MODELS FOR FEATURES EXTRACTION FROM SAR IMAGES OF URBAN AREAS

Giorgio Franceschetti[(1),(2)], Raffaella Guida[(1)], Antonio Iodice[(1)], Daniele Riccio[(1)], Giuseppe Ruello[(1)]

[(1)]DIET, Università di Napoli Federico II, via Claudio 21-80125 Naples, Italy
{gfrance, rafguida, iodice, daniele.riccio, ruello}@unina.it

[(2)]University of California, Los Angeles, USA

ABSTRACT

Features extraction from SAR images of urban scenes represents one of the most interesting subjects of research in the field of remote sensing; new, more adequate and specialised backscattering and radar models for features retrieval are studied and strongly required.

In this paper, a synoptic view of three different approaches to the problem, accounting for the dynamism and complexity of urban scenarios, is presented. Stochastic analysis and neural networks based approaches are here analysed and compared together with a new theory for a deterministic extraction (inverse problem) of geometric and electromagnetic building parameters from the corresponding SAR image.

I. INTRODUCTION

Nowadays, continuous monitoring of urban areas represents one of the most attractive subjects of research in remote sensing whenever a Synthetic Aperture Radar (SAR) instrument is employed. SAR technology, being indifferent to weather conditions, ensures permanent monitoring, while its latest innovations grant very high resolutions images. The wide band on one side and new acquisition modes on the other represent requirements that can not be given up to obtain SAR sensors with excellent performance and even decimetric resolutions.

But, in spite of high resolutions, analysis and interpretation of SAR images relative to urban areas are still open questions. Difficulty in images interpretation arises for many reasons: above all, the extreme complexity and variety of urban landscape constituted by objects of different form, size and material. Moreover, for a complete description, mutability of a scenario changing over time has to be considered.

These features emphasize when resolution improves because new details become visible on the image. Consequently, we can follow, in principle, any evolution (in form or material) of a great amount of objects. In practice, in order to exploit availability of huge amount of data, we need elaboration processing and techniques being in step.

Nowadays, new and original approaches are studied and tested. The most interesting ones are presented in this work (Section II) together with an innovative point of view which lead us to adopt a deterministic approach (Section III) in the problem of urban areas SAR images processing. Helped by some simulation examples, we present our first results obtained by employing a deterministic method (Section IV); some comments on future developments are also included.

Since different approaches face the problem of processing at different scales with different requirements, a synergy, and not a competition, among them is desirable for a better interpretation of SAR images relative to urban scenes. That is why we present them together, stressing their key features and showing how they can support each others.

II. COMPARISON OF EXISTING APPROACHES

Let us consider a generic urban area and let us inspect the information content of relative SAR images. A structural analysis, able to provide a macroscopic view of the scene, allows to obtain useful global information also studying SAR images with low resolution. For example, the monitoring of buildings or streets density in built-up areas, as well as the singling out of boundaries between urban and not urban areas, is possible in different ways, [1]-[3].

The dynamism of urban scenes, usually higher than those relevant to a natural landscape, justifies the use of a neural based processing. The risk of working with a strongly mutable environment, in fact, is finding processing solutions which, if strictly dependent on the problem at issue, result no more efficient in short. Instead, solutions taking into account the dynamism of the scene will be flexible and able to pursue the change taking place. Neural networks allow this kind of approach, able to adapt to the scene and its changes, thanks to its ability to learn from the environment and to modify its responses to the external stimuli even in circumstance not a priori known.

A first time of learning, the so called training phase, is requested every time we desire to update the network after that a change has taken place in the scene. But being unknown both the rapidity and the number of changes, the user will decide when an updating of the network is needed, thus defining the performance of a neural network based approach.

