BUILDING HEIGHT RETRIEVAL FROM RADIOMETRIC PARAMETERS ON SAR IMAGES

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ABSTRACT:
Urban structure detection, in terms of both geometric and electromagnetic features, from a single Synthetic Aperture Radar (SAR) image is, nowadays, an interesting still open challenge. Within this framework a new deterministic approach for the extraction of the height of an isolated building on a rough terrain is presented. The approach is based on a sound electromagnetic model which fully represents the electromagnetic return from an isolated building to an active microwave sensor, analytically evaluated in closed form. Particularly, building height is extracted from double scattering contribution to the radar cross section measured on the SAR image. Some simulation examples, relative to canonical scenes, accompany and validate the approach proposed.

1. INTRODUCTION

The growth of urban centers calls for a real time monitoring able to check any change in this kind of scenario. Synthetic Aperture Radar (SAR) represents a powerful instrument allowing any weather conditions monitoring and, in particular operating modes, e.g. spotlight, very fine resolutions on data collected.
In the last years, some attempts to retrieve information on man-made objects from SAR images have been carried out. This inverse procedure can be motivated: as shown in [1], a set of analytical relationships among radiometric and geometric parameters of the scene and of the SAR image, can be found; it turns out that some scene parameters could be in principle estimated from even a single SAR image.
Within this framework, the first studies were limited to the building height estimation from geometric parameters on the SAR image [2,3]. Range extensions of layover and shadow areas, in fact, are simply connected to building height [1], so that, height retrieval is immediate when extension of these areas can be easily estimated on a SAR image. But the error affecting the measure is dependent on the SAR acquisition geometry and on the SAR image range resolution; for spaceborne SAR this approach often leads to building height estimation affected by unacceptable measurements errors.
A new way to extract height information is presented in this work.
The idea of building height retrieval from radiometric parameters measurable on SAR image is here presented. The proposed method relies on an electromagnetic model that quantifies the radar return from an isolated building on a rough terrain [4]-[5].
The model takes into account any relevant macroscopic geometrical parameters of the building [4] and evaluates the corresponding radar cross section.
Single, double and triple scattering are considered as main contributions to the backscattered field [4]. Moreover, multiple scattering twists together with layover and shadowing effects to form the SAR image in a not trivial way according to the geometric (building dimensions) and electromagnetic (ground roughness, complex dielectric constants of soil and building) parameters in the scene and the radar functioning mode (look angle, polarization, frequency..).
Particularly, we observed that building heights affect notably SAR image formation not only in the pixel extension of some contributions but also in their intensities.
In the follow this consideration is explained in details in order to motivate our approach in building height retrieval from radiometric parameters and, particularly, from double scattering contribution to the radar cross section.
Different simulation examples relative to canonical urban scenes have been conducted leaving radar parameters and scene features vary. All them proved not only the reasonableness of the methodology proposed but also its major effectiveness in many actual cases respect to height retrieval from geometric parameters.

2. GEOMETRIC AND ELECTROMAGNETIC MODEL

Let us consider the simple urban scene represented in Fig.1. A single building, modelled as a parallelepiped with roof and walls smooth, is placed on a rough terrain. Any direction φ respect to the radar flight trajectory can be considered.
For the model adopted all main building and ground parameters are defined: the height h, the length l and the width w of the building together with its complex dielectric constants (ε_r for the roof and ε_w for the walls); the correlation length L and deviation standard σ of the stochastic process describing the roughness of the soil and its complex dielectric constant ε_s.
Really, for our analysis, we do not need strictly of a scene with a single building. Many buildings can be present together provided that they are isolated in electromagnetic sense, i.e. relative contributions to the radar do not overlap. In such a manner, our attention can be focused on each building separately from others. This hypothesis, which can be released in future, is important in this work where, for the first time in literature, an attempt of retrieve geometric parameters from electromagnetic ones, measurable on the SAR image, has been lead.

