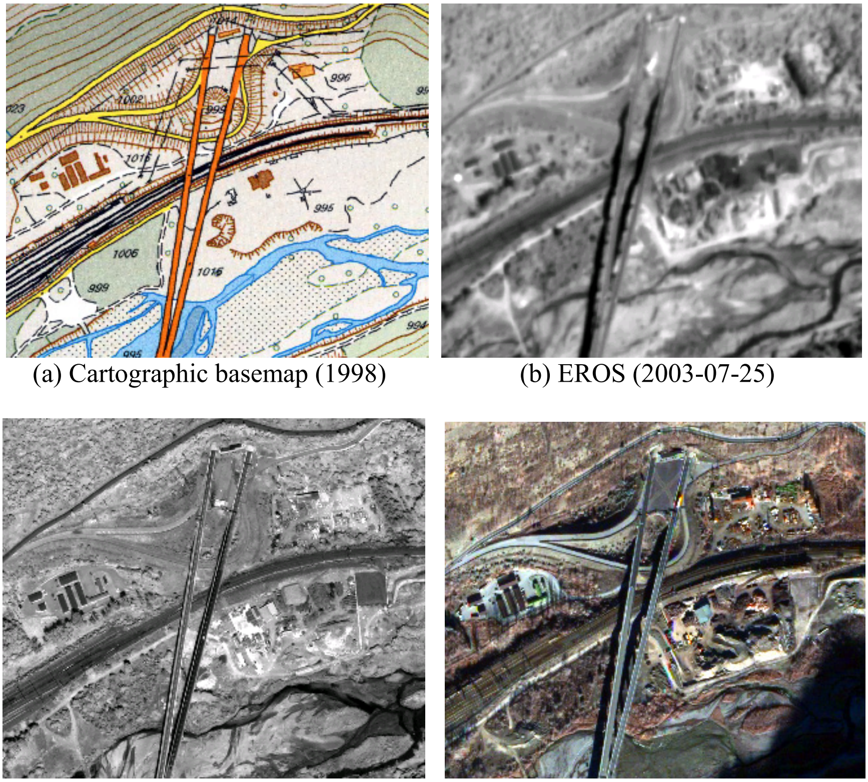
Table 2: Data set used for the study.

Data	Scale/resolution	Colour/Bands	Initial Datum	Final Datum
Technical cartography	1:10000	Colour	Gauss Boaga	Registered to QB
EROS	1.8m	PAN	1A	Registered to QB
Ikonos	1m	PAN	Basic	Registered to QB
Quickbird	0.6-2.4m	PAN & MS	Basic	UTM32N WGS84

The subset in Figure 1 is representing the Torino-Bardonecchia railway and the Torino-Frejus motorway. This set was selected in order to show the interpretability of the images and how different segmentation parameters can influence results in information extraction, in particular in infrastructure extraction; some sparse buildings are also present in the subset, to finalize the analysis to different objects of interest in an emergency scenario. When starting the analysis of the EROS image (Figure 1b), the motorway and the railway are clearly distinguishable, while it is not possible to establish the presence of buildings. In the Quickbird and Ikonos images (Figure 1c and 1d), both the objects of interest, buildings and infrastructure are extractable. The capability of information extraction from an image depends first of all on the spatial resolution. The analysis continues in Figure 2, showing the results of segmentation of the Quickbird image, the most suitable for information extraction, also thanks to MS channels. The first result of image segmentation, constituting 12664 objects, is shown in Figure 2a: the segmentation parameters, in particular those concerning color and shape, are selected following some tests and previous experiences [6], as being the most suitable for this kind of data. Raising the scale parameter, from 10 in Figure 2a to 30 in Figure 2b, the number of objects decreases to 1796, and it is possible to clearly distinguish roads, railways and buildings. Increasing the scale parameter up to 90, and using a different shape factor (0, indicating most elongated objects, see equation 2), only the infrastructures are extractable. The final result of a rapid image segmentation/classification is shown in Figure 2d.

3.2 Application to a response scenario

The information extraction capabilities are applied to the real case of the 26 December 2004 Bam Earthquake [4]. In this destructive event, most parts of the



(a) Cartographic basemap (1998) (b) EROS (2003-07-25)

(c) Ikonos (2002-08-15) (d) Quickbird (2005-11-19)

Figure 1: Comparative analysis of different kinds of co-registered images.

