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Remote Sensing of Environment 92 (2004) 409–413

Remote Sensing of Environment

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Object-based image classification for burned area mapping of Creus Cape, Spain, using NOAA-AVHRR imagery

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Received 18 July 2003; received in revised form 2 June 2004; accepted 8 June 2004

Abstract

Due to the ability of the NOAA-AVHRR sensor to cover a wide area and its high temporal frequency, it is possible to quickly obtain a general overview of the prevailing situation over a large area of terrain and, more specifically, quickly assess the damage caused by a recent large forest fire by mapping the extent of the burned area. The aim of this work was to map a large forest fire that recently took place on the Spanish Mediterranean coast using innovative image classification techniques and low spatial resolution imagery. The methodology involved developing an object-based classification model using spectral as well as contextual object information. The burned area map resulting from the image classification was compared with the fire perimeter provided by the Catalan Environmental Department in terms of spatial overlap and size in order to determine to what extent they were compatible. Results of the comparison indicated a high degree ($\approx$90%) of spatial agreement. The total burned area of the classified image was found to be 6900 ha, compared to a fire perimeter of 6000 ha produced by the Catalan Environmental Department. It was concluded that, although the object-oriented classification approach was capable of affording very promising results when mapping a recent burn on the Spanish Mediterranean coast, the method in question required further assessment to ascertain its ability to map other burned areas in the Mediterranean.

Keywords: NOAA-AVHRR; Object-based image classification; Burned area mapping

1. Introduction

Fire is an integral part of many ecosystems, particularly in Mediterranean areas. However, in recent decades, the general trend in the number of fires and surface burns in the European Mediterranean region has increased spectacularly (Pausas & Vallejo, 1999).

When a forested area is damaged by fire, detailed and current information concerning the location and extent of the burned area is important in assessing economic losses and ecological effects, monitoring land use and land cover changes, and modelling atmospheric and climatic impacts of biomass burning (Caetano et al., 1994; Pereira et al., 1997). Reliable monitoring and effective analysis techniques need to be implemented to estimate the ecological impact of fire on Mediterranean ecosystems (Gitas, 1999).

Several studies have investigated the ability of satellite imagery to produce accurate burned area estimates (Caetano et al., 1994; Chuvieco & Congalton, 1988; Milne, 1986; Mitri & Gitas, 2002; Pereira, 1992; Pereira et al., 1997; Pereira & Setzer, 1993; Siljeström & Moreno, 1995; Tanaka et al., 1983). Since satellite sensors are able to cover wide areas, provide high temporal frequency, and also reveal information about non-visible spectral regions, they represent a very valuable means of preventing, detecting and mapping wildland fires. According to Chuvieco et al.

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doi:10.1016/j.rse.2004.06.006

(1999), remotely sensed data can contribute to a better cost effective, objective, and time-saving method of specifying the location of fire, intensity of fire events, and the extent of the burned area.

Despite the advantages of remote sensing, several problems are inherent in burned area mapping using satellite data. Consequently, the development of methodologies that are able to produce more accurate burned area estimates from remotely sensed data on local, regional, and global scales constitutes an active topic of research (Justice et al., 1993).

An important issue that has recently been emphasised is the need for the use of remotely sensed data on an operational basis (Chuvieco et al., 2001). It should be noted that the transition to an operational mode for burned area mapping pre-requisites the development and validation of robust satellite image analysis algorithms that can be extended through space and time.

Object-based image classification, which is based on fuzzy logic, allows the integration of a broad spectrum of different object features such as spectral values, shape, and texture. Such classification techniques, incorporating contextual and semantic information, can be performed using not only image object attributes, but also the relationship among different image objects (Civanlar & Trussell, 1986; Driankov et al., 1993; Kosko, 1992; Kruse et al., 1993; Pierce et al., 1994). An object-based classification model that has been developed for Landsat-TM images has proven to be accurate and transferable for the mapping of different burned areas in the Mediterranean (Mitri & Gitas, 2002).

Low spatial resolution NOAA-AVHRR imagery has been successively used for the mapping of large forest fires on a regional scale (Martin et al., 2002; Pereira, 1999; Pereira et al., 1999). In particular, the thermal channels of AVHRR play a significant role in separating the burned areas from other land cover classes (Martin et al., 2002). However, the NOAA-AVHRR system is reported to have a number of inherent problems when employed in the classification procedure. These problems can be summarized as follows:

- AVHRR scans over 55° off-nadir (68° satellite zenith angle relative to the earth's surface), while Landsat Thematic Mapper scans less than 8° off-nadir. This large scanning angle can cause several problems, among which are the following:
  - the area sampled by the radiometer is not uniform, but increases with scan angle;
  - the amount of atmospheric interference increases with scan angle; and
  - the direction of scan can influence the greenness values recorded by the radiometer (Holben, 1986).
- The data acquired by the radiometer is dependent on the observed geometry. This geometry is repeated using almost the same procedure, every 8 days, therefore producing important radiometric instability on the daily images.

