Monitoring of Flooding in Urban Areas

Gerardo Di Martino, *IEEE Graduate Student Member*, Antonio Iodice, *IEEE Senior Member*, Daniele Riccio, *IEEE Senior Member*, Giuseppe Ruello, *IEEE Member*

Dipartimento di Ingegneria Elettronica e delle Telecomunicazioni,
Università di Napoli "Federico II"
Via Claudio 21, 80125 Napoli, Italy
E-mail: {gerardo.dimartino, iodice, daniele.riccio, ruello}@unina.it

Abstract — **Urban areas are crowded environments, where a disaster can bring dramatic consequences, if not adequately forecasted and faced. Remote sensing instruments can be fruitfully used for both prediction and aid organization purposes. In particular, in this paper we present innovative Synthetic Aperture Radar (SAR) techniques for the detection of a flooded area in urban settlements. A SAR raw signal simulator is presented and used, in order to improve the comprehension of the main physical phenomena and to plan the most adequate sensor characteristics for detection purposes. The single and multiple scattering phenomena, in conjunction with strong layover effects make the SAR images relative to urban areas extremely involved. The presented study is focused on a canonical environment, in order to provide a complete and powerful instrument for the comprehension of the complex texture of urban area SAR images.**

Keywords – Synthetic Aperture Radar

I. Introduction

Half of the Earth population lives today in urban areas. Therefore, the continuous sensing of urban characteristics is particularly effective to understand people condition of life, migration flows and so on. The velocity of changes of the city is typically moderate with respect to the repetition of acquisition of almost all the actual sensors. Anyway, natural disasters can cause sudden temporal discontinuity in the urban environment, making necessary a reliable and immediate response to the crisis condition.

Moreover, in case of disasters, it is usual that the acquisition environment is strongly perturbed, typically by atmospheric phenomena. For instance, if a flooding happens, it is highly probable that the clouds impede an optical analysis of the area hit by the event. In this case, it is highly desirable a sensor able to acquire information independently of the weather condition and the hour of the day.

In addition, when a flooding occurs, the surface profile is modified at several scales. The water tends to cover the ground and to change the macroscopic topography as well as the roughness properties of the scene. The dielectric parameters of the scene are changed as well, due to the presence of water [1].

Above expressed considerations lead to deal with Synthetic Aperture Radar (SAR) sensors. In fact, they are mainly sensitive to the macroscopic and the microscopic surface characteristics, as well as the dielectric surface parameters [2].

The microwave frequencies employed by radar instruments and the obtained geometric resolutions are well tailored to monitor the geometrical features of the area under survey.

Anyway, SAR image formation mechanisms are extremely involved due to the strong layover, shadow effects, single, double, and triple reflection mechanisms occurring in presence of walls on the city ground. Therefore, the interpretation of SAR images in urban areas is not cumbersome, and it requires a deep knowledge of the electromagnetic field interaction with city structures.

To this scope, a SAR data simulator is an important added-value tool to help scientists and non-expert users in better understanding the mechanisms underlying SAR image formation and in the data interpretation. If the mechanisms underlying the SAR image formation are properly accounted for, a reliable simulation can drive quantitative analysis of urban SAR images.

In this paper, we present a SAR raw signal and image simulator, developed to reproduce the above cited phenomena. Physical Optics (PO) and Geometrical Optics (GO) models are employed to account for single, double and triple reflections from the wall-ground structure [3].

When the water covers an urban area, the relative building height, the surface roughness, the dielectric properties of the observed scene simultaneously change.

In this paper, we simulate the presence of a flooding, by changing these parameters on the observed scenario. A parametric study on the effect of each of the above cited phenomena on the SAR signal allows the comprehension on how a single physical parameter acts on the SAR signal formation mechanisms.

The use of the simulator provides a value added instrument for the comprehension of SAR images. In addition, it can be used to drive retrieval algorithms devoted to extract significant parameters from urban SAR images, as well as for detecting an area hit by a flooding, by comparing pre- an post-crisis data [4].

II. SIMULATION TECHNIQUE

In this Section we present the technique employed to model the most important phenomena governing SAR raw signal and image formation.

In recent years, a SAR raw signal simulator for urban areas was developed and tested [5], [6], according to the principles recalled in this Section.

