A SEMI-AUTOMATIC HIGH RESOLUTION SAR DATA INTERPRETATION PROCEDURE

F. Dell'Acqua, P. Gamba, G. Lisini

Remote Sensing Group, department of Electronics, University of Pavia, via A. Ferrata, 1, I-27100 Pavia, Italy, {name.surname}@unipv.it

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ABSTRACT:

This paper describes a semi-automatic procedure for cartographic mapping using high resolution SAR data. Two-dimensional and three-dimensional feature extractions are combined in order to achieve a basic yet effective recognition of the elements in the scene. Many interesting elements of the landscape are automatically extracted without requiring a large interaction with the operator. In particular, the procedure is well suited for detecting man-made features, such are the road network (outside and inside human settlements) and built up areas. It can be used, however, to extract higher level elements of the scene, such as crossroads, bridges and overpasses, by data fusion at the feature level of the previous extraction, because it is characterized by a multi-scale object-based approach.

1. INTRODUCTION

Land cover mapping (and consequently land use mapping) relies, at the level of detail required by most planners, on high spatial resolution sensors. Cartographic feature extraction has been traditionally obtained by optical and near infrared sensors, installed on airborne or, more recently, spaceborne platforms. Instead, due to the rather coarse resolution and the complexity of their data sets, radar sensors are usually not considered for these tasks. However, because of their interferometric capabilities, they are very useful and indeed they are almost universally exploited for their three-dimensional characterization of the landscape, i.e. for a different kind of cartographic feature extraction.

The availability or the development of new airborne and satellite SAR sensors, with high spatial resolution, and short revisit time, is going to change this "status quo". In particular, high spatial resolution SAR sensors are starting to provide enough information for the recognition and characterization of two-dimensional cartographic features within a radar image. This possibility, further enhanced by the straightforward combination of 2D and 3D information for sensors with interferometric capabilities, makes modern SAR system really appealing for mapping purposes.

This is testified by some recent papers using SAR for mapping of human settlements, down to the scale of single urban features. Examples are those presented in special sessions devoted to SAR urban mapping in the last IEEE Geoscience and Remote Sensing Symposium (IGARSS'06), European SAR conference (EUSAR06) and Joint Urban Remote Sensing Event (JURSE2007). These sessions highlights the fact that some urban features, which are among the most complex to be identified in remotely sensed images, can be obtained using SAR data with a satisfying accuracy level. No doubt that current optical data sets provide better input to cartographic practice, mostly because it is manually done, and radar data is very difficult to be analyzed by untrained (and sometimes also for trained) analysts. The point is that there are already available semi-automatic procedures that could provide outputs at a commercially effective level. However, they are often dedicated to the extraction of single features, such as urban extent (He *et al.*, 2006), water bodies (Hall *et al.*, 2005), vegetation (Askne *et al.*, 2003), road elements (Lisini *et al.*, 2006) and/or road networks (Bentabet *et al.*, 2003), and so on. Moreover, although a number of approaches meant for SAR image analysis has been available in technical literature, no approach is likely to introduce all the spatial and spectral features that are needed for a cartographic feature extraction process starting from SAR data. For instance, road extraction can be found in many works, but this is seldom connected to urban area extraction and the use of different strategies according to the urban or non-urban areas (see Tupin *et al.*, 2002, or Wessel, 2004). The same is true for the reverse approach.

It is therefore interesting to try and prove that an effective procedure can put together starting from (some of) these or similar algorithms, and thus exploiting as much as possible the full range of information available within a high spatial resolution SAR scene. This works is instead a first attempt to provide a comprehensive approach to SAR scene characterization paying attention to the multiple elements in the same scene. This research is based on the experience of the Remote Sensing Group of the University of Pavia in analyzing airborne SAR high spatial resolution images and on the SAR acquisition campaign over the Piemonte region, in Northern Italy, performed by Intermap Technologies using their Star-3i sensor.

The data was used for the Geographic Infomation Ssystem developed for the 2006 Winter Olympic Games in Turin. Additionally, a study about the feasibility of cartographic feature extraction and scene interpretation was considered as a joint effort of Intermap Technologies, the University of Pavia and the national mapping agency for Italy, the Istituto Geografico Militare Italiano (IGMI). The aim of this research was the definition of a simple yet effective approach for image analysis and cartographic feature extraction starting from SAR data.

