NEW METHODOLOGIES FOR THE INTEGRATION OF MULTISPECTRAL DATA ACQUIRED FROM AERIAL AND SATELLITE PLATFORMS: THE NOVEMBER 1994 FLOOD IN PIEDMONT (ITALY) CASE STUDY

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Commission VII, Working Group 1

KEY WORDS: Land_Slides, Change_Detection, Recognition, DEM/DTM, Feature, Extraction, Image, Classification

ABSTRACT

The aim of the present work is to develop a new methodology that is suitable for landslide and flooded area extraction assessment using remotely sensed data acquired from satellite platform. This study has been conducted after the famous flood event that occurred in Piedmont (Italy) during November 1994, which was caused by the heavy precipitation and by slope instability (due both to natural and artificial causes) in the southern part of Piedmont (and in particular in the Langhe area). An impressive series of catastrophic events occurred with the flooding of almost all of the rivers of the area and a rather large number of landslides occurred in correspondence the most hazardous slopes.
Particular attention has been paid to the setting up of a methodology that is suitable to establish the relationships between landslides (essentially debris flows and slides), flooded areas and the reflectance data obtained from the earth surface and recorded by the sensors mounted onboard artificial satellites and aerial platforms.
In this work, all the data have been georeferenced, pre-processed and filtered and the images have been classified in order to evaluate a typical landslide and water spectral signature from training samples.
The creation of these cartographic features (Landslide and flooded area themes) however involves, the possession of a methodological tool that is capable of allowing the passage from the radiometric data to the information content, which offers an opportunity of interpreting the image with the consequent creation of relationships between the image structure and the elements of the corresponding real scene.

RÉSUMÉ

Le but de ce travail est le développement d'une nouvelle méthodologie utile pour l'extraction des zones avec éboulements ou esondations avec l'utilisation des données acquises par la télédetection avec plate-formes satellitaire. Cette étude a été conduite depuis l'événement alluvionnaire qui s'est produit en Piémont (Italie) en Novembre 1994. A cause d'une insistante précipitation et d'une instabilité des versants (due à des causes naturelles et artificielles) dans le Piémont méridional (et en particulier dans la région des Langhe), une impressionante série d'événements catastrophiques s'est produite avec l'esondation de presque tous les fleuves et un grand nombre des éboulements en correspondence des versants les plus au risque.
Une particulière attention a été placée pour le développement d'une méthodologie capable d'établir les relations entre les éboulements (essentiellement *debris flows* et *slides*), les zone esondées et les données de refléctance dépagées de la surface terrestre et enregistrées par les senseurs montés sur les satellites artificiels et les plate-formes aériennes.
Dans ce travail, toutes les données ont été géoréférencées, pre-traitées, filtrées et les images ont été classifiées pour évaluer dans la zone étudiée, la signature spectrale.
La création de ces thématismes cartographiques (zone des éboulements et des esondations) comprend de toute façon la possession d'un ensemble d'instruments méthodologiques capables de permettre le passage des données radiométrique aux informations contenues, qui permet l'interprétation des images avec la conséquente création de relations entre la structure des images et les éléments de la correspondante scène réelle.

1. INTRODUCTION

During the flood event that occurred in November 1994 in the north-western part of Italy, several multispectral images were acquired from both airborne and satellite platforms. Thematic Mapper multispectral data, Spot-2 panchromatic, ERS-1 radar and panchromatic photogrammetric coverages were acquired in particular. These images, which have not yet been totally exploited to obtain information, are suitable for the analysis of the territorial effects of such tremendous catastrophic phenomena.
The present study has been conducted paying particular attention to flooded areas extraction and landslide morphologic characterisation, thanks to the development of the remote sensing techniques that allow one to collect environmental data in real-time. Remotely sensed data present advantages such as:

- **multispectral acquisitions**, that permit one to overcome the electromagnetic spectrum limitation that is due to the sensibility of human eye;
- **multitemporal acquisition** over the same area thanks to satellite eliosynchronous orbits, that permit one, to collect data at the same local time with respect to the latitude;
- fast **data availability**, that is no usually longer than a few days;
- relative **low cost** of data unit;
- availability of **digital data** that allow digital processing using standard PCs, without any loss of information.