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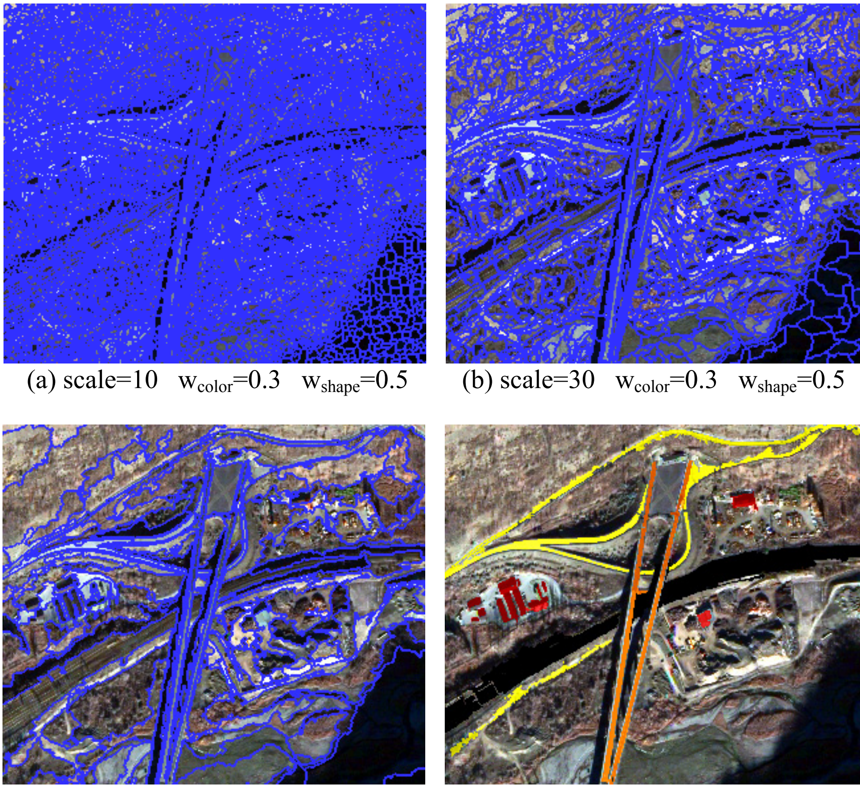


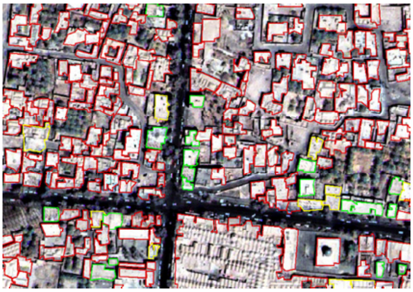
(a) scale=10 w_{color}=0.3 w_{shape}=0.5 (b) scale=30 w_{color}=0.3 w_{shape}=0.5

(c) scale=90 w_{color}=0.3 w_{shape}=0 (d) feature classification

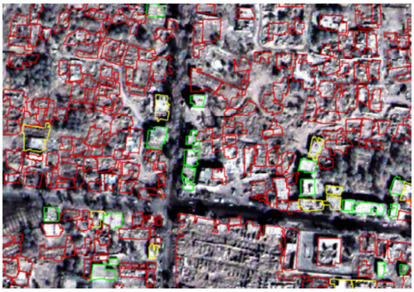
Figure 2: Results from the application of different segmentation parameters (Quickbird image).

built environment were lost, and an effective count of destroyed habitations is important to correctly evaluate the response effort. The test data is composed of two Quickbird images: a before event acquired on 30-09-2003 and an image taken right after the event on 03-01-2004. In order to verify the applicability of the information extraction technique, the before event image was segmented in order to extract buildings, using convenient parameters (scale=40, w_{color}=0.3, w_{shape}=0.5). The extracted buildings outlines were superimposed to the after event image and all buildings were classified using a remote sensing adaptation of European Macroseismic Scale EMS98 proposed by Grünthal [5] for building damage classification. This scale, originally developed for ground surveys, also comprehends building vulnerability classification. In the absence of site specific information, all buildings were here classified with the same criteria.

In the analysis of remote sensing imagery, it is reliable to distinguish between three damage levels, which can be associated to EMS grades: EMS 0, when no visible damage occurred; EMS 3, when dust and partial collapse of the building structure is visible; and EMS 4-5, when a complete destruction of the building occurred. The results were interesting, and it took about one hour to classify the test area, resulting as 84 EMS 0, 47 EMS 3 and 530 EMS 4-5 buildings. The accuracy of the results obtained and the speed in the analysis suggests the use of this technique whenever it is necessary to quickly count and classify a wide urbanized area, and the speed is an important issue.



(a)



(b)

Figure 3: Bam earthquake: example of building inventory performed on Quickbird images (a) before event image (b) after event image.

4 Conclusion

The increasing capabilities of satellite imagery and related processing procedures lead to a significant improvement in the use of remote sensing in all phases of emergency management. Furthermore, these data are now widely known and commonly used by a broad range of users, coming to the awareness of the global community. Some main current remote sensing platforms were reviewed, in order to discuss the trend in geometric, spectral and temporal resolutions, which are becoming higher and higher. A peculiar approach for information extraction and for quantitative image classification was discussed, with the aim of demonstrating the rapidity and the efficiency of building and infrastructure extraction, in order to aid image interpretation and saving resources in the mitigation and in the response phase to a severe event. The use of object oriented image analysis, such as the one proposed, could furthermore be an effective way to integrate and ameliorate the amount of information coming from vector databases and the increasing number and typology of satellite imageries.

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