A FUZZY-LOGIC-BASED APPROACH FOR FLOOD DETECTION FROM COSMO-SKYMED DATA

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1. INTRODUCTION

Several studies proved the potentiality of spaceborne Synthetic Aperture Radar (SAR) for flood mapping. The synoptic view, important for monitoring events occurring in remote regions, the capability to operate in almost all-weather conditions and both during daytime and nighttime, which are distinctive requirements for managing this kind of events, are the key features of this sensor. Moreover, the new very high spatial resolution SAR allows carrying out a fairly accurate delineation of the flood extent. However, the temporal repetitiveness of SAR measurements was a critical issue for their operational use, so far. To overcome this problem, the availability of images provided by a constellation of satellite radars can be exploited, in order to reduce the revisit time. The COSMO-SkyMed (COnstellation of small Satellites for Mediterranean basin Observation) mission offers a unique opportunity to obtain a large amount of daily acquired images, characterized by high spatial and radiometric resolutions.

A method to map inundated areas from SAR data that integrates the theoretical knowledge on the radar return from flooded areas, image processing techniques and both hydraulic and contextual information is presented in this work. It takes also advantage of ancillary data such as a digital elevation model and a land cover map. The method is based on the application of the fuzzy logic, particularly useful to integrate different sources of information and suitable to deal with images that possess ambiguities [1] such as radar observations of flooded (and also non-flooded) areas. Although our procedure is developed considering different frequency bands, attention is paid to the COSMO-SkyMed data. Indeed, a test of the method on COSMO-SkyMed imagery of recent flood events, such as the overflow that occurred in the city of Alessandria (Northern Italy) in April 2009 is planned.

2. THE FUZZY APPROACH AND THE ELECTROMAGNETIC MODEL

Most of the literature algorithms for inundation mapping from SAR data were based on thresholds applied on an image temporarily close to the event. However, an analysis accounting for the various electromagnetic mechanisms that determine the radar return in the presence of a water surface may improve the accuracy of flood mapping. Indeed, not only specular reflection, characteristic of bare soil, but also double bounce backscattering, typical of vegetated/forested and also urban areas, may take place in the presence of an inundation. While a specular surface is characterized by low radar return, double bounce backscattering involving trunks can be increased by the underlying water.

To account for the uncertainty of the radar return from flooded areas and to limit the subjectivity of a method based only on the user ability to determine the most suitable threshold to separate flooded and non-flooded pixels, we propose an approach based on the fuzzy theory. The fuzzy sets basically represent an extension of the classical notion of set. While in classical set theory an element either belongs or does not belong to the set, elements of a fuzzy set have degrees of membership defined by membership functions whose values are real numbers in the interval [0, 1].

In the method that we propose, the parameters of the fuzzy membership functions (fuzzy threshold) are derived by an analysis of the outputs of an electromagnetic forward model allowing the simulation of the backscattering from both flooded and non-flooded areas. This model, developed by the Tor Vergata University of Rome, is based on the radiative transfer theory, adopts a discrete approach [2], and is suitable to simulate the backscattering of agricultural land. The latter is represented as a homogeneous half space with rough interface (soil) overlaid by a lower layer filled with discrete dielectric scatterers (stems or trunks), and an upper layer of twigs, or branches, and leaves.

The Tor Vergata model is applied considering different stages of growth of the crops (from bare soils to well-developed vegetation) and considering L, C and X bands, horizontal and vertical polarizations (only co-polarized data are considered) and, as observation angles, 20°, 35°, 50°. Flooding is simulated substituting the soil with a semi-infinite layer having a height standard deviation of 1 mm and a dielectric constant equal to the one of water.

3. THE ALGORITHM

The fuzzy logic based algorithm assumes as inputs a SAR observation (intensity image) of the flooded area (image1), a SAR image of the same area in “dry conditions” (image2), helpful to detect vegetated inundated regions, a land cover map and a digital elevation model. To design the algorithm, we have defined four fuzzy membership functions [3]. The first one is the membership function for low backscatter, used to identify open water surfaces on the SAR image. Such a membership function is a standard-*Z* function, whose parameters are chosen in agreement with the results provided by the electromagnetic model. A membership function for backscatter increase (a standard *S*-function), used to detect the areas involved in the enhancement of the double bounce scattering mechanism is also applied. In this case the difference between the backscattering coefficient predicted by the electromagnetic model in the presence and the absence of the inundation is employed.

To integrate also simple hydraulic considerations in the algorithm we define: (i) a membership function for pixels close to water bodies (rivers, lakes, small artificial basins, etc.); (ii) a membership function for pixels located at lower altitude with respect to the water bodies. The membership degree for the fuzzy set of flooded areas is a weighted average of the four degrees defined by the functions previously introduced. We give to the fuzzy sets derived from SAR data a larger weight than that given to the ones derived from hydraulic considerations.

The membership degree to the set of inundated pixels is successively modified considering inter-pixel relationships: the probability of the presence of one isolated flooded pixel inside an area of non flooded ones (or vice versa) is small; the probability of the presence of a non-inundated pixel close to inundated ones located at higher altitude is small; the probability of the presence of an inundated pixel close to non-inundated ones located at lower altitude is small. Finally, the map of flooded areas is obtained through the so-called defuzzification procedure, simply consisting of using a threshold on the membership degree. We mark as flooded the pixels having a membership degree greater than a threshold value of 0.5.

An example of map produced by processing a Cosmo-SkyMed observation of the flood occurred on April 2009 in Norhtern Italy (Tanaro river basin) is presented in Fig. 1. The images have been acquired in spotlight mode, at horizontal polarization, with an observation angle of about 50°, during a right ascending orbit. The first image was collected on April, 30 2009 (image1) when the effects of the river overflow were still present. The second image was collected on May, 16 2009 in “dry conditions” (image2). The portion of the imaged area mainly involved by the flood is shown.

Fig. 1 Map of flooded areas derived from the analysis of a portion of the Cosmo-SkyMed observation of the Tanaro River basin acquired on April, 30 2009 and May, 16 2009 (cyan: flooded; yellow: non-flooded; blue: water bodies).

4. REFERENCES

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