2. INVESTIGATED TOPICS

The goal of the present study is to investigate the relationships between physical parameters such as reflectance and emittance from features located on the earth surface (recorded in the different digital images) and to investigate two particular occurrences: landslides and flooded areas.

As far as the flooded areas are concerned, when remotely sensed data area available, feature reflectance and/or emittance:

- decreases when a water layer covers the ground surface or when the soil is humid;
- increases in the red band (0.63-0.69 μm) because of the vegetation stress caused by moisture;
- changes noticeably when different temperatures (due to thick water layer) are recorded.

In the microwave band, the water presence could also be appreciated by estimating the surface roughness, where water layers smooth surfaces; dielectric constant is then heavily correlated to soil water content and electromagnetic polarisation.

As far as the control of slope instability (landslides) is concerned, a traditional analysis method of the problem is constituted by a geologic surface mapping, integrated by ground investigations and specific checks that could include both geophysical prospecting and geognostical drilling. In order to analyse phenomena that occur on a regional scale, it is necessary to have photogrammetric coverages and then to proceed with a stereoscopic inspection of the landslides.

In particular, in order to characterise slope instability occurrences on the ground in digital remotely sensed images, it is necessary to point out one of the landslides' main characteristics (at least one of the more superficial): the presence of mud and debris in the accumulation slope foot, such material being characterised from an accented reflectivity in the visible spectral band. Thus, it is possible to evaluate, from the digital images, the landslide recurrent reflective behaviour; the radiometric range thus isolated can then give rise to an interpretation key when exploring other images (or other spectral bands), where the presence and the location of the aforesaid occurrences can be detected.

3. THE STUDIED AREA

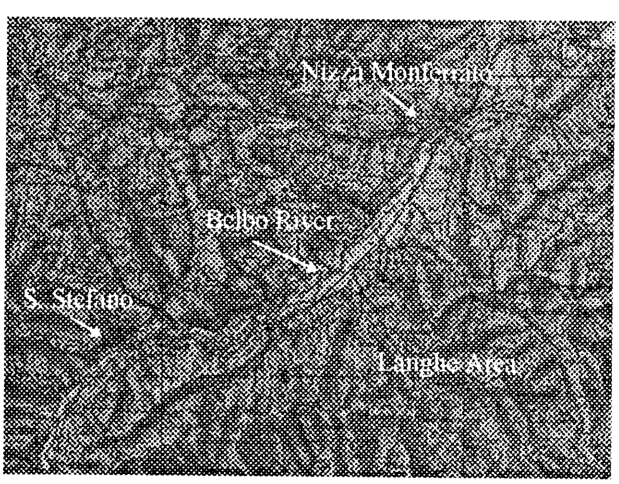

Figure 1 - The studied area

In November 1994, a flood event occurred throughout almost all the Piedmont region, and in particular in the southern part of the region in the Cuneo province, between the Appennine mountains (South) and the Padana plain (North) not far from the cities of Asti and Alessandria (fig. 1).

4. DATA AVAILABLE

Different data sets have been used, such as:

- a Spot-2 panchromatic image acquired in June 1994;
- a Spot-2 panchromatic image acquired in November 1994;
- a Spot-2 panchromatic image acquired in April 1995;
- a Thematic Mapper multispectral (7 spectral bands) acquired in June 1991;
- a Ers-1 radar image acquired in November 1994;
- a panchromatic photogrammetric coverage acquired in November 1994;
- a panchromatic photogrammetric coverage acquired in May-June 1992;
- a DEM derived from the 1992 panchromatic photogrammetric coverage.

The Spot-2 panchromatic image acquired in April 1994 has been absolutely georeferenced, while all the other images have been relatively fitted to the previous one.