This kind of processing is useful when a first, even if coarse, classification of the image is desired, for example to separate vegetation from built up areas or streets [1]. Neural approach for images classification turns out to be more robust to training site selection and, above all, it is able to well recognize intrinsically heterogeneous classes [2]. But, because of possible multiple training phases, this kind of solution produces high computational costs. In order to reduce

processing times, the training phases should be reduced; however this correspond to obtain a processing chain that is very precise on training data set but much less accurate on effective data to be tested.
In this situation, we propose to choose a different solution which, being not adapted to any training data set, shows an usually better accuracy on effective data.
A statistical approach allows to reach such a performance. Moreover, the complexity of urban scenarios, where natural and artificial objects live together, is well faced by a stochastic analysis. As a matter of fact, the urban landscape complexity presents two different aspects. The simpler one relies on the urban area elementary constituents (buildings, terrains,…) which are characterised by their different geometrical and electromagnetic parameters. The more involved source of complexity relies on the almost unpredictable ways these constituents populate the scene and interact on the radar return. .
When the image resolution is improved, new details can be appreciated on the scene which shall appear much more complex. This happens when resolution is of the order of 1 meter or less. Very high resolution SAR images are notably complex and of difficult interpretation even if they are plenty of information.
Some information from HR (High Resolution) SAR images can still be extracted with an approach based on statistical analysis [3]. In fact, we can exploit information relative to strong and low backscattering areas in which the scene can be subdivided by a simple Bayesian classification, obtained by providing training areas and considering appropriate statistics.
This way allows to work with a great variety of urban scenarios composed by structures of different forms (buildings with slope or flat roof, of rectangular or circular base etc..). But this approach, whose objective is the reconstruction of the objects in the scene, is able to supply a still structural analysis, even if more detailed. For a highly detailed view of reality, a different approach has to be taken into consideration. This is presented in the next Section.

III. A DETERMINISTIC APPROACH

Till few years ago, the difficulty in detailed information extraction from SAR images was due to the lack of physical and mathematical models able to describe the complex interactions between radar signal and man made objects in the scene. In [4]-[5], a first attempt in this direction was faced, producing a SAR raw signal simulator for urban structures implementing a complete and widely applicable electromagnetic model of scattering from isolated buildings. Availability of such an instrument has represented an important support in developing the idea of a deterministic extraction of geometric and electromagnetic parameters from HR SAR images [6]. Being analytical known the links between the set of scene and building parameters to be extracted and the set of parameters measurable on the image, we proposed to exploit this knowledge for information extraction. In [6], the basic idea was first presented in general and then developed, by way of example, for a specific geometric parameter (i.e., the building height) and an electromagnetic parameter (i.e., the complex dielectric constant of building walls).
For the height estimation, a conventional procedure was conducted beginning from the extensions along the slant range direction of layover and shadow zones. But, at the same time, we pointed out that other ways could be explored, thanks to the system of equations found in [6], whose solution leads to multiple determinations of the same parameter.
Here this approach is supported and strengthened showing, for the first time in the literature, a building height estimation from a radiometric parameter measurable on SAR images.
Let us focalize our attention on the double reflection contribution to the radar cross section.
It is simple to understand that the higher a building the more shining double reflection strip on the image. In fact, since double reflection contributions are determined by rays running along the same distances, they arrive at the sensor at the same time thus causing, on the image, a line of high intensity [5]. These contributions increase with the height of the building, that is why the intensity of relative pixels includes information about the height [4]. Moreover, because of this particular brightness, these regions are simply distinguishable, and so extractable, on the image respect to other contributions less evident.
Other geometric parameters, besides the height, (length and orientation of building respect to flight trajectory) as well as electromagnetic ones (ground roughness, complex dielectric constants of soil and building walls) contribute to the double reflection. For example, for particular values of ground surface roughness, we can adopt the Kirchhoff approach in the Geometric Optics (GO) approximation to evaluate both the field reflected by the smooth wall toward the ground or the sensor and the field scattered by the ground toward the wall or the sensor. Now, the field $\mathbf{E_S}$ backscattered from a plane surface at the observation point $\mathbf{r}$ can be written as:

$$\begin{bmatrix} E_{Sh} \\ E_{Sv} \end{bmatrix} = jk \frac{e^{jkr}}{4\pi r} \begin{pmatrix} S_{hh} & S_{vh} \\ S_{hv} & S_{vv} \end{pmatrix} \begin{bmatrix} E_{0h} \\ E_{0v} \end{bmatrix} I_S \qquad (1)$$