2. THE PROPOSED PROCEDURE

A common methodology for scene interpretation is based on knowledge-based segmentation of the image into simpler elements, exploiting the relationships between objects and features. This approach, usually labelled as "top-down" analysis is also implemented in this work. The novelty of the analysis proposed in this work is the contemporaneous exploitation of spectral and spatial features. Spatial feature are here referring to both texture analysis and linear element extraction and recombination, which allows a better characterization of the elements in the scene than each of the two spatial analysis taken alone. Moreover, specific approaches are introduced for different parts of the scene, and associated spatial features are chosen accordingly.

The overall structure o the procedure is presented in fig.1, where solid lines represent computational steps, while dashed lines relationships. As said, this procedure exploits numerous spatial and spectral features, namely

- spectral and spatial features to extract river/water bodies,
- linear features to be grouped into the main road network,
- texture features for delineation of human settlements and urbanized areas,
- linear feature extraction, junction characterization and urban road network delineation,
- texture features for discrimination of vegetated areas along water bodies,
- statistical features for extra-urban areas segmentation and analysis of different cultivations.

The procedure has been devised for SAR images. When InSAR information is available, two additional steps are implemented:

- discrimination of low-rise and high-rise building inside the boundary of human settlements, using 3D features;
- refinement of urban roads by data fusion of two-dimensional and three-dimensional data, using a combination of linear and 3D features.

More precisely, some of the procedures implemented for extracting the above mentioned elements are summarized in the following paragraphs.

- **Water bodies extraction:** water bodies are characterized by homogeneous or low textured areas, with low backscattering values. Moreover, their shape is smooth and regular. Therefore, "low" backscattered values are considered, and a shape regularization algorithm based on Gamba *et al.* (2007) is implemented by a reduction of the "irregularities" of the borders due to misclassifications and considering spatial relationships with other classes in the same environment.
- **Human settlement delineation:** heavily textured areas are connected to human settlement usually, but relationships with water bodies are to be considered, which allows for instance discarding highly textured area long the rivers because they most probably are woods or isolated groups of trees. Furthermore, constraints on the kernel for texture extraction can be considered, to take into account the scale of these settlements.
- **Extraction of the main road network:** roads extraction in the suburban context can be computed using a spatially reduced version of the image. A scale reduction of about 1/3 is an indicative value. In high-resolution SAR images roads are no more a subset of image edges. Instead, they usually appear as dark elongated areas with bright lateral edges. Therefore, one may detect roads by looking for pairs of parallel

