The Use of Aerial and Satellite Images in Detection and Monitoring the Forest Fires

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Abstract: *In this paper are presented the aspects regarding the use of means of aerophotogrammetry and remote sensing for detection and monitoring of fires. In principle, the problems treated had in consideration the methods and algorithms as well as the kinds of aerial and satellites images used in this case. Also, are presented the means of evaluation of damages occurs by fires using the means of remote sensing.*

Keywords: *remote sensing, aerophotogrammetry, satellite images detection and monitoring resolution.*

1. Introduction

Forest fires lead to disastrous social, ecologic, and economic impacts, because they can affect urban areas, agricultural fields nearby, the wild habitat, destroying vegetation, oil and water resources, leading to material and human damage (Miller and Yoll, 2002). In the case of wooden fuel burning, a significant quantity of carbon involved in its cycle and in global warming can be rapidly released into the atmosphere. The mountain areas remain the ideal conditions to ensure a great variability in view of the fire's frequency, size, and intensity growth (Conrad and al., 2002, Cahoon and al., 1994).

The forest fires' complexity can lead to important changes. The fire leads to different burnings according to the species' features, to the trees' features (consistency, diameter, height, crown size and type), to the field, to the humidity, to the wind, to the soil type, to the dust layer, to the regeneration manner, etc. Thus, the fires can affect the sights in a different manner and can lead to uncertainties in estimating the emissions caused by them (French and al., 2004). During the collection of data on the vegetation before and after the fire, a plenty of information must be obtained to show the changes caused by fires and by the carbon emissions caused by them. Due to the fact that most of the time these information lack, the usage of data collected by means of remote sensing should be considered (Lentile and al., 2006).

Nowadays, remote sensing is used on a large scale for detecting forest fires, for assessment and monitoring, starting from the digital air photograms' interpretation to the satellite images' examination (Fraser and Li, 2002; Jia and al., 2006; Lentile and al., 2006), by the advantage of the latter, offered by *spatial resolution* (from a local scale to a continental one, from a pixel's size of under one metre to kilometres), by *spectral resolution* (from multispectral to hyperspectral), and by *temporal* (from biweekly to daily). The air and satellite remote sensing means, together with the methods used for image digital processing, are the most efficient ways in fire detecting and monitoring. Since the creation of the digital image, air and satellite remote sensing overlap – without a separation line between the two fields –. The recordings are captured through sensors fitted on air or satellite platforms and are used for *fire prevention, for making maps in real time of the surfaces affected by fires, for fire extension and advancing tracking, for the assessment of the surfaces affected after putting out the fires and after assessing the damage.*

The plane and satellite sensors used for detecting and monitoring forest fires capture recordings of different types as *infrared thermophotography, laser recordings, video recordings, air photography, satellite images*, etc.

2. Air photography in detecting and monitoring forest fires

Air photography have great potential for detecting and delimiting burned surfaces, especially in the case of easy air vectors and sensors capturing the *infrared and the near infrared* reflectance. Using air photography in fire localisation and in assessing their effect has had a large applicability for a long period of time, gaining experience in this field. Laborious research has been performed after 1961, using new means, in view of setting up some techniques to allow the detection of the fires caused by different factors (people, lightings, explosions, etc.), according to given atmospheric conditions, both by day and by night. Thus, far infrared and infrared *thermal scanning techniques* have been set up.

Detecting fires by using air photography implies using regular means as helicopters and sensitive emulsions in the visible spectrum used only by day. Detection on any kind of weather and at any time by day or by night is possible only by own remote sensing means, by using infrared thermal recordings. Through these, surfaces affected by the fire can be detected, on surfaces of only *0.09* square meter*s*, from a 5000-metre height. Another remote sensing system is the linear infrared scanner, a light device which can record a surface affected by the fire of *0.09* square meters, from a 600-metre above the field.

Making maps of extended fires and of the temperature emitted by these, as well as the locations of the fires' front, can be performed according to thermal infrared images captured with scanners fitted on planes. Processing the image data on board allows automatic drafting of the maps and the conveying of these to fire command, control, and monitoring centres. Microwave scanning by means of radiometers on planes allows obtaining images in the most different conditions possible (cloud coverage or thin smoke coverage can clog the signal conveying), but at a certain loss of spatial details. The maps containing the temperature produced by fires – in different stages of these fires – can also be useful for setting the fires' gravity, the soil, and the affected vegetation's nature.