The aim of this work was to accurately map large forest fires using innovative image classification techniques and low spatial resolution imagery. The specific objectives were:

- to develop an object-oriented model for mapping a large forest fire on the Mediterranean coast of Spain using NOAA-AVHRR imagery; and
- to evaluate the accuracy of the mapping by comparing the burned area produced by the classification with the digital fire perimeter map provided by the Catalan Environmental Department.

2. Study area and dataset

This work focuses on a large fire that occurred on 6th August 2000, in the Eastern extremity of the Pyrenees in Creus Cape, Spain (Fig. 1); total burned area 6000 ha, comprising 83% wooded and 17% non-wooded. The fire, which was human-induced and worsened by the prevailing strong wind, broke out at 11:00 in the morning in the town of Garriguella and was extinguished the following day.

A NOAA-14 AVHRR image was acquired immediately after the fire (10th August 2000) by the receiving station based in the Geography Department, University of Alcalá de Henares, Madrid, Spain. In addition, a fire perimeter of the

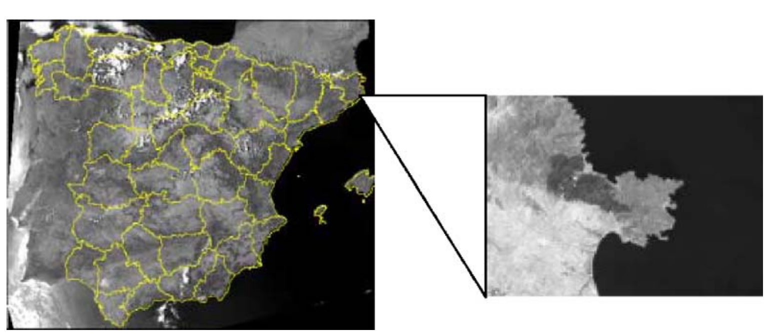

Fig. 1. The study area in Spain. To the left, NOAA-AVHRR image of the Iberian Peninsula; to the right, Landsat-TM subset of the Creus Cape.

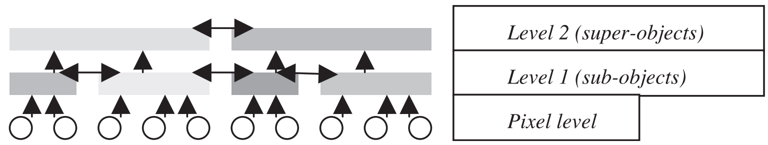

Fig. 2. Hierarchical network of image objects in abstract illustration.

aforementioned fire was acquired from the Catalan Environmental Department.

3. Methodology

The methodology involved pre-processing the image, building an object-oriented model (using eCognition 2.1) for mapping the burned area and assessing the accuracy of the resulting map by comparing it with the officially produced fire perimeter. The development of the object-oriented model comprised the following two steps:

- Image segmentation and
- Image object-based classification.

The AVHRR image, which was received in High Resolution Picture Transmission (HRPT) format, was first geometrically corrected and then the bands were calibrated. It should be noted that after pre-processing, the image covered the entire Iberian Peninsula. The development of the object-oriented model is discussed in detail below.

3.1. Image segmentation

A prerequisite to classification is image segmentation, which is the subdivision of an image into separated regions. Image objects resulting from segmentation represent image object primitives, serving as information carriers and building blocks for further classification or other segmentation processes (eCognition User Guide, 2002). Each image object has a large number of characteristic properties; the so-called object features or attributes. In this sense, the best segmentation result is that which provides optimal information for further processing (Baatz & Schäpe, 2000; Chaudhuri & Sarkar, 1995; Hofmann et al., 1998; Laine & Fan, 1996; Mao & Jain, 1992).

Multiresolution segmentation results were used to construct a hierarchical network of image objects that simultaneously represented image information in different spatial resolutions. The image objects were networked, so that each image object "knew" its context (neighbourhood), its super-object, and its sub-objects (Fig. 2).

The segmentation used in this study was a bottom up region-merging approach, starting with one-pixel objects. Throughout the segmentation procedure, the whole image was segmented and image objects were generated based upon several adjustable criteria of homogeneity in colour and shape. In a subsequent step, smaller image objects were merged into bigger ones. This procedure simulates an even and simultaneous growth of segments over a scene in each step. Visual interpretation of different image segmentation results showed that it was extremely beneficial to use band 4 (10.3–11.3 μm). Finally, only band 4 was considered in the segmentation process. The scale parameter at level 1 was set to 15. The composition of homogeneity criterion was set as follows: colour 0.7 and shape 0.3. For the shape criterion, smoothness was 0.8 and compactness was 0.2.

3.2. Object-based classification

The objects resulting from the segmentation at level 1 were classified into three different classes. Each class is defined by a fuzzy set which consists of membership functions of the object features (Fig. 3). Membership functions identify those values of a feature regarded as typical, less typical, or non typical of a class.