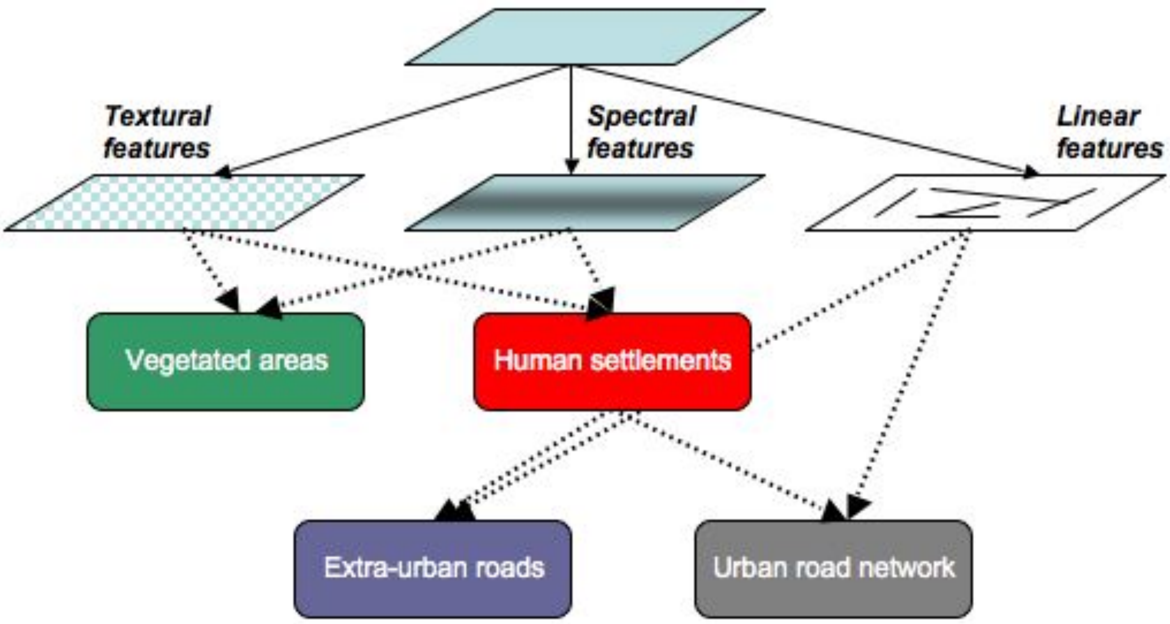

Figure 1. Overall structure of the proposed procedure.

edges or searching for dark homogeneous areas. Both of these methods, however, are subject to false positives (e.g., other artificial structures and low-reflectance areas, respectively). A more precise approach may be one using a combination of these ideas. This is the aim of the algorithm used in this context (Dell'Acqua *et al.*, 2003), which furthermore integrates road features into a multiscale-feature fusion framework whose results will be further elaborated by an alignment routine (Dell'Acqua *et al.*, 2005).

- **Extraction of urban road network:** inside the human settlement areas delineated in one of the previous step, more precise linear feature can be used to extract the road network. Here not only road candidate, but also junctions are considered according to (Negri *et al.*, 2006). Scale factors are also different than for extra-urban analysis and the full resolution is to be considered.
- **Extraction urban roads through DSM/DTM:** in case of availability of SAR and InSAR data, which is the case for the available data set, it is possible to improve the extraction of roads in urban area. Indeed, a computation of DTM allows finding areas raising above the ground. Ground areas are parks and roads. While the first ones are easily discriminated due to their shapes, candidate roads may be injected in the above found urban road network to improve the overall results.

3. EXPERIMENTAL RESULTS

As stated in the introduction, the proposed procedure was applied to a portion of the whole Piemonte data sets, recorded by Intermap Technologies and released to IGMI. The available portion consists in one IGMI tile, i.e. a 30 km by 40 km area covering a portion of the Southern part of the Piemonte region. An IGMI tile correspond to more (exactly, 16) Intermap tiles, each one covering a 4800 by 6000 pixel area, corresponding to 45 square km. The SAR data were provided in georeferenced format, with spatial posting of 1.25 m. Coregistered to the intensity two-dimensional information, three-dimensional interferometric data were also provided. Together with the raw 3D data, labelled as Digital Surface Model (DSM), a Digital Terrain Model (DTM), obtained by Intermap technologies by means of proprietary software and procedures was also provided, featuring the terrain height, as well as corrected 3D information for water bodies. DTM and DSM have twice the spatial resolution than intensity data, and are thus provided on a 2.5 m spaced grid.

To provide a working example of the procedure proposed in section 2, in the following the intermediate elaboration results for one sample of an Intermap tiles are proposed and results are discussed. This would be useful, for instance, to highlights the advantages but also the problems of the proposed semi-automatic feature extraction and combination approach. In turn, this could also be useful for detecting new research or implementation lines for the future.

Fig. 2(a) shows the original 2D data, while fig. 2(b) provides a bird's eye of the area, as obtained overlaying the SAR intensity information of the corresponding DSM. The area covers a portion of the path of the river Po, the major river in Northern Italy, and the mostly rural area surrounding the river. In particular, the small settlement in the areas is named Ceretto.