In the case in which the trees' crowns did not burn completely, it is recommended to use infrared colour emulsions in view of assessing the intensity of the burning, while the image scale can be of 1:20000 (Rusu, 1988). Nowadays, when the digital images are more and more used, one can use images captured in infrared, irrespective of scale, because the latter can be modified by means of the image processing software.

3. Satellite images in fire detecting and monitoring

The use of space-borne instruments for the detection, monitoring and impact assessment of vegetation fire is being promoted by the *Global Observation of Forest and Land Cover Dynamics* (GOFC-GOLD – http://gofc-fire.umd.edu). *GOFC-GOLD* is a panel of the *Global Terrestrial Observing System Programme*, which is sponsored by the *Integrated Global Observing Strategy*. Its main goal is to provide a forum for international information exchange, observation and data coordination, as well as a framework for establishing long-term monitoring systems. The *GOFC-GOLD Fire Mapping and Monitoring Theme* aims to refine and articulate international observation requirements and to make the best possible use of products from existing and future satellite observing systems for fire management, policy-making and global change research. Regional *GOFC-GOLD* fire networks have been developed in Africa, Eurasia, Latin America and Southeast Asia. Bilateral and multilateral agreements for joint use of satellite assets have been developed, for exemple between Mexico and various Mesoamerican countries and within the Baltic region.

The space-bornes sensors which has been made the progress in using data in *fire monitoring*, *assessment of areas burned* and *emissions* are:

- *Advanced Very High Resolution Radiometer* (AVHRR);
- *Moderate Resolution Imaging Spectroradiometer* (MODIS) on the *Earth Observing Syst*em (EOS) *Terra* and *Aqua* satellites;
- *Medium Resolution Imaging Spectrometer* (MERIS);
- *Advanced Spaceborne Thermal Emission and Reflection Radiometer* (ASTER);
- *SPOT – Vegetation*;
- *Measurements of Pollution in the Troposphere* (MOPITT).

A new generation of dedicated space-borne sensor for fire characterization has been designed to provide more precise information on fire extent and characteristics, for exemple the *Bi-spectral Infrared Detection* (BIRD) mission on the *German Aerospace Center* (DLR).

Together with these sensors, one can also use *Landsat TM* and *ETM+* sensors, according to which one can calculate certain vegetation indexes rendering information on the gravity of the fire. For detailed studies, in view of assessing damage produced by fires, one can use *Ikonos, Quickbird*, and *WorldView* images, whose spatial and spectral resolution is very good.

Optical multispectral images captured from satellites for Earth Observation (EO) are the rising segment of satellite remote sensing in the last decade, due to relatively low costs and to the increase in spatial resolution (Wuldner and Franklin, 2003). Almost all types of images captured through available passive and active techniques – of EO type – have undergone experimental tests and/or in view of operative service development regarding the prevention of the fires' risk, announcing them in real time, using them as a support in fire fighting, making maps of burned areas, quantifying burned areas, quantifying destroyed biomass, fire gravity and damage assessment, and vegetation reinstallation monitoring. For most operational applications after the fire, high and very high spatial resolution images are available, characterised by information depth (over 8 bits per pixel and per band), allowing the making of high geometric precision maps of the areas affected, for reaching the proposed managerial objectives (10 m in panchromatic for *SPOT HRV*; 6 m for *IRS-1C* and *SPOT 4*; 2,5 m for *SPOT 5*; ≤ 1 m for *Quickbird* and *Ikonos*; ≤ 0,5 m for *WorldView-1* and *GeoEye-1*).