5. EXTRACTION OF THE FLOODED AREAS

The determination of the extension of the flooded areas is particularly important for a regional scale analysis when it is necessary to evaluate the damages and the potential flooding risk.

To obtain this goal a new methodology has been implemented, and a flow chart is shown in fig. 2.

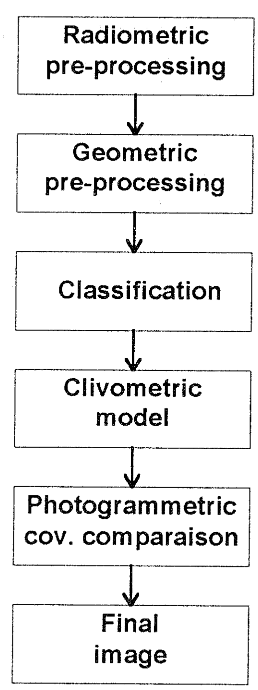

Figure 2 - Assessment flow chart of the flooded areas

a) **Radiometric pre-processing**. In a multitemporal investigation, the first step concerns the different image radiometric calibration. This calibration has been performed by equalising the June illuminating conditions to those of April, subtracting a linearly increasing digital number (Dn) variable value to the June image. The variation curve

$$(\Delta x = x_{Jun} - x_{Apr} = f(x_{Jun}) = a x_{Jun} + b) \qquad (1)$$

has been determined by means of a linear regression that was calculated by taking into account non time-variable features radiometric values (in this example, these features are large industrial buildings roofs in Alba surroundings). The features' DN differences is only related to different illuminating conditions, thus, the difference can be used to equalise the whole image set. The Dns recorded in correspondence to different features, show a linear dependence between the Dns variation and the Dns recorded in the reference image (for example the June image). The calculated regression curve and the correlation coefficient is shown in Tab. 3.

Calculated function	**Y=0.8659X - 15.923**
Correlation index	$R^2 = 0.9989$

Table 3 - Calculated regression curve and correlation coefficient (R)

b) **Geometric pre-processing**. This step only concerns the absolute georeferencing of one image and the relative image to image geometric fitting: An accuracy of less than half the geometric ground resolution (accuracy < 5 m in the case of Spot 2 PAN image) has been obtained, allowing a good multitemporal overlapping.

c) **Image classification**. This step derives from the assumption (verified by field evidence) that flooded areas appear in brighter grayscale tones on the image, because of the presence of mud and sand carried by the rivers.

Thus, extracting a radiometric range (a pseudo-spectral signature in Spot-2 PAN images), it is possible to classify the whole data set, subtracting the April image from the classified June image in order to eliminate features that are not directly linked to the flood event.

d) **Generation of a clivometric model**. A clivometric model has been generated from the DEM acquired for the Piedmont regional technical map (scale 1:10.000), resampled to a 10×10 m grid. This model has been used to define the hydrographic basins, and thus to eliminate any noise from the features (landslide, mud areas. etc.) not directly related to the flooded areas.

e) **Photogrammetric coverage comparison**. Stereoscopic models derived from the panchromatic photogrammetric coverage acquired in the days following the flood event has been analysed in order to plot the flooded areas; this vector plot has permitted one to compare the classification results and to calibrate the radiometric range extracted.

f) **Final image generation**. By forcing all the features classified as not-flooded areas to a null value, a new synthetic image has been generated, and it is shown in fig. 4.

6. LANDSLIDE ASSESSMENT

Following the November 1994 flood in the southern part of Piedmont (in particular in the Langhe hilly region), several landslides (debris flows and slides) occurred. The aim of the study is thus, to locate and classify the above mentioned phenomena, using remotely sensed data.

