DETERMINISTIC EXTRACTION OF BUILDING PARAMETERS FROM HIGH RESOLUTION SAR IMAGES

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ABSTRACT:

Urban structure detection, in terms of both geometric and electromagnetic features, from a single High Resolution (HR) SAR image is, nowadays, an interesting still open challenge.
Within this framework a possible approach to extract information from a single HR SAR image is presented. We first define a set of geometric and radiometric parameters measurable on a SAR image of isolated buildings, and a set of geometric and electromagnetic parameters to be estimated; then we find a set of analytical expressions that relate parameters to be estimated to the measured ones. These quantitative relationships are individuated by appropriately modifying the material presented in some recently published papers in which, for an isolated building, the electromagnetic return to an active microwave sensor is analytically evaluated in closed form. The method is complete and has a wide range of applicability and can be exploited whether the scattering problem is addressed in the phasor domain or whether a pulsed imaging radar is considered.
The obtained relationships linking parameters to be estimated to the measured ones lead to a system of equation: a solution scheme is presented for some significant particular cases.

1. INTRODUCTION

Nowadays, the efforts of scientific community, active in the field of remote sensing, in extracting information as much as possible from a single High Resolution (HR) Synthetic Aperture Radar (SAR) image are notably increased. For many reasons this is a still more pressing requirement when urban scenes are under observation. In such cases, in fact, the occasion of telling a prompt and clear word about the health of urban centres, especially when natural disasters fall to them or negligence and bad management cause heavy damage, is of vital importance. Besides, many studies proved the SAR interferometry inability whenever built-up areas are in order. As a matter of fact, this technique meets crisis, for instance in the phase unwrapping, whenever areas with strong layover and shadowing effects, typical of the urban scenarios, are considered.
Very few approaches, dealing with building reconstruction from a single HR SAR image, can be found in literature. An approach to extract, for an isolated building, information from a stochastic analysis of strong scattering and no return areas of a HR SAR image is reported in (Quartulli, 2004). However, an alternative deterministic approach, able to invert geometric and electromagnetic models, is still strongly required and needed. In this paper, we have taken into account all phenomenological aspects influencing the formation of a SAR image represented by an isolated building. Then we defined a set of geometric and radiometric parameters measurable on a SAR image of isolated buildings (sizes of layover and shadow areas, building angle of orientation, radar cross section), and a set of geometric and electromagnetic parameters to be estimated (height, length and width of the building; complex dielectric constants of walls, roof and soil; soil roughness parameters).
After that we looked for a set of analytical expressions that linked parameters to be estimated to the measured ones. These quantitative relationships have been found by appropriately modifying the material presented in some recently published papers (Franceschetti et al., 2002; Franceschetti et al., 2003). In particular, in (Franceschetti et al., 2002) a geometric and electromagnetic model of a typical element of urban structure has been found; in that paper, for an isolated building, the electromagnetic return to an active microwave sensor is analytically evaluated in closed form. The method is complete, as it accounts for both single and multiple scattering, and has a wide range of applicability, being able to work with either physical optics (PO) or geometrical optics (GO). But in (Franceschetti, 2002) the scattering problem is addressed in the phasor domain, thus leading to results that are not straightforwardly applicable whenever a pulsed imaging radar is considered. Modifications of those results, in an appropriated mixed time-phasor domain, have been found by appropriately considering the theory presented in (Franceschetti et al., 2003) where radar and electromagnetic models are presented that allow to design a SAR simulator able to compute the raw data received by the sensor.
The obtained relationships linking parameters to be estimated to the measured ones allow us to write, for each geometric and electromagnetic feature of an isolated building, a system of equations which solution supplies multiple determinations of the same parameter. In the last section, for some significant particular cases, a solution scheme together with simulation examples are presented and discussed.

2. PHENOMENOLOGY

Let us consider a scene represented by a single isolated building, with any orientation φ respect to the line of trajectory flight, placed on a rough terrain as exampled in Fig.1.

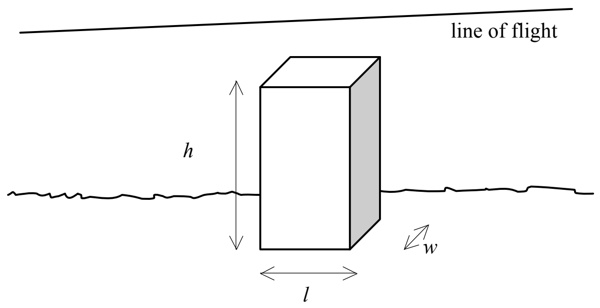

Figure 1. Isolated building on a rough terrain.