As discussed in previous section, the first step of the procedure is the extraction of any existing water body in the scene, based simply on backscatter analysis. Since thresholding is not going to be effective due to speckle noise, the following shape analysis discards false positives and redefines the overall shape of the features by smoothing erroneous detection results on the boundary area between water and soil. Fig. 3(a) and (b) refer to these two intermediate results. According to the procedure, next step is human settlement extent delineation. Technical literature agrees that the best approach for this task is based on texture-based discrimination. The problem is the choice of the texture and the corresponding scale, which depends on the spatial resolution of the data and the settlement spatial structure. Multi-scale analysis would be more effective, as well as multiple direction for oriented textures. A suitable combination of these features is indeed able to obtain "hints" for human settlements (Pesaresi *et al.*, 2007), to be further specialized to find urban extents. In this work, we apply morphological closing to fill in the gap and obtain the boundaries of areas that are mostly likely to be human settlement or man-made elements of the landscape (with the exception of roads and other transportation infrastructure, which are oriented and can be discarded using this assumption). Fig. 3(c) shows a simple anisotropic texture information, the data range, which highlights human settlement hints, while fig. 3(d) provides a mask delineating what are likely to be human settlements.

Figure 2. Sample HR SAR amplitude image and corresponding interferometric DSM in 3D view.