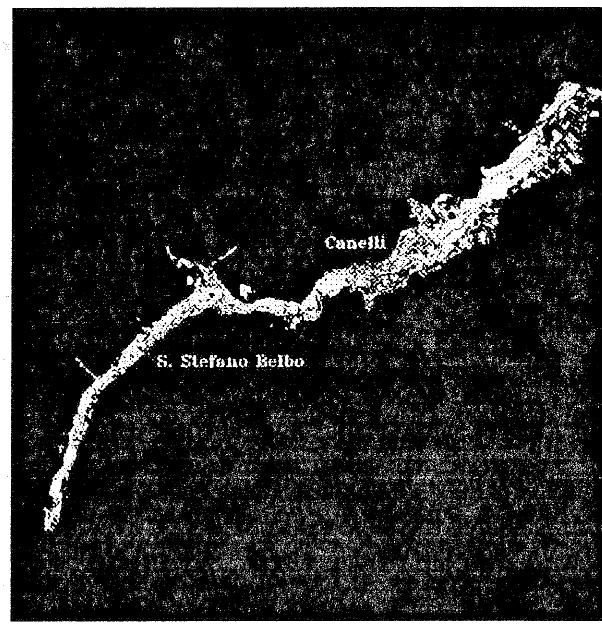

Figure 4 - The flooded areas extracted by Spot-2 panchromatic data sets

Images acquired from satellite platforms present several advantages, taking both the landslides regional scale and the efforts that should be accomplished in the case of an *in-situ* analysis into account.

As mentioned and shown in fig. 1, the new methodology has been implemented in a training area, using the data described in § 4.

A flow chart showing the different steps of the analysis is presented in Fig. 5.

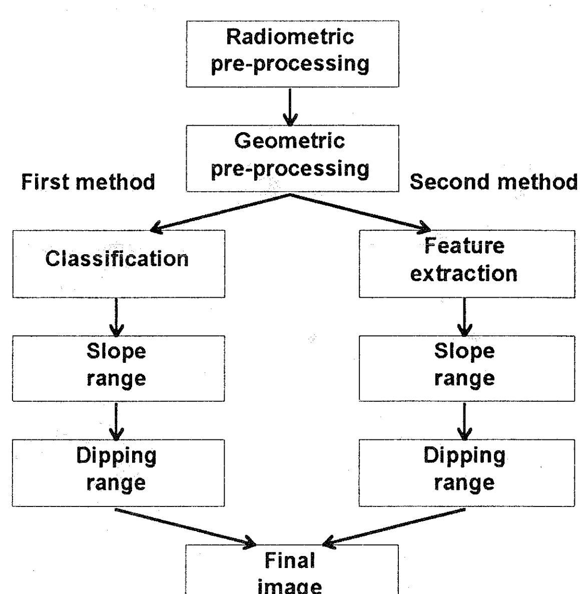

Figure 5 - Landslide assessment flow chart

The first two steps are the same used for the flooded areas assessment (§5); then, the analysis is split into two different methods: the first is related to image classification, while the second is related to feature extraction techniques.

a) **First methodology**. In the post-flood image a radiometric range that characterises the different known landslides has been determined, forcing all the other Dns to a null value. In the pre-flood image the same area Dns have been then recorded; a difference between these two new synthetic images has pointed out the existence of landslides caused by the heavy November precipitation. In order to reduce the radiometric noise generated by the extraction of non-landslide features that show a similar reflective behaviour, a general consideration has been deducted. The majority of the slides in that area occurred in N-W dipping, with an angle dip in a range comprised between 6°-15° with respect to the horizontal plane. Thus, a clivometric model has been generated determining the dipping plane as the projection on the horizontal plane of the interpolating normal one, which was previously calculated for each slope angle. The new image locates the dipping direction in each cell. An automatic procedures has then been implemented in order to verify the three restrictions previously determined:

1. the radiometric range;
2. the slope range;
3. the N-W dipping.

b) Second methodology. The aim of the second approach is to perform a feature extraction (from the geometric and radiometric point of view) based on landslides of known morphologic characteristics. The suitability of this methodology is based on some basic assumptions:

- the majority of the slides occurred in a N-W direction;
- the slides presents a series of parallel fractures perpendicular to the flow direction (SW-NE).