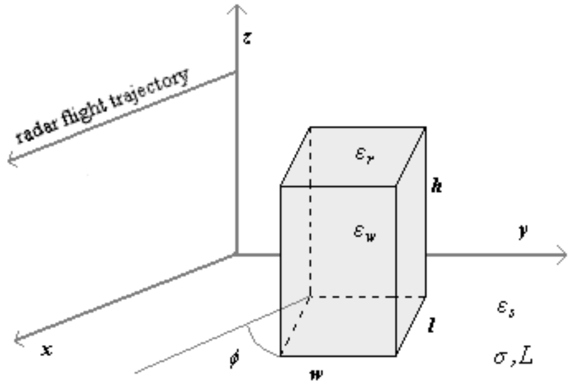


Figure 1. Geometric model of the scene

In fact, as shown in Fig.2 where single, double and triple scattering have been considered, for a single building we already expect a very complex composition of different contributions on SAR image.
As far as concerns the electromagnetic model adopted, a few words are now needed.
High frequency allows us to adopt Kirchhoff approach to compute electromagnetic field backscatterd towards the radar, in Geometric Optics (GO) or Physics Optics (PO) approximation according to the soil roughness [4]. For the geometrical model studied, contributions till third order are demonstrated to be sufficient for a realistic description of backscattered field which 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 E_0 is the incident field, r is the range distance between the target and the sensor, k is the wave number, S_{pq} is the generic element of scattering matrix, with p and q each standing for h or v (horizontal or vertical polarization), I_s is the surface integral accounting for the portion of surface invested by radiation.
As shown in [4], under the hypothesis above I_s can be written in closed form and assumes a different expression according to the order of contribution and the approximation (GO or PO) considered. All these forms, each in a different way, involve geometric and electromagnetic parameters previously defined to describe the scene under detection that is why, in principle, an inversion of direct formulation in [4] can be thought. How this has been applied to building height is shown in the follow.

3. BUILDING HEIGHT RETRIEVAL

As demonstrated in literature [2], building height can be retrieved from geometric parameters measurable on SAR image that are layover and shadow range extensions. Unfortunately, not always these extensions can be appreciated on a real SAR image affected by speckle. Telling where layover begins can be difficult and shadow area on the image, i.e. those pixels characterized by absence of signal, is not directly linked to the height. Moreover, provided that we are able to measure these areas, our evaluation of the building height will be always affected by an error linked to the range resolution of the SAR image.
Here, a completely different approach is presented.
Starting from [1] and [4] we found that building height affects single reflection from wall, double reflection and triple

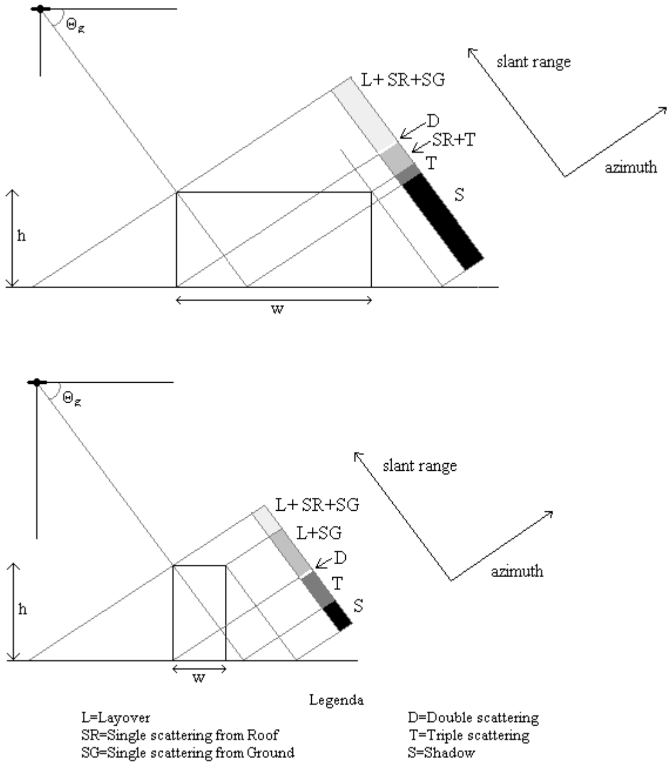


Figure 2. Composition of different contributions on SAR image relative to a canonical scene with an isolated building.

reflection. But triple scattering, which contribution has been emphasized in Fig.2, is weak and difficult to be extracted; single reflection from wall (that is layover) is usually mixed with single scattering from roof and from ground and so not immediately available; double reflection, instead, is always easily distinguishable for its peaked value. Then, a building height retrieval from double scattering contribution can be attempted.
Now, let us suppose that, for roughness parameters involved, Geometric Optics (GO) can represent a reasonable approximation for both bounces of double scattering. The link between the building height and the integral surface I_s found in [4] can be inverted giving

$$h = \frac{\left\langle I_S \cdot I^*_S \right\rangle}{l \tan\vartheta \cos\varphi \dfrac{1+\tan^2\vartheta \sin^2\varphi}{4k^2\cos^2\vartheta \cdot 2\pi\sigma^2 C''(0)} \exp\left[-\dfrac{\tan^2\vartheta\sin^2\varphi}{2\sigma^2 C''(0)}\right]}. \qquad (2)$$

where θ is the radar look angle, $C''(\cdot)$ is the second derivative of normalized correlation function of stochastic process describing the microscopic profile of ground, (x_0, y_0) are the coordinates of building base centre onto the ground plane and $< I_S \cdot I_S^* >$ represents the mean square value of I_s.
In such a way, the building height can be expressed in terms of the radar and scene parameters.
But what we measure on the SAR image is the radar cross section *RCS* linked to the backscattered field, and so to the integral surface, by the well known expression:

$$RCS = \frac{4\pi r^2 < \left|E_s\right|^2 >}{\left|E_o\right|^2} \qquad (3)$$

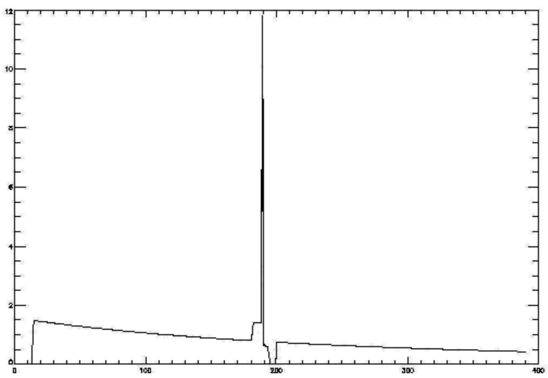
with obvious meaning of symbols. Equations (1), (2), (3) have been used in the next section in evaluating building height after having measured *RCS* relative to double scattering on the SAR image. Some considerations are now in order. In the next we suppose each parameter describing the scene, except the height, to be known for sake of simplicity but they also can be extracted from the image, particularly l and φ in a very simple way. Moreover, being SAR image not calibrated we need the presence of two buildings of which the height is assigned to radiometrically calibrate the image. In a more general case with n buildings in the scene the height of only two of them has to be known to evaluate the heights of the remaining n-2.

Many simulation examples have been realized letting radar and scene parameters vary. Some of them, presented in the follow, are accompanied by interesting results showing the efficiency of the approach adopted.

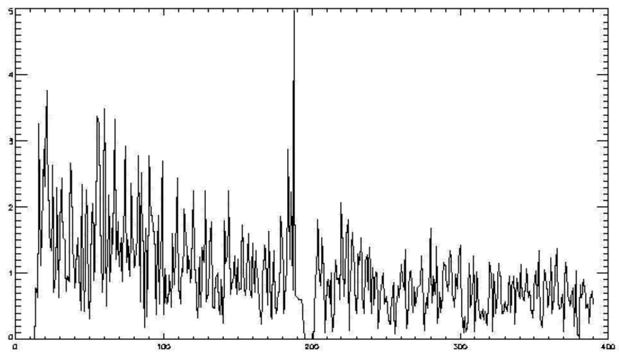
4. SIMULATION EXAMPLES

The urban canonical scene simulated in the next examples is represented by three buildings aligned along a direction in general not parallel with radar trajectory flight. As anticipated, all geometric and electromagnetic parameters in the scene are assumed to be known except for the height of the central building that we propose to retrieve. We let these parameters, as well as radar ones, vary observing as follows.

Double reflection is always easily distinguishable, and so extractable, on SAR image.



(a)



(b)

Figure 3. Range cut of the amplitude $|E_S|$ backscattered by the central building: (a) in absence of speckle; (b) in presence of speckle.

In fact, as shown in Fig.3a, if we plot a range cut of the amplitude $|E_S|$ of the field backscattered by the central building, we see that every contribution can be recognized only in absence of speckle. When speckle is present, see Fig.3b, this operation becomes critic for the most of contributions but double scattering remains particularly peaked in the image.

The major difficulty in this approach appears when we manually cut the double scattering line in the image. This step, simple for buildings aligned with radar trajectory flight, becomes crucial for φ increasing. In order to overcome this problem cross polarization can be adopted. In fact, in this case, backscattering from ground and roof is practically null and double reflection is perfectly isolated on the image.

Anyway, the error committed is always independent from SAR range resolution and the height evaluation is often better than that retrieved from geometrical parameters.

An example is given for the simulated SAR image in Fig.4 relative to φ=40° and in presence of speckle. Horizontal polarization has been considered both in transmitting and receiving mode. Radar parameters adopted are relative to an hypothetic, but not really existing, airborne sensor functioning in L-band. Scene parameters are synthesized in Table 1. We realize from the last row in the table that the error committed is about 1.65 m. In each other simulation conducted the error is even inferior, often inferior to one meter.

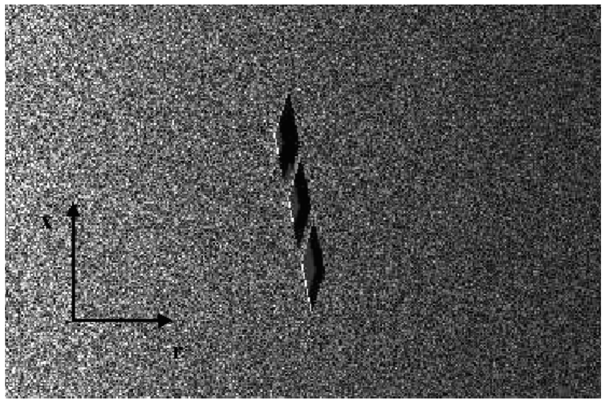


Figure 4. Simulated SAR image relative to three buildings aligned along the direction φ=40°.

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	33.65 m

Table 1. Scene parameters relative to the simulated SAR image.

5. CONCLUSIONS

The need of not conventional approaches to retrieve geometrical features from single SAR image has been highlighted. Particularly, building height retrieval from radiometric parameters, such as intensity of double reflection region, has been described in details. The suggested approach has been applied to simulated canonical scenes with a few buildings. It results to be efficient, being the measure independent from SAR resolution image, and the obtained first results encourage application to real data.

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