Let x and r be the independent space variables, standing respectively for azimuth and range. By using primed coordinates for the independent variables of the SAR raw signal, $s(x',r')$, this can be expressed as [5]:

$$s(x',r') = \iint dxdr\gamma\left(x,r\right)g\left(x'-x,r'-r;r\right), \qquad (1)$$

where $\gamma(x,r)$ is the reflectivity pattern of the scene and $g(x'-x,r'-r;r)$ the unit impulse response of the SAR system [5], [6]. In urban areas, the evaluation of the reflectivity function requires a description of the observed surface in terms of the topography of the city and the position and height of the buildings, as well as a model for their interaction with the electromagnetic fields radiated by the SAR antenna [5]. Hence, the considered simulator requires as input a DEM relative to the scene of interest, sampled with a resolution coherent with the considered sensor parameters.

When an electromagnetic field impinges on a structure formed by a building on a rough ground, the electromagnetic return is formed by single, double and triple reflection mechanisms [3]. In this paper the SAR simulator uses Physical Optics (PO) and Geometrical Optics (GO) models, which are consistent in the high frequency region employed in the usual operational SAR radar frequencies, as presented in the recent literature.

The development of such a simulator allows to evaluate and to interpret the SAR images relevant to urban areas. As an example, we present a canonical study representative of most of the physical phenomena occurring in the formation of the SAR signal. We consider a reference sensor, whose main characteristics are provided in the first three lines of Table I. A single building is placed on a rough surface, with a wall parallel to the sensor direction of flight. In Fig. 1, the corresponding simulated image with a 1 x 4 multilook is shown. The single look image resolutions are provided in the last two lines of Table I.

TABLE I. SENSOR PARAMETERS

Platform height [km]	200
Look angle [deg]	28
Carrier frequency [GHz]	1.282
Azimuth resolution [m]	2.574
Slant range resolution [m]	4.83

Figure 1. Simulated SAR image relative to a single building on a rough surfaces. Main simulation parameters are provided in the first line of Table II. Near range is on the left.

In Fig. 1 we can recognize the layover, double and shadow effect, typical of a SAR image of urban structure. Their extension and intensity depend on the observed scenario characteristics (ground roughness standard deviation *sd* and correlation length *lc*, dielectric constant ε and conductivity σ, and on the building height h) [3]. The most significant simulation parameters are presented in Table II. The simulator allows to quantitatively define the position and extension of each contribution, therefore the characteristics of the scene that appeared to obstacle the image interpretation can be used to improve the comprehension of a given scenario.

In addition, the observation of the changes in each contribution is crucial for detecting roughness, relative building height and dielectric parameter modification, hence the disaster effect.

III. FLOODING EFFECTS ON SAR IMAGES

A flooding in a city causes the modification of small and large scale surface parameters, and it influences the electromagnetic return from a building. In this Section we present the basic mechanisms of such modifications, by using the presented SAR raw signal simulator for a canonical scene.

Note that, the intensity of the layover and the double reflection mechanisms depends on the surface roughness. If the roughness increases, most of the electromagnetic signal is backscattered to the sensor, therefore the layover effect can be dominant with respect to the double scattering, which is mainly formed by contributions arisen from specular reflections.

In addition, it is expected that, if the water covers the ground, the relative height of the building can change, modifying the intensity of the double reflection contribution and the intensity and the extension of the layover effect.

In Fig. 2, we present the effect of roughness modification on the SAR image when the terrain standard deviation and correlation length are changed to *sd*=0.01m and *lc*=0.2m, respectively.

TABLE II. SCENARIO PARAMETERS

sd [m]	*lc* [m]	ε	σ [S/m]	*h* [m]
0.019	0.154	4	0.001	35
0.01	0.2	4	0.001	35
0.019	0.154	4	0.001	30
0.019	0.154	80	1	35
0.01	0.2	80	1	30

Figure 2. Simulated SAR image relative to a single building on a rough surfaces. Main scenario parameters are provided in the second line of Table II.

As expected, the decrement of the surface roughness leads to a mean decrement of the backscattered field, and the terrain appears darker in the SAR image. The equalization is such that in each image the grey level corresponds to the same intensity value.