An automatic feature extraction procedure has thus been implemented based on a target (both extracted from the real images and synthetically generated) that reproduces those morphologic characteristics. The algorithm adopted is based on the restitution of the correlation coefficient (R) calculated on the target and search area; the correlation coefficient is considered acceptable when R>0.75. The output image is composed by null values when the restriction over R is not satisfied, where the original values are restored when satisfied. This method allows one to determine similar features ever where not directly visible (shadowed slopes), because the correlation index is independent from the original reflective values, and takes only the morphology of the subset (Dns geometric arrangement) into account. The different synthetic images generated (one for each target) using the above mentioned algorithm have then been added, and the resulting image has been substituted to the radiometric range image (1.) used in the previous methodology. In fig. 6 a colour composite (converted B/W values) of the resulting image is shown.

7. FINAL REMARKS AND FURTHER DEVELOPMENTS

The extraction of flooded areas when compared to plotted ones, shows a remarkably correspondence; further developments concern the usage of ERS-1 Sar images, that have not yet been integrated in the model because of the extreme difficulty to fit them to the absolute georeferenced one (discrepancies grater than 1.5 the ground resolution).
With regards to landslide assessment, the two methodologies presented show a good description of the phenomena. Further developments will regard the integration with multispectral remotely sensed data (such as Thematic Mappers sets) in order to evaluate possible correlation with humidity (extracted by TM5 band) and vegetation index (extracted mainly from TM4 band).

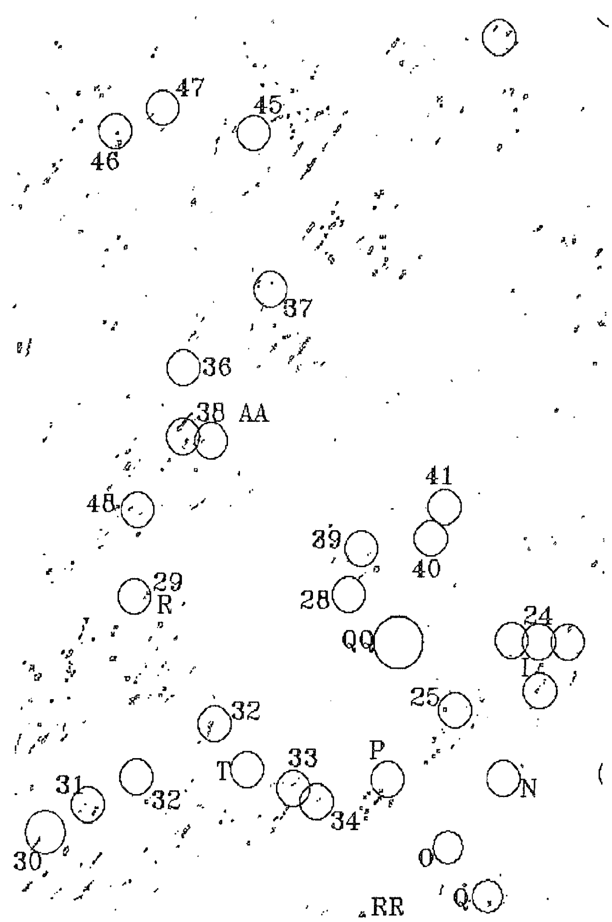

Figure 6 - B/W composite showing the final image; circled areas are recognised slides, while the black values remaining are noise (less than 20-25%).

8. ACKNOWLEDGEMENTS

This research has been conducted in collaboration with Prof. John Mc. Mahon Moore and Dr. Philippa Mason of the Centre for Remote Sensing at the Imperial College of Science and Medicine in London. The majority of the analysed images have been provided by C.S.I. Piemonte in Turin; without their aid the experimental image processing could not have been done. A special thank to everybody at the Dipartimento di Georisorse e Territorio who helped us, and in particular to Andrea Lingua and Fulvio Rinaudo. Least but not last, many thanks to Enrico Borgogno Mondino and Marco Pastè, who, as graduating students, carried out large part of the experimentation in the framework of their dissertation thesis.

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