TERRASAR-X FOR URBAN AREAS MONITORING:
NOVELTIES AND PROMISES OF HIGH RESOLUTION

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ABSTRACT
This paper shows the suitability of High Resolution (HR) TerraSAR-X data for monitoring urban areas by means of feature extraction algorithms able to exploit the new information content provided by HR Synthetic Aperture Radar (SAR) images.

The approach we follow is deterministic and model-based, meaning that the building feature extraction is based on the direct inversion of the electromagnetic scattered field as proposed in [1-4]; the novelty of high resolution is faced adapting the geometric model of the building in order to consider also the presence of windows, balconies or, more in general, of dihedral and trihedral configurations which can now be sensed by the SAR. Consequently, the scattering model is tailored to take into account also contributions from such geometries.
With this approach many and different TerraSAR-X data have been analyzed investigating also the most suitable products for this kind of feature extraction.

1. INTRODUCTION
Urban areas are probably the scenario which more benefits of very high resolution recently achieved in SAR images. A rich information content, previously hidden or not clearly distinguishable in low resolution images of urban areas, is now disclosed but only proper approaches are able to retrieve it.
The research here presented is part of the project “Urban objects’ characterization via SAR data inversion”, proposal LAN0044, for the exploitation of TerraSAR-X data and, more precisely, contains the first results of the phase B of the project, aimed at designing and implementing algorithms for the extraction of urban objects’ geometrical parameters. The goal of this paper is twofold: to further validate the model-based approach presented and applied by the authors in [2-4] showing how it is able to detect also features in the order of high resolution; to show which TerraSAR-X data are more suitable to monitor urban areas with our approach, in terms of geometric localization and radiometry reliability.
To this aim, the next section contains a short discussion of how the model based approach can be adapted to fit the high resolution; after that, much more emphasis is given to the image analysis and the comment of the achieved results. The retrieval process has been carried out on different TerraSAR-X products in order to not only validate the proposed feature extraction algorithms, but also assess the best product for the application of our approach.

2. METHODOLOGY
The study carried out on TerraSAR-X images clearly show that high resolution in SAR images needs to be faced with new and proper approaches especially when man-made objects are present in the observed scene. This is true for any goal we propose to fulfil: from classification to change detection, to feature extraction, any previous approach needs update and, often, a completely new reformulation.
Also in the case of the deterministic model-based approach for feature extraction from SAR images of urban areas, introduced the first time in [2] and then applied successfully in [3-4], some modifications have been introduced. The approach we follow to extract building information is based on the direct inversion of the electromagnetic scattered field $E$, as proposed in [2-4]

$$
\begin{bmatrix}
E_{\text{inc}} \\
E_{\text{scatt}}
\end{bmatrix} = \frac{1}{4\pi} \int \frac{E_{\text{inc}}}{r^2} \begin{bmatrix}
S_{hh} & S_{hv} \\
S_{vh} & S_{vv}
\end{bmatrix} \begin{bmatrix}
E_{\text{inc}} \\
E_{\text{scatt}}
\end{bmatrix} \mathrm{d}S
$$

where $E_{\text{inc}}$ is the incident field, $r$ the range distance, $k$ the wave number, $S_{pq}$ the generic element of the scattering matrix, $p, q$ stand for $h$ or $v$ (horizontal or vertical polarization) and $I_S$ the surface integral accounting for the portion of the surface hit by the radiation.

In [2-4], the scattered field is that coming back from a simple geometry, a parallelepiped with smooth walls on a rough terrain. But now, to face the novelty of high resolution, we adapt the geometric model of the building in order to consider also the presence of windows, balconies or, more in general, of dihedral and trihedral configurations which can now be sensed by the SAR. This means that, consequently, the scattering model is also tailored to take into account contributions from such geometries. In practice, now we consider also the field $E_S$ scattered by the geometry of a window or a balcony and the integral $I_S$ is obviously evaluated on the involved surface.

The new information content hidden in these contributions is important. For example, a contribution from dihedral/trihedral geometry may arise at each floor of the building: then, the capability of detect and number these contributions means the possibility of extract the number of floors, while, measuring the relative distance between two contributions, the floor height may be retrieved as shown in the next section. These considerations can be simply derived by the improved geometric model.

The authors refer to [1-4] for a close examination of the theory being their main goal to point to novelties and promises of high resolution by directly applying and testing their approach to TerraSAR-X data as presented in the following.

3. IMAGE ANALYSIS AND RESULTS

Since the beginning of TerraSAR-X data deliver, we have been working with our approach on four different urban sites (Algeria, Munich, Oberpfaffenhofen, Naples), two different modes (stripmap and high spotlight) and three different data products: the Enhanced Ellipsoid Corrected (EEC) data, in detected representation, the Multi Look Ground Range data also in Detected representation (MGD) and the Single Look Slant Range data in Complex representation (SSC), see [5] for more details on products.

To collect ground truth, the sites of Munich and Oberpfaffenhofen have been also visited after the data acquisition; the most interesting areas in Naples have been visited during the data acquisition while the ground truth of interest relevant to the Algeria site has been mostly derived by optical images.

In each site we looked for man-made structures that fulfill the requirements of our approach (mainly the requirement of being isolated since any deviation from geometric model can be properly treated).