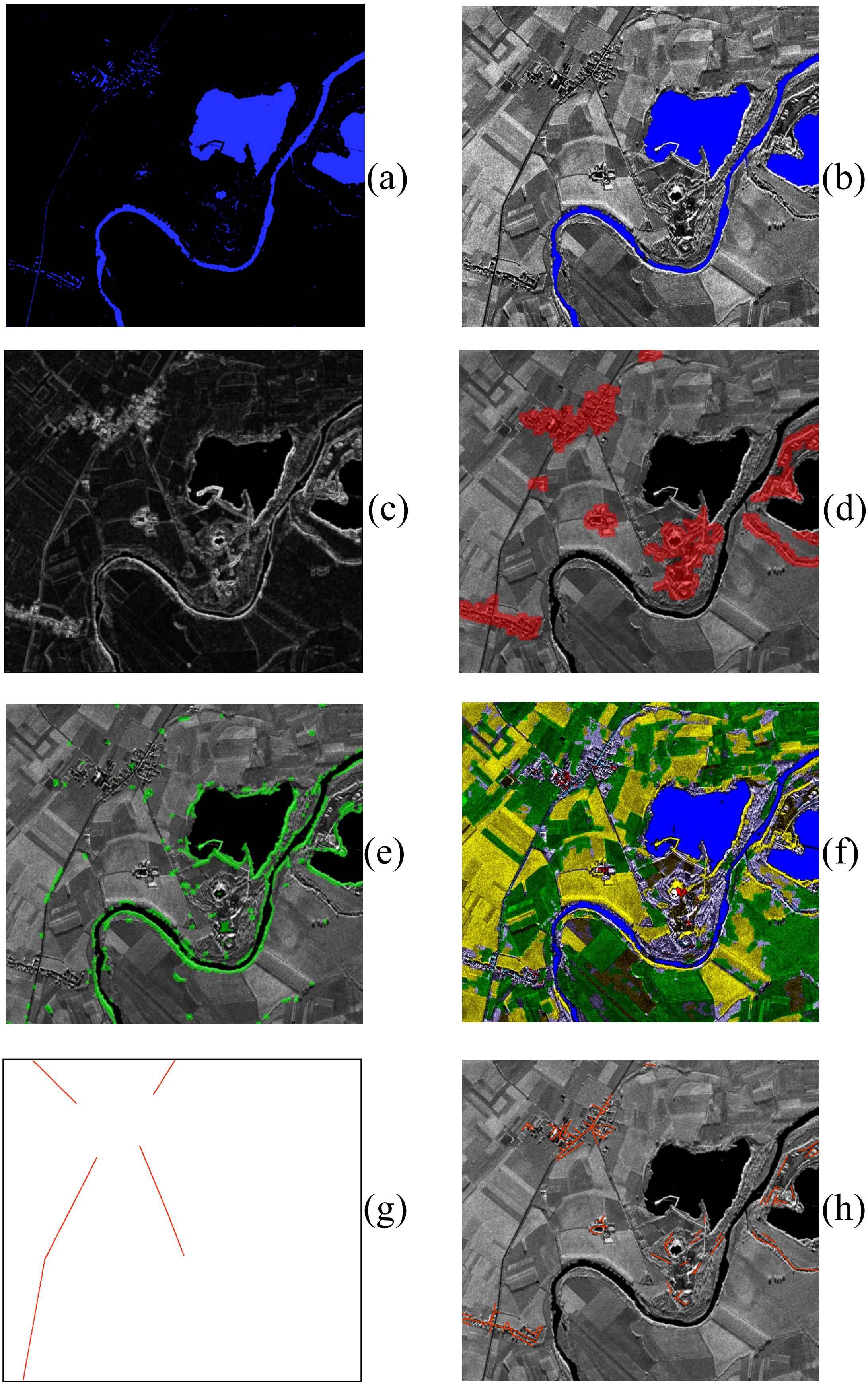

Figure 3. (a) water body extraction by amplitude SAR data thresholding; (b) refined water bodies using shape information to improve previous extraction results; (c) data range image; (d) human settlements extracted from previous image; (e) vegetation; (f) crops (two classes); (g) main road outside the human settlements; (h) road network inside the settlements.

As noted above, roads and other transportation infrastructures, although man-made landscape features, can be easily discriminated because of their geometrical characteristics, which could be coupled in HR SAR images with typical radar responses as in Negri and Gamba (2006). Moreover, they tend to be connected in a topologically consistent network, and this could be used to improve the first step, i.e. element extraction, by inserting missed elements and discarding false positives. In order to retrieve main road elements, a suitably downscaled image is considered, and the procedure proposed in Dell'Acqua *et al.* (2005) is applied. Results are shown in fig. 3(g) while in fig. 3 (h)the same procedure, but with full data resolution and stronger constraints on road network connectivity has been applied to the portion of image labelled as "human settlement". Road density might be used, in the end, as a further validation of the human settlement hypothesis or to refine the urban extent boundary. Finally, vegetation mapping is considered. Woods are extracted by the assumption that they are characterized by means of a different textural feature set than human settlement, due to the scale and physical nature of the elements in the texture (trees instead of buildings). The procedure exploits therefore the same data range information, but with different scale and threshold values. Moreover, proximity to the water bodies is considered as another hints for woods and trees. As for other vegetation types, SAR amplitude data may be able to extract boundaries between crops, if a suitable segmentation algorithm is applied. After a despeckling procedure, therefore, a Markov Random Field approach, well validated by most recent technical literature (Huawu and Clausi, 2005) is used, and corresponding classes of crops are extracted.

At the end of this procedure, there a clear need for evaluating its results. However, the only independent validation of these results is obtained by comparison with the existing Regional Technical Maps and the corresponding GIS layers of the area provided by the competent regional administration. As shown in fig.4, the Regional Technical Map and these layers are far more detailed than the extracted maps. It is however worth noting that, qualitatively speaking, the results of the semi-automatic procedure are good. Indeed, the main features of the scene have been correctly extracted, the change of the river path correctly detected and the main road network is where it is expected. A quantitative evaluation of the results in fig. 4(a) is underway. The cartographic features extracted in this as well as another sample area are going to be validated by means of a ground campaign by IGMI later this year.

As a final example, fig. 5 shows the scene results for two complete Intermap tiles. In particular, the map on the right refers to an urban-rural fringe (referring to the towns of Nichelino and Candiolo) has been enriched by detecting the road overpasses (red dots). As stated above, this is an example of high-level cartographic features easy to obtain by combining two- and three-dimensional features. In this case, road junctions, detected starting from extracted road elements, are combined with terrain height to validate or discard the "overpass" hints based on junction detection.

4. CONCLUSIONS

This work shows that a suitable combination of feature extraction algorithms, specifically developed for high spatial resolution SAR data, can be combined to obtain an effective mapping chain. It includes both two-dimensional and three-dimensional feature extraction, and possibly 2D and 3D feature combination. The main outcomes of this work are therefore mainly the following two points.

1) There exist a few specific processing tools developed for SAR scene interpretation, able to jointly consider spectral and spatial, as well as context information. These tools provide effective mapping results for HR SAR in both rural and urban areas.
2) The exploitation of HR SAR for mapping purposes can be based on the competitive advantage that interferometric SAR provides at once both the two-dimensional and the three-dimensional representation of the same scene. A combined use of both data sets, by their same nature already co-registered, is able to improve purely 2D mapping results. It can also detect features that are more complex to detect from aerial optical data just because of the lack of 3D information.

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