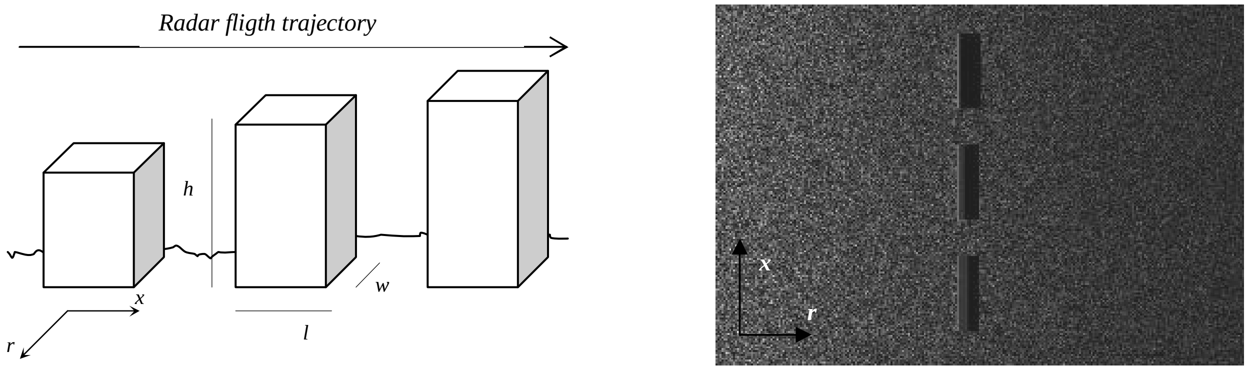
where k is the wave number, $\mathbf{E_0}$ is the incident plane wave, S_{pq} is the generic element of scattering matrix, with p and q each standing for h or v (horizontal or vertical polarization) while I_s is the surface integral accounting for surface shape. By GO approximation, we find for the mean square value of I_s the expression below [4]:

$$\left\langle I_S \cdot I_S^{*} \right\rangle = hl \tan\vartheta \cos\varphi \frac{1+\tan^2\vartheta \sin^2\varphi}{4k^2\cos^2\vartheta} \frac{1}{2\pi\sigma^2 C''(0)} \exp\left[-\frac{\tan^2\vartheta\sin^2\varphi}{2\sigma^2 C''(0)}\right] \tag{2}$$

where h and l are, respectively, height and length of the building, θ is the radar look angle, φ accounts for the direction of the building wall, σ and $C''(\cdot)$ are, respectively, standard deviation and the second derivative of normalized correlation function of the stochastic process describing the ground surface.
All these parameters must be known to extract only the height. A not trivial aprioristic knowledge of the scene is so needed.
In spite of this, the error committed in the height estimation is independent of geometric resolution involved, unlike estimation by geometric parameters (range extension of layover and shadow).
Next session shows some interesting examples attesting the effectiveness of this new approach in canonical cases, and showing the potentiality of the method for real scenes too.

IV. RESULTS AND DISCUSSION

Let us consider a canonical scene composed by few isolated buildings. The adjective ‘isolated’ refers to a building whose returns towards the sensor do not overlay to any other building return in the SAR image. For the sake of simplicity, let us consider buildings lying aligned and parallel (side-looking) to the radar flight trajectory (this is a not necessary hypothesis for the processing we propose). The buildings are modelled as parallelepipeds [4], i.e. the walls are not rough, as well as the roof supposed flat, and the angles between the walls are right.
In the examples we show, the SAR raw signal, relative to urban scenes composed by three buildings with the features above, have been simulated, and then processed. We supposed the complete knowledge of geometric and electromagnetic parameters of two of the buildings in the scene. Of the third one, only the height is unknown and we propose to retrieve it by measuring the intensity of relative double reflection region. Also complex dielectric constant and roughness of the ground are known.
In Fig.1, a pictorial description of simulated scene and relative SAR image are reported. At a first glance, by qualitative analysis, we recognize, respectively in the top and the bottom of Fig.1, the highest building and the lowest one, simply comparing the different intensities of double reflections contributions.
The regions in the image linked to this effect have been isolated and, after a statistical analysis, the mean value of the grey level of each region has been assumed as proportional to the square root of double reflection contribution to the radar cross section. The average operation is needed to reduce the effect of the speckle and knowledge of the height of two buildings in the scene is needed to radiometrically calibrate the image.
For roughness parameters involved, optic geometric approximation has been considered, thus estimating double reflection contribution in closed form [4].
As suggested in [6], we put the analytical expression in (2) in explicit form with respect to the height of building, thus computing the only parameter unknown.
In Tab.1, geometrical and electromagnetic parameters relative to the simulated scene are reported, together with range and azimuth resolutions and the building height retrieved values. We note that the error made on height estimate is independent of geometric resolution: therefore, processing beginning from radiometric parameter, instead of geometric one, can represent an efficient alternative when detailed information is required to be extracted from SAR images of not very high resolution.
The possible influence of wide dynamics in the scene under investigation on information extraction from radiometric parameters has still to be investigated. In these cases, a worsening in the results of the proposed method is expected.