Three different classes representing a "non-burned" area, "burned-a" for a fire affected area larger than 3900 ha, and "burned-b" for a fire affected area smaller than 3900 ha were created at level 1. The threshold for the burned area size was chosen in such a way so as to match the image segmentation results. In addition to the features based on spectral and shape information, other features based on

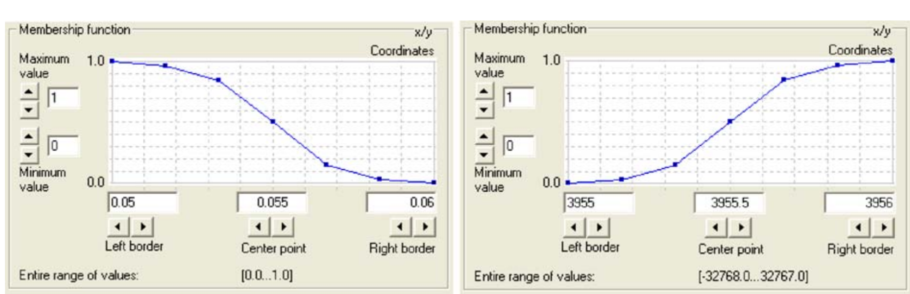

Fig. 3. Two examples of a membership function. To the left, ratio band 1; to the right, mean band 3.

Fig. 4. Burned area classification. The figure at level 1 shows a “burned” object larger than 3900 ha in white and “burned” objects smaller than 3900 ha in light grey. The third figure represents the final result.

contextual information, such as the relation to neighbouring objects, were also used in the class description.

The second step was to apply a classification based-fusion to the image. In this way, image objects of class “burned-b” and neighbouring objects of class “burned-a” (representing the same structure group) were merged into a single image object. A structure is defined by organizing all classes that semantically form this structure in a structure group. By merging image objects at level 1, a new image object level (level 2) was created. At level 2, the fire under examination was thoroughly mapped by classifying the previously merged objects (Fig. 4). Statistics of the classification from the two levels of the classified image are given in Table 1.

Despite the fact that, during the development of the model, spectral confusion was noticed between class “burned-b” and other landcover types such as water bodies, bare soil and dark shaded unburned areas, the combination of object features, such as spectral values together with contextual information, made it possible to avoid these confusions through the successive mapping of the large burned area with the smaller burned objects around it. Following classification, the classes of burned objects could be merged together to produce one entirely burned area, thus removing all other misclassified burned objects.

4. Results and discussion

The burned area resulting from the object-based classification of the AVHRR image was compared with the fire perimeter provided by the Catalan Environmental Department in terms of spatial overlay and size (Fig. 5). The spatial comparison made it possible to discern areas common to and uncommon to the two maps. An area of 6900 ha was mapped as burned by the object-based classification model, while an area of 6000 ha was mapped as burned on the official map.

An area of 5400 ha (78% of the classified burned area and 90% of the official fire perimeter) was common to both maps. A difference of 900 ha (13%) in the area classified as burned was noted between the two maps; however, this difference was related to non-burned islands located inside the fire perimeter that could not be detected on the AVHRR imagery due to its low spatial resolution. The areas uncommon to both maps could be attributed to a mis-registration of the fire perimeter. It should also be emphasized that, due to the larger original pixel size of the image, the delineation of the classified burned area in comparison to the real shape situation appeared to be very rough.

Table 1
Classification statistics of the NOAA-AVHRR image

Classes	Number of objects	Sum area (ha)	Mean area (ha)
Classification of the NOAA-AVHRR image at level 1			
Burned-a	1	4400	4400
Burned-b	6	2500	417
Not burned	84201	100,984,000	1199
Classification at level 2			
Burned	1	6900	6900
Not burned	84,184	100,984,000	1200

5. Conclusions

This study demonstrated the potential use of the object-oriented approach as a tool for effectively mapping large burned areas, even when low resolution imagery was employed. More specifically, an object-oriented model

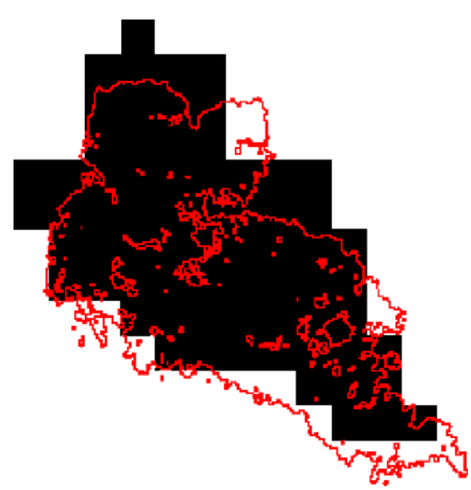

Fig. 5. Classification result (black) vs. fire perimeter (red).

was developed for accurately mapping a burned area on the Mediterranean coast of Spain using an AVHRR image. The spatial comparison of the classification map with the official "burned area" map showed a very high degree of consistency both in spatial overlap (90%) and in total burned area. Although the preliminary results of this attempt to apply the developed model to an AVHRR image appear to be promising, further research and assessment are required before the proposed method can be considered sufficiently robust for use in other AVHRR images.

Acknowledgements

The authors are grateful to the Catalan Environmental Department, especially to Esteve Canyameres, for providing a digital copy of the fire perimeter. Our sincere thanks go to Professor Emilio Chuvieco, University of Alcalá, for his valuable and critical comments on this study. Many thanks go to Miss Linda Lucas for her valuable help in reviewing the English language content of this work.

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