NBR (Normalized Burned Ratio) is used on a large scale in the USA for making maps of forest fires and for highlighting the burning's gravity (Key and al., 2003; Key and Benson, 2006). The method is very sensitive to changing the surfaces covered by vegetation recorded on the image before and after the fire and has been recommended by Brewer and al. (2005) in comparison with other six methods for classifying and making maps of the fire's gravity. The NBR report is calculated for *Landsat TM* or *ETM+* images, by using reflectance in *band 4* (NIR: 780-900nm) and in *band 7* (SWIR: 2090-2350nm). These bands provide the greatest difference in the spectral reply related to the damage produced by the fire on vegetation, but in opposite directions. Thus, after the fire, reflectance in band 4 decreases, while that in band 7 increases. A modification derived from the thermal band is thus obtained, including a so-called "*scaled brightness temperature*" (Holden and al., 2005). The NBR report is calculated for each image, before and after the fire, by using the equation (similar to NDVI):

$$NBR = \frac{band4 - band7}{band4 + band7} \quad (1)$$

The final value of the fire normalised differential index – *dNBR* – (differential Normalized Burned Ratio), also known as *ΔNBR*, is obtained by:

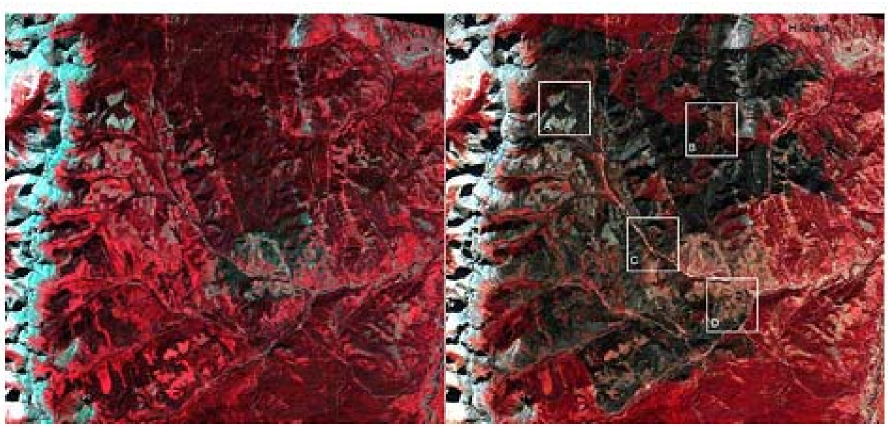
$$dNBR = NBR_{prefire} - NBR_{postfire} \quad (2)$$

dNBR index proves to be an efficient indicator in assessing both the fire extension and its degree determining. Together with the burning gravity, the dNBR index can also show the surfaces the regeneration is started on and the vegetation installation speed after the fire, in comparison with the typical seasonal models. According to dNBR values, the surfaces affected by the fire can be classified in the following manner: without burnings, with incipient burnings, with light burnings, with moderate burnings, with severe burnings, and with very severe burnings. The results obtained according to the satellite images captured before and after the fire must be correlated and checked with the information on field (Key and Benson, 2006).

Classification methods of the areas affected by forest fires by using satellite recordings are based on manual photo interpretation or on automated/semi-automated algorithms of image processing (Franklin, 2001; Lillesand and al., 2004). We can use the mono-temporal method, based on a single image captured after the fire's start, or the multi-temporal method, based on acquiring at least two images – one before and one after the fire's start –.

The mono-temporal approach is relatively cheap and easy to implement from a technical point of view. However, identifying the burned surfaces can be difficult to perform if the image is acquired in springtime or at a certain interval from the fire's start. In these situations, the vegetation increase leads to a change in the spectral response of the surface affected by the fire, which becomes similar to that of the nearby surface not affected by the fire. Problems regarding the classification may arise when having to distinguish between forest fires and other fires in agricultural and incorporated fields. The mono-temporal approach is generally applied to *HR/VHR* data. In a distinct manner, the classification techniques based on object orientation can significantly improve the burned surface detection mapped throughout *VHR* data (Gitas and al., 2004; Mitri and Gitas, 2004, 2006). In the case of the medium and low resolution data (pixels sized between 180-1000 m), pixels that are part of the surfaces affected by the fire frequently show a mixed spectral signature equal to the average of the digital values mainly corresponding to that of the vegetal carpet not affected by the fire.