In this framework we are interested in giving just a general overview of the work has been carried out, being impossible to detail all the features extraction performed in each image and, actually, this is not our aim.

In this paper, essentially, we are interested in discussing as features extracted those ones could not be retrieved by applying the same approach to images with resolution worsen than 2m, so mainly windows and balconies.

A noticeable signature of these urban elements is due to the fact that, according to the radar view, they may act as dihedrals or trihedrals causing sparkling lines or points in the radar image.

A clear example is given in Fig.1 where the same building in the DLR airport of Oberpfaffenhofen is represented in a TerraSAR-X MGD image (Fig.1a) and in a previous E-SAR image (Fig.1c); an aerial optical view is also given, see Fig.1b. Resolutions are, respectively, 1.2m x 1.0m (azimuth x ground range) in the TerraSAR-X image and 1.8m x 2.0m (azimuth x ground range) in the E-SAR image.

A deep analysis on the case at issue, [6], has shown the number of bright points corresponding to the number of windows on the facade of the short side, Fig.2, and the mean distance we measured between each couple of brilliant points is 3.09m against the value 3.16m obtained by optical images.

This result has been achieved after a careful reconstruction of the building under study, see Fig.2, in particular of the facade hit by the radar signal. Even if the building geometry does not fit the simple model assumed in [1], the study of each contribution localization has been possible considering the trihedral configurations occurring. In this way, after localizing the range distance of the main double reflection lines, the position of the window has been extracted together with the relative distance between two adjacent windows by means of simple trigonometric expressions.
This is a case of a geometric parameter retrieval (distance between windows) from a geometric distance measurable on the SAR image (that between two sparkling points) that only high resolution allowed us to achieve. In fact, a little worsen resolution like that of E-SAR sensor let the sparkling points be mixed in one long brilliant line, see again Fig.1c.

Another interesting case is that of building floors detection, carried on in many sites and here shown for the main building of the Faculty of Engineering in Naples, Fig.3a. The analyzed image, Fig3b, is an MGD acquired in high spotlight mode (relevant resolution is 1.3m x 1.5m, respectively in azimuth and ground range).

Also here we first worked on the geometric model. The site has been visited and the height of the floors has been measured with a laser tool with 3mm resolution. The façade of the building has been analyzed too and numerous dihedral and trihedral configurations have been found, Fig.4a, and consequently considered in the reproduced geometric model, see Fig.4b.

The bright lines in the SAR image are ascribable to the windows geometry and, consequently, the relative distance between two lines is linked to the height floors. Comparisons between the floors height measured \textit{in situ} and the distance between the bright lines confirm the above hypothesis: the error in the measures, see Tab.1, is always much lesser than the resolution \( \Delta z \) along an axes vertical to the azimuth-ground range plane.

More and different tests have been performed. Another interesting case is a further proof of our model-based approach efficiency in the height retrieval from radiometric parameters as performed in [3]. The heights retrieved are those of big tanks in the area of Naples, and the cylinder shape of these structures, so far from the geometric model in [1], show the ability of our approach to fit many different cases in a very flexible way (the cylinder shape is discretized and, once again, each part is treated as the model in [1]). The heights are retrieved with an error much lesser than the image resolution. Moreover, for this kind of retrieval not every TerraSAR-X product is suitable but the SSC in high spotlight mode ensures very good performance. More details about this interesting case are provided at the conference.
Figure 3

Figure 4

Table 1

<table>
<thead>
<tr>
<th>REAL VALUES</th>
<th>RETRIEVED VALUES</th>
<th>ERROR</th>
<th>PERCENTAGE ERROR</th>
</tr>
</thead>
<tbody>
<tr>
<td>h_{122} = 4.23 m</td>
<td>h_{122} = 4.158 m</td>
<td>e =</td>
<td>h_{122} - h_{122}</td>
</tr>
<tr>
<td>h_{23} = 4.23 m</td>
<td>h_{123} = 4.188 m</td>
<td>e =</td>
<td>h_{23} - h_{123}</td>
</tr>
<tr>
<td>h_{34} = 4.23 m</td>
<td>h_{134} = 4.051 m</td>
<td>e =</td>
<td>h_{34} - h_{134}</td>
</tr>
<tr>
<td>h_{45} = 4.23 m</td>
<td>h_{145} = 3.190 m</td>
<td>e =</td>
<td>h_{45} - h_{145}</td>
</tr>
</tbody>
</table>

h_{2} = 1.972 m
4. CONCLUSIONS

An extensive use of TerraSAR-X data has been performed in the framework of the project “Urban objects’ characterization via SAR data inversion”, proposal LAN0044, and some examples are described in this paper. On one side, the analysis shows the efficiency of a model-based approach [2-4], properly adapted, to interpret high resolution SAR images by quantitatively retrieving urban features of huge interest as the height of a building and its floors. On the other, the best TerraSAR-X products have been identified for a correct and successful application of the same approach. For features extraction from geometrical parameters MGD products are good and the features are retrieved with an error much lesser than the image resolution while for extractions using the image radiometry a product as less post-processed as possible is much more reliable and, in this sense, the SSC product is the best.

5. REFERENCES