In critical cases a flooding can cover the city streets and the water can rise to several meters above the usual level. From the detection point of view, it means that the building height with respect to the ground decreases, in accordance with the water level. Therefore, the intensity of layover and double reflection mechanisms can be modified. In Fig. 3, we show the SAR image relative to the scenario described in the third line of Table II, which differs from the first line only in the building height. Note that in the relative image the layover effect is reduced, in accordance to the fact that the area is reduced. The double reflection effect is reduced as well, in accordance with theoretical considerations presented in [3].

Figure 3. Simulated SAR image relative to a single building on a rough surfaces. Main scenario parameters are provided in the third line of Table II.

A further element which is significantly modified by the presence of water in urban environment is the fact that the dielectric constant of water and wet terrain is higher than that of dry soils. The presented simulator allows the study of the dielectric parameters on the SAR signal, as presented in the simulation shown in Fig. 4, whose parameters are provided in the fourth line of Table II.

The dielectric constant and the conductivity of the area surrounding the building are set to the typical water values. It is evident that the increasing of the dielectric constant causes an increment of the backscattered signal, witnessed by a clearer background in the SAR image.

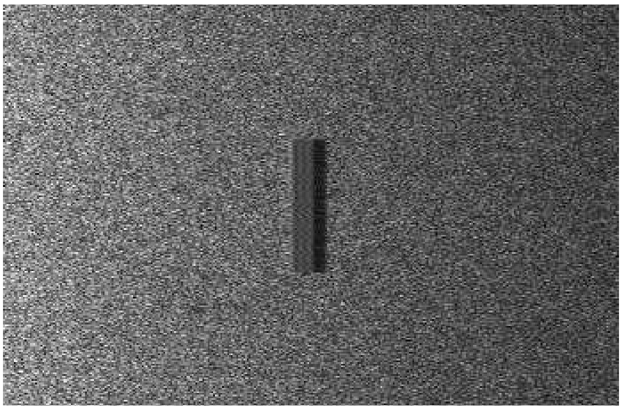

Figure 4. Simulated SAR image relative to a single building on a rough surfaces. Main scenario parameters are provided in the fourth line of Table II.

The simultaneous presence of all the phenomena described above is then conjunctly provided as input to the simulator (see last line of Table II), in order to investigate the whole effect of a flooding in the SAR signal. The corresponding SAR image is shown in Fig. 5. It proves that it is extremely hard to separate each single phenomenon effect, so providing a meaningful evidence of the simulator ability and its importance in the image interpretation process.

1-4244-0712-5/07/$20.00 ©2007 IEEE

Figure 5. Simulated SAR image relative to a single building on a rough surfaces. Main scenario parameters are provided in the fifth line of Table II.

IV. THE CASE STUDY

In the following, we present a case study, showing the effects of flooding in a more complex situation, involving more buildings in a scene with a non constant height profile.

The region of interest is a 2.5 X 4 Km^2 area: a digital elevation model (DEM) with resolution 2.5 X 10.3 m^2 (azimuth-ground range) of this area was provided as input for the simulator. In the lowest part of this DEM was considered the presence of a set of 16 buildings, presenting different angles with respect to the sensor line of flight. The considered sensor presents a 28° look-angle from an height of 20 Km, as can be seen in Table I.

As first, we obtained the pre-crisis SAR image from the simulated raw signal via standard processing and averaged with a 1 x 4 multi-look, so obtaining an azimuth-ground range approximately square pixel, see Fig. 6.

Figure 6. Simulated pre-crisis SAR image.

The electromagnetic scattering model used to compute the reflectivity pattern of the observed scene is, as in the previous canonical studies, a Physical Optics (PO) solution: different models can be used for the evaluation of the single scattering return from the terrain. We used this model because it gives an analytical closed form expression for the double scattering return from buildings [3].

After this simulation, the second step was the modification of the original DEM to simulate a flooding. We modified the input parameters of the simulator according to the rationale previously presented for the canonical studies. In order to appropriately simulate the presence of water in the flooded region, we modified the microscopic roughness, the dielectric parameters and the relative height of the buildings in the zone hit by the flooding.

In Fig. 7 we present the image relative to a scenario where, in a given area, the simulator input parameters (microscopic roughness, electromagnetic parameters and building relative height) vary, in accordance with a flooding event.