Some assumptions have been implicitly made:

- The building presents only four vertices and the angles between the walls are right;
- We do not consider the presence (and so the relative contribution to the SAR image) of windows and balconies;
- The roof is flat and not rough.

Let us define a set of building geometric parameters to be estimated (see Fig.1):

- The height h;
- The length l;
- The width w.

Now, let us define a set of building and soil electromagnetic parameter to be estimated:

- The complex dielectric constant of walls ε_w;
- The complex dielectric constant of roof ε_r;
- The complex dielectric constant of soil ε_s;
- Soil roughness parameters, i.e., the deviation standard σ and length correlation L.

Many studies (Bennette et al., 2003; Bolter, 2000) attempted to extract information on geometric parameters from range extensions of layover L_r and shadow S_r areas present on a SAR image but nobody tried, to the best of our knowledge, to derive further information on the same parameters from contributions of single, double and triple scattering to the radar cross section σ^o (Franceschetti et al., 2002).
Besides, from multiple scattering we can get information also on electromagnetic parameters (Franceschetti et al., 2002).
In a few words, a set of analytical expressions relating parameters to be estimated to the measured ones (see Fig.2) can be found and it is what we do, in the next section, for some significant cases.

3. EXTRACTION

Let us imagine we would extract information on the height h (geometrical parameter) and on the complex dielectric constant of the walls ε_w (electromagnetic parameter) of an isolated building from a HR SAR image.
In the first step, we derive relationships among h, ε_w and measurable parameters on the image.
From Fig.3 and (Franceschetti et al., 2002; Bennett et al., 2003) we find that h determines size of layover L_r, shadow S_r areas and influences radar cross section σ^o through single scattering from wall, double and triple scattering.

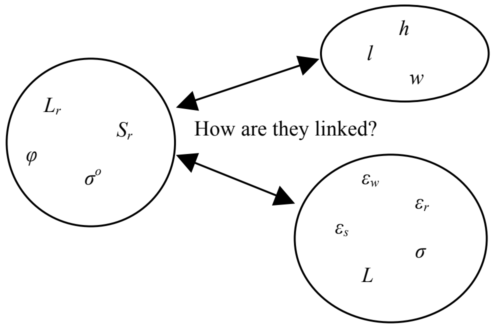

Figure 2. Parameters to be estimated (on the right) on a SAR image of isolated buildings and measurable ones (on the left).

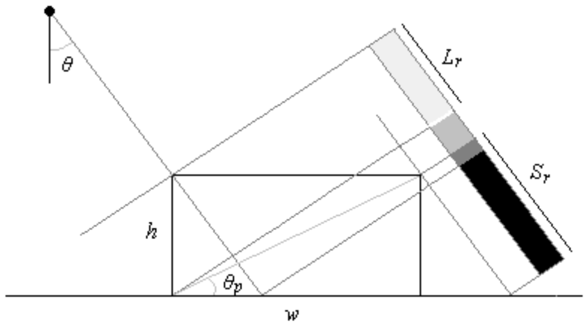

Figure 3. Single and multiple scattering contributions on a SAR image of isolated buildings.

In Fig. 3 triple scattering contribution is emphasized but, usually, it is impossible to distinguish triple scattering area on a SAR image, being it irrelevant (Franceschetti et al., 2002).
As far as concerns ε_w, obviously, it influences only σ^o through single scattering from wall, double and triple scattering as shown in (Franceschetti et al., 2002).
The proposal of a solution scheme is now in order.
For h we have:

- from layover and shadow sizes (Bennett et al., 2003),
  - if $\theta > \theta_p = tg^{-1}\left(\frac{h}{w}\right)$
    - $h = \frac{L_r}{\cos\theta}$
    - $h = S_r \cos\theta$
  - if $\theta < \theta_p = tg^{-1}\left(\frac{h}{w}\right)$ and backscattering from roof is not distinguishable from layover, h can be extracted only from L_r:
    - $h = \frac{L_r}{\cos\theta}$

where θ is the look angle of the sensor.

- from multiple scattering, converting relative equations presented in (Franceschetti et al., 2002) from implicit to explicit form we get the analytical expressions that link h to radiometric parameters.

Analogously, quantitative relationship relating ε_w to the radar cross section can be found through explicit form of scattering equations involving ε_w in (Franceschetti et al., 2002).
For each of the geometrical and electromagnetic parameters defined in the previous section similar solution schemes can be derived thus obtaining a full and complete framework for deterministic extraction of building parameters.

