FLOODING LEVEL ESTIMATION IN URBAN AREAS WITH SAR IMAGES

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Abstract – **The main aim of this paper is to evaluate the level of flooding in proximity of sensible targets in urban areas using Synthetic Aperture Radar (SAR) images. To this purpose two approaches are possible: Local Approach and Global Approach. The Local approach is based on just one SAR Image (in this case, the post-event SAR image) and allows the evaluation of the water level in proximity of the selected local target; to this aim, the a-priori knowledge of the target ground truth and two gauges in the premises is required. The Global approach, instead, relies on a couple of SAR Images (pre and post-event) and permits to retrieve the flood level at a global scale all over the image once co-registration and calibration procedures have been performed. Here just the Global approach is presented and then compared with results coming from the application of the Local approach in previous studies. The approaches are tested on High Resolution (HR) TerraSAR-X images: the first acquired during the flooding occurred in the Gloucestershire in July 2007 and the second one year later in normal weather conditions**

1. INTRODUCTION

Most natural hazards occur in an unpredictable way and, when it happens, they cause extensive damage sometimes resulting in a huge number of deaths. In all these situations a reliable and timely response is necessary. Several are the means available to monitor and manage crisis conditions like those accompanying a flooding event: in situ measurements and remote sensing. When a flood occurs the environment is always greatly perturbed by atmospheric phenomena and the heavy presence of clouds makes the use of optical sensors tough, while ground-instruments, instead, could be washed out by water and rain. However the scale of these phenomena is often too large to depend solely on in situ measurements. For all these reasons the satellite observation with Synthetic Aperture Radar (SAR) is a fundamental monitoring mean: it is able to acquire data independently from weather condition and daytime; moreover, modern systems working in constellations provide images of the same scene in a few hours, especially in emergency situations.

In order to estimate the flooding level the approach shown in [1] for building height retrieval has been modified in order to consider the presence of water, changes to relative building height, surface roughness and the dielectric properties of scenario for the case at issue. The approaches of this paper employ the electromagnetic model presented in [2] with adequate changes. For example, the presence of water leads to dual interpretation of double reflection mechanism: from one hand the building height decreases and consequently also the double reflection line should appear darker into SAR image; from the other hand the permittivity of wet terrain is much greater than that of dry soil and this leads to a brighter double reflection line. [3].

Local approach has been already presented in [4] and so in this paper the authors prefer to exploit the Global Approach; however, for the sake of completeness, the retrieval results for both procedures are shown and finally compared.

2. GLOBAL APPROACH PROCEDURE

Global Approach is based on a couple of SAR images and it is useful to evaluate the flood level all over the scene; a flow chart of all necessary steps to retrieve the water level is shown into Fig. 1. Since two different SAR views of the same area do not completely match each other, a co-registration procedure is needed in order to align the pixels in the slave image (post-event) to those ones in the master image (pre-event). In addition, a calibration process has to be performed to consider the differences in antenna-pointing, orbit-track and radar look angleduring two consecutive radar acquisitions.

A multiplicative calibration constant is evaluated using the contribution of double reflection from several buildings to the ratio image of the pre- and post-event amplitude SAR images:

$$c = E\left[\frac{\hat{\sigma}^0_{\mathbf{POST}}}{\hat{\sigma}^0_{\mathbf{PRE}}}\right] \tag{1}$$

where $\hat{\sigma}^0_{\mathbf{POST}}$ and $\hat{\sigma}^0_{\mathbf{PRE}}$ are the Radar-Cross-Section (RCS) relevant to double reflection line of the coregistered slave

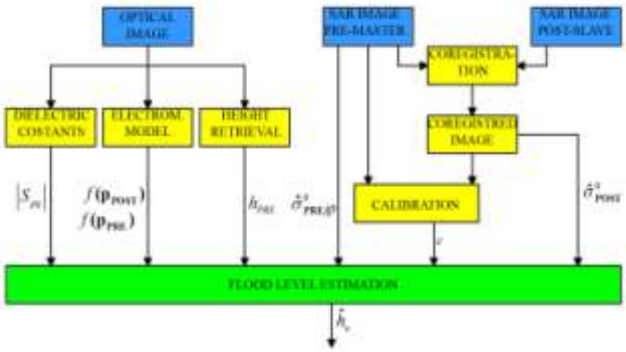

Fig.1 - Global Approach's flow chart.