Multi-temporal approach, based on acquiring at least two images, before and after the fire, allows an easier identification of the burned surface as the image captured after the fire is acquired nearby the event (Figure 1). The burned surfaces examined on multi-temporal images show a typical spectral response due to the vegetal carpet above the soil before the fire and the conditions after the fire (white and black ash, uncovered soil, burned vegetation) (Lentile and al., 2006). Surface classification based on the burned vegetation type is much easier than through the mono-temporal approach. However, the multi-temporal method is more expensive and more complex to implement from a technical point of view, because all the images used must be geometrically corrected and normalised from a spectral point of view.



a. Image from 11 September 2002 b. Image from 30 September 2002

Figure 1. Landsat-5 TM imagery pre-fire (a) and post-fire (b). Bands 4, 3, and 2 (NIR, Red, Green) displayed as RGB, respectively. Boxes A, B, C, D in (b) indicate positions of sub-areas burned (after Derek R. Peddle, Ronald J. Hall, Chris D. Jackson, Scott A. Soenen, Mark R. Gibb, Daniel T. Juhlin and Ronald J. Hall)

Medium and low resolution multi-temporal images are frequently used for monitoring forest fires on a large surface. *HR/VHR* type images are usually used for supporting after-fire management by comparing the digital values from the selected bands or their combinations (vegetation indexes) before and after the fire or by comparing the classifications independently realised before and after the fire.

Multi-temporal quantitative comparison can be expressed through the *MNI* index, whose interval is comprised between *-1* and *+1* and is calculated through the relation:

$$MNI = \frac{image_{postfire} - image_{prefire}}{image_{postfire} + image_{prefire}} \quad (3)$$

where *image* is a vegetation index or the digital value of a certain band, $image_{prefire}$ and $image_{postfire}$ is the image acquired before, respectively after the fire. *MNI* index can be applied in view of identifying the burned surfaces also based on the regeneration after the fire; if the images are immediately acquired, before and after the fire, the *MNI* index obtained for the burned surface is characterised through values significantly greater than the nearby surfaces' values, not affected by the fire (Chirici and Corona, 2005).

Geographic information systems play an important part in view of allowing the integration of the data coming from different sources also comprising those from satellite and air remote sensing, and exploiting them in different purposes. These systems have found a new application area in the case of forest fires. The geographic information systems used in this sector integrate the database related to the field with the data captured through remote sensing means and preview the fire creation, being able to ensure even a simulation of the fire's development by using *the modular dynamic models* (Vasconcelos, 1993). In order to forecast the spreading and the behaviour of fires by using GIS technology, a series of numerical models has been set up: *BEHAVE,* widely used in the USA, *CFFB* used in Canada, and *IGNITE* in Australia. The development of the fire by using the *Huggen principle* has also been set up by Andre (1994), throughout which the spreading of the forest fire has been described on a local and global scale. The fire spreading rate can be determined by using a combination between the *Rothermel model*, the fire form, and an algorithm for the simulation of its faster propagation than in real time. For taking into account the wind factor, *SIMPLEC procedure* (Lopes, 1994) is used in simulation.

Also, a computerised system has been created, able to collect information useful for the fire units' coordinator in fighting forest fires, so that he could rapidly set up an efficient and secure intervention plan. The system consists in GIS information on the sight's features and in *AIOLOS-F* forest fire simulator, able to forecast, more rapidly than in real time, the development of the forest fire's front. One of the method's advantages consists in the fact that equations related to the wind and to the fire's diffusion are simultaneously solved and are able to interact.

4. Conclusions

The creation of new air and satellite sensors makes possible capturing high spectral and spatial resolution images, allowing their usage in monitoring high efficiency forest fires, due to the clear presentation of the situations in the field. It should be remarked that each image type – having a certain spatial and spectral resolution – plays a certain part in identifying and monitoring forest fires. Thus, medium and low spatial resolution images can be used for tracking fires spread on large and very large surfaces. Certain satellite recordings captured in a visible manner can show large regions covered by smoke, as well as information on smoke extension and ash storage. The high resolution satellite images can be used both on large surfaces – for damage assessment –, and on small surfaces or when the fire is in an incipient stage.

Thus, the new design of the sensors and the quality of the collected data have lead to new changes and opportunities for developing the algorithms allowing the extracting of the information from the remote sensing images regarding the complexity of the forest fires.

As far as using the geographic information systems in fire detecting and monitoring is concerned, the future development will allow its integration with the remote sensing techniques collecting data in view of updating the maps in relation to the field usage categories and also obtaining information – in real time – on fire ignition points.

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