4. EXAMPLES

SAR raw signals of different cases of isolated buildings on rough terrain have been simulated and processed, letting geometrical and electromagnetic parameters vary as well as the building orientation as regards sensor trajectory flight.
For our aim, first, second and third-order contributions to the radar return have been considered for the evaluation of electromagnetic fields backscattered. Higher order contributions add nothing to the backscattered field to the radar antenna because the wall surface is supposed to be flat.
In our simulator model (Franceschetti et al., 2002), for electromagnetic field backscattered evaluation, physical or geometrical optics (respectively PO or GO) approximations, depending on surface roughness, have been considered for single-scattering. In order to account for multiple scattering between buildings and terrain, we use GO to evaluate the field reflected by the smooth wall toward the ground or the sensor and GO or PO (according to ground surface roughness) to evaluate the field scattered by the ground toward the wall or the sensor.
In Table 1, geometrical and electromagnetic parameters regarding the scene under observation are reported. In simulation examples here presented, a frequency of 1.282 GHz has been set. For roughness parameters (Tab. 1) involved, GO approximation has been considered for multiple scattering. PO model has been used, instead, for single scattering from the building.
Images relative to isolated building on a rough terrain, obtained by processing the simulated corresponding SAR raw signals, are reported in Figs.4-5. Images with speckle are on the right.
Image in Fig.4 corresponds to a building parallel to the line of trajectory flight while image in Fig.5 is relative to a building with a front wall oriented with an angle of 22.5° respect to the trajectory flight.
In both examples, the error committed in height evaluation from layover and shadow sizes and the SAR system range resolution are of the same class. In fact, the height esteem is 33.52 m and range resolution, for the radar system adopted, is 4.84 m.
As expected, other simulation examples have shown that evaluation of layover area extension turns out to be more simple when soil roughness decreases being, in this case, layover contribution greatest than double reflection one.
High resolution SAR images availability will allow to knock down the errors in geometrical parameters thus leading to notice variations in building dimensions under the meter.

h	35 m
l	200 m
w	200 m
ε_w	$3\text{-}j0.71*10^{-3}$
ε_r	$3\text{-}j0.71*10^{-3}$
ε_s	$4\text{-}j0.71*10^{-4}$
σ	0.19 m
L	1.54 m

Table 1

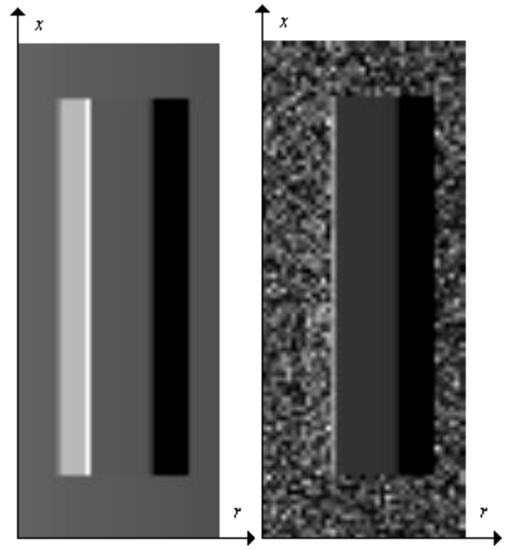

Figure 4. Simulated single-look SAR image relative to an isolated building on a rough terrain, with (on the right) or without (on the left) speckle.

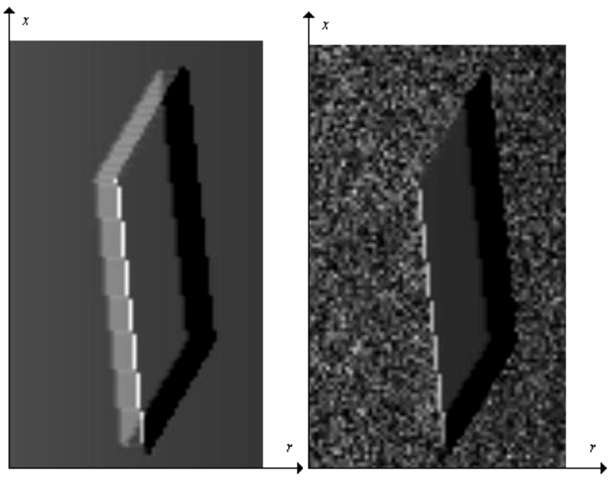

Figure 5. Simulated single-look SAR image relative to an isolated building on a rough terrain, with (on the right) or without (on the left) speckle. The angle between SAR trajectory flight and the building wall is 22.5°

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5. CONCLUSIONS

A framework for deterministic extraction of building parameters from high resolution SAR image has been presented.
The phenomenology relative to electromagnetic field backscattered by an isolated building on a rough terrain has been analyzed together with the methodology for all building parameters extraction from geometric and radiometric ones measurable on a SAR image.
As example, accuracy relative to height estimation has been evaluated in some different cases showing that high resolution in SAR image will allow to detect variations under the meter in building dimension.

6. REFERENCES

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