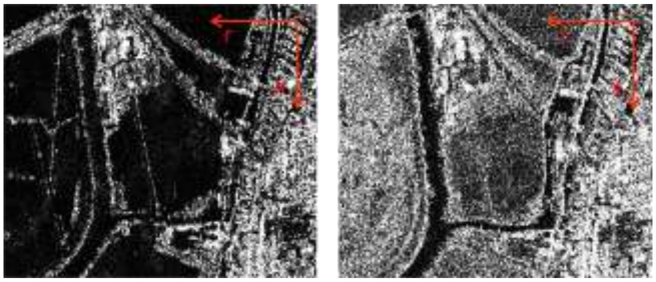
(a) (b)

Fig.2- Stripmap SAR image of Tewkesbury at flooding time (a) and one year later (b).

image and the master image respectively while c is the calibration constant.

The flooding level estimation relies on the height retrieval procedure introduced in [2] within the Physical Optic (PO) or the Geometrical Optic (GO) approximation; according to that electromagnetic model, the building height is linked to RCS of double reflection contribution:

$$\sigma^0 = h \cdot f(\mathbf{p}) \tag{2}$$

where σ^0 is the incoherent radar cross section and $\mathbf{p}$ is a known parameters vector, $\mathbf{p} = (l, \sigma, L, \varepsilon_w, \varepsilon_s, \varphi, \vartheta)$, l is the building length, σ and L are the standard deviation and the correlation length, respectively, of the random process describing the soil, ε_w is the complex dielectric constant of the building wall, ε_s is the complex dielectric constant of the soil surface, φ is the angle between the sensor line of flight and the projection of the building wall to the ground, ϑ is the SAR look angle. The function $f(\mathbf{p})$ can be described by two different equations (GO-GO or GO-PO) according to the ground roughness [2]. Employing this model for both the images, it is possible to retrieve the post event building height by the ratio between equation (2) in pre and post conditions:

$$h_{POST} = \frac{1}{c}\frac{f(\mathbf{p}_{\mathbf{PRE}})h_{PRE}\hat{\sigma}_{\mathbf{POST}}}{f(\mathbf{p}_{\mathbf{POST}})\hat{\sigma}_{\mathbf{PRE}}} \tag{3}$$

Fig.3 - Tridimensional view of building chosen as target.

Finally the flooding level is evaluated as the difference between the building height (h_{PRE}) and the reduced height caused by flood (h_{POST}).

In the next section the approach here presented is applied to a case study.

3. DATA SET AND RESULT

In July 2007, Gloucestershire (U.K.) experienced one of its worst flood and Tewkesbury was the most damaged town. At that time one TerraSAR-X Stripmap image, shown in Fig.2(a), was acquired on the area on the 25th July 2007 and is used in this study. The look angle is 24°, the spatial resolution respectively 3.3m and 1.2m for the azimuth and the slant range, the polarization mode is HH. One more image of same area was acquired in ordinary conditions one year later on 22nd July 2008 Fig.2(b). The water level is now evaluated for a building target: Tewkesbury waterworks, whose tridimensional view is shown in Fig.3.

Some parameters have been directly estimated from the image: the angle between the sensor line of flight and the projection of a wall of the building to the ground and the RCS relevant to double reflection line by performing a simple supervised mean. Geometric parameters and materials relevant to the building, instead, have been directly acquired *in situ*. The building target is mostly made up of bricks (97%) and glass (3%); this consideration let us estimate a weighted average dielectric constant of the building target as done in [5].

$$\varepsilon_m = p_b\varepsilon_b + p_g\varepsilon_g = 4.55 - j0.29 \tag{4}$$

where p_b and p_g are the percentage of brick and glass; ε_b and ε_g the complex dielectric constant of brick and glass at the work frequency (9.65 GHz) [6].

The choice between electromagnetic models depends on the standard deviation and correlation length chosen to describe the Gaussian process of the soil; these and all the other parameters employed are listed into the Table I.

The values selected to describe the stochastic process of the soil are the same for ordinary conditions (pre-event) and flood situation (post-event) because in the near surroundings of the building very high trees and thick vegetation are present; this leads us to assume there was no relevant change at ground roughness scale. The adopted values, in addition, fulfill neither GO-PO nor GO-GO approximation; since $k \cdot \sigma > 1$ we employ GO-GO model in according to [7].