By observing the post-crisis image we can analyze all the phenomena described in the previous section. The most evident effect is the decrement in the backscattering return from the affected zone due to the smaller microscopic roughness in presence of water, partially reduced by the increment of the dielectric constant: this makes steeper the difference between terrain and roof returns. Another interesting phenomenon, is the increment of the intensity of the double scattering return relative to the flooded buildings. This effect is more relevant for the buildings located near to the border of the zone hit by the flooding, where the relative building height is almost unchanged, and the angle between their walls and the sensor line of flight is moderate.

Conversely, the other flooded buildings present very different geometric conditions: in particular the decrement of the ground roughness is balanced by the strong decrement of the relative building height. The evident effect in the image is that no significant variations can be appreciated in their double scattering return.

A visual comparison of Fig.7 and Fig.6 leads to a clear identification of the flooded area. A complete analysis of the techniques devoted to extract the flooded area is beyond of the scope of this paper. Anyway, it has to be stressed that an intensive use of this simulator can provide a training set for classical change detection algorithms [7] and new hints for developing innovative techniques.

Figure 7. Simulated post-crisis SAR image.

V. CONCLUSIONS

SAR images hold a huge amount of information on the building heights and dielectric properties, the soil characteristics and so on. This information can be retrieved only if a reliable geometrical and electromagnetic model is available. In this paper we presented a SAR raw signal simulator relative to urban areas. The presented simulator requires the topography of the observed scene, the microscopic roughness and it employs the Physical Optics and Geometrical Optics electromagnetic models.

When a disaster hits an urban area, the whole physics of the urban structures is changed, and it is required to retrieve where these modifications are mainly occurred.

In order to shed light on the involved mechanisms that contribute to the SAR signal formation, we analyzed the effect on the SAR images of the most significant scenario parameters (surface roughness, surface topography, dielectric constant, and so on) affected by meaningful changes in case of intensive presence of water in an urban scenario.

The ability of retrieving information from a single SAR image or by comparison of pre- and post- crisis scenarios depend on all the above cited actors. In order to quantitatively understand the intensity of each measurable in the actual scenarios, we performed a parametric study. The obtained results are consistent with the theory. The effect of roughness, dielectric properties and so on were shown.

Note that the presented simulator can be fully inserted in a wide framework involving inverse tools for the extraction of information. Presented simulations show that standard retrieval algorithms can be employed to extract value added information via classical and innovative change detection techniques.

REFERENCES

[1] L. Hess, J. M. Melack, S. Filoso, and Y. Wang, "Delineation of Inundated Area and Vegetation Along the Amazon Floodplain with the SIR-C Synthetic Aperture Radar", *IEEE Trans. Geosci. Remote Sens.,* vol. 33, no. 4, pp. 896-904, July1995.

[2] F. T. Ulaby, R. K. Moore and A. K. Fung, *Microwave Remote Sensing: Active and Passive,* Reading, MA: Addison-Wesley, 1982.

[3] G. Franceschetti, A. Iodice, D. Riccio, "A Canonical Problem in Electromagnetic Backscattering from Buildings" ", *IEEE Trans. Geosci. Remote Sens.*, vol. 40, no. 8, pp. 1787-1801, Aug.2002

[4] G. Di Martino, A. Iodice, D. Riccio and G. Ruello, "A Novel Approach for Disaster Monitoring: Fractal Models and Tools", in press on *IEEE Trans. Geosci. Remote Sens.*, Disaster Special Issue.

[5] G. Franceschetti, M. Migliaccio, D. Riccio, G. Schirinzi, "SARAS: a SAR Raw Signal Simulator", *IEEE Trans. Geosci. Remote Sens.*, vol. 30, no. 1, pp. 110-123, Jan.1992.

[6] G. Franceschetti, A. Iodice, D. Riccio, G. Ruello, "SAR Raw Signal Simulation for Urban Structures", *IEEE Trans. Geosci. Remote Sens.,*vol.41, n.9, pp. 1986-1995, September 2003.

[7] E. Rignot and J. van Zyl, "Change Detection Techniques for ERS-1 SAR Data", *IEEE Trans. Geosci. Remote Sens.*, vol. 31, no. 4, pp.896-906, July 1993.

1-4244-0712-5/07/$20.00 ©2007 IEEE