(a) (b)

Fig.1. (a) A canonical scene; (b) SAR image obtained by processing the simulated raw signal relative to the scene pictured in (a).

V. CONCLUSIONS

A synoptic view of modern processing procedures of SAR images of urban scenes has been presented and discussed. A constructive synoptic review, synthesized in Tab.2, of deterministic, stochastic and neural based approaches, for geometric and electromagnetic parameters relative to the scene under investigation, has been expressed with the aim of promoting a synergic cooperation among available methodologies.
Building height retrieval from radiometric parameters, such as intensity of double reflection region, has been described in details for deterministic approach. Method originality has been highlighted together with effectiveness tested on simulated data relative to canonical scenes. Results allow us to hope in an efficient application to actual SAR data.

REFERENCES

[1] F.Dell'Acqua, P.Gamba, "Detection of urban structures in SAR images by robust fuzzy clustering algorithms: the examples of street tracking", *IEEE Trans. Geosc. Remote Sensing*, vol.39, pp.2287-2297, 2001.

[2] T.Macrì Pellizzeri, P.Gamba, P.Lombardo, F.Dell'Acqua, "Multitemporal/Multiband SAR Classification of Urban Areas Using Spatial Analysis: Statistical Versus Neural Kerned-Based Approach", *IEEE Trans. Geosc. Remote Sensing*, vol.41, pp.2338-2353, 2003.

[3] M.Quartulli, M.Datcu, "Stochastic Geometrical Modeling for Built-Up Area Understanding from a Single SAR Intensity Image with Meter Resolution", *IEEE Trans. Geosc. Remote Sensing*, vol.42, pp.1996-2003, 2004.

[4] G.Franceschetti, A.Iodice, D.Riccio, "A Canonical Problem in Electromagnetic Backscattering from Buildings", *IEEE Trans. Geosc. Remote Sensing*, vol.40, pp.1787-1801, 2002.

[5] G.Franceschetti, A.Iodice, D.Riccio, G.Ruello "SAR Raw Signal Simulation for Urban Structures", *IEEE Trans. Geosc. Remote Sensing*, vol.41, pp.1986-1995, 2003.

[6] G.Franceschetti, R.Guida, A.Iodice, D.Riccio, G.Ruello, "Deterministic Extraction of Building Parameters from High Resolution SAR Images", *Proceedings of the 3rd RSS/ISPRS joint Symposium on Remote Sensing and Data Fusion over Urban Areas,* Tempe (Arizona, USA), 2005.

Tab.1. Geometrical and electromagnetic parameters relative to the simulated scenes and central building height estimation.

Buildings length and width	100 m x 100 m
Buildings height	25,35,45 m
Roof and wall dielectric constant	3
Roof and wall conductivity	0.01 S/m
Ground dielectric constant	4
Ground conductivity	0.001 S/m
Ground standard deviation	0.19 m
Ground correlation length	1.54 m
Image resolution (range x azimuth)	4.839 m x 2.571 m
Central building height estimation	34.045 m

Tab.2 . Comparison among deterministic, stochastic and neural based approaches.

Approach	Neural networks	Stochastic	Deterministic
Kind of scenario	Any	Any	Isolated buildings on rough terrain
Image resolution	Medium-high	High	High for building reconstruction from geometric parameters; medium-high for building reconstruction from radiometric parameters.
Applications	Evaluation of building densities, boundaries between urban and non urban areas, street tracking.	Building geometric feature extraction.	Geometric and electromagnetic feature extraction.
Advantages	Robust to training site selection.	Able to deal with structures, in the scene, of different shapes. Good shape identification.	Multiple and independent determination of the same parameter.
Limits	High computational costs.	Low accuracy of building size estimation.	High a-priori knowledge.