Once known all parameters and established the electromagnetic model, the water level in the surroundings of the building target has been estimated to be 2.53m referring to the equation (3). It is known that the measured water level at Mythe Bridge water gauge, situated close to the local target, was 12.22m a.s.l. (*above sea level*) on the 25 of July 2007 [8]; the water level in ordinary conditions is 8m a.s.l., instead. Finally it is possible to calculate the measurement error as:

$$E = \left(h_{POST} - h_{PRE}\right) - \hat{h}_w = \left(4.22 - 2.53\right)m = 1.69m \quad (5)$$

where h_{POST} and h_{PRE} are the water level measured at the water gauge in flood and non-flood conditions respectively while $\hat{h}_w$ is the measured water level. The measurement error represents the worst-case because the river embankment has been ignored and so the flooding level is certainly lower than the measured one at water gauge.

A similar measurement has been performed employing the Local Approach obtaining a water level of 2.08m and an absolute error of 2.14m. The achieved results are very encouraging for both the approaches since the error is lower than the azimuth spatial resolution at worst case. More outcomes will be shared at conference time.

4. CONCLUSIONS

A new approach to retrieve the water level from SAR images has been introduced. We consider very positively these first measurements attempts witnessed by an error lower than the spatial resolution. The error could even be decreased if Spotlight images were used since the double reflection line detection would be more accurate. Considering the previous approach introduced by the authors, it is important to underline that the two proposed methods do not clash each other, but they can use at the same time for different goals. Local approach is more adequate to monitor sensible targets such as hospitals, waterworks or power stations which have to be work also in emergency situation; instead Global Approach is more useful to retrieve a flood map all over the scene since we need only one calibration procedure.

The importance of this work is timely and its exploitation huge if we consider the last Italian flooding disasters of Genova and Messina (2011); the algorithms here introduced could be useful to manage and better response these crisis situations. The authors are currently working at further scenario in order to provide a more reliable performance analysis of their approaches and they are testing the efficiency of inverse procedure on different case studies.

TABLE I

SCENARIO PARAMETERS

Parameter	**Value**
Length l [m]	77.50
Width w_1 [m]	35.00
Width w_1 [m]	42.00
Angle φ [deg]	4.80
Building height h_{PRE} [m]	13.50
Dielectic constant of brick ε_b	$4.53 - j0.31$
Dielectric constant of glass ε_g	$6.27 - j0.04$
Dielectric constant of building ε_m	$4.55 - j0.29$
Dielectric constant ofwater ε_w	$55 - j38$
Standard deviation σ [m]	0.02
Correlation length L [m]	0.15

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5. REFERENCES

[1] R. Guida, A. Iodice, D. Riccio,” Height Retrieval of Isolated Buildings From Single High-Resolution SAR Images”, *IEEE Transactions on Geoscience and Remote Sensing*, vol.48, n.7, pp.2967-2979, August 2010.

[2] G. Franceschetti, A. Iodice, D. Riccio, “A Canonical Problem in Electromagnetic Backscattering From Buildings”, *IEEE Transactions on Geoscience and Remote Sensing*, vol. 40, no. 8, August 2002.

[3] D. Di Martino, A. Iodice, D. Riccio, G. Ruello, ” Monitoring of Flooding in Urban Areas”, *IEEE Urban Remote Sensing Joint Event 2007*,pp 1-5

[4] P. Iervolino, V. Diessa, A. Iodice, D. Riccio, R. Guida, “A New Local Approach for Flooding Level Estimation in Urban Areas Using Single SAR Images“, *IEEE Joint Urban Remote Sensing Event 2011*, pp 257-260, April 2011 (Munich).

[5] R. Guida, A. Iodice, D. Riccio, and U. Stilla, “Model-based interpretation of high-resolution SAR images of buildings,” *IEEE J. Sel. Topics Appl. Earth Obs. Remote Sens*., vol. 1, no. 2, pp. 107–119, Jun. 2008.

[6] F. T. Ulaby, R. K. Moore, A. K. Fung, “Microwave Remote Sensing- Active and Passive”, Volume III.

[7] R.Guida, G.Franceschetti, A.Iodice, D.Riccio, G.Ruello, U.Stilla, “Building Feature Extraction via a Deterministic Approach: Application to Real High Resolution SAR Images”, *Proceedings of the International Geoscience and Remote Sensing Symposium*, pp.2681-2684, Barcelona (Spain), 2007.

[8] D. Mason, R. Speck, B. Devereux, G. Schumann, J. Neal, P. Bates, “ Flood Detection in Urban Areas Using TerraSAR-X“, *IEEE Transactions on Geoscience and Remote Sensing*, vol.48, n.2, pp.882-894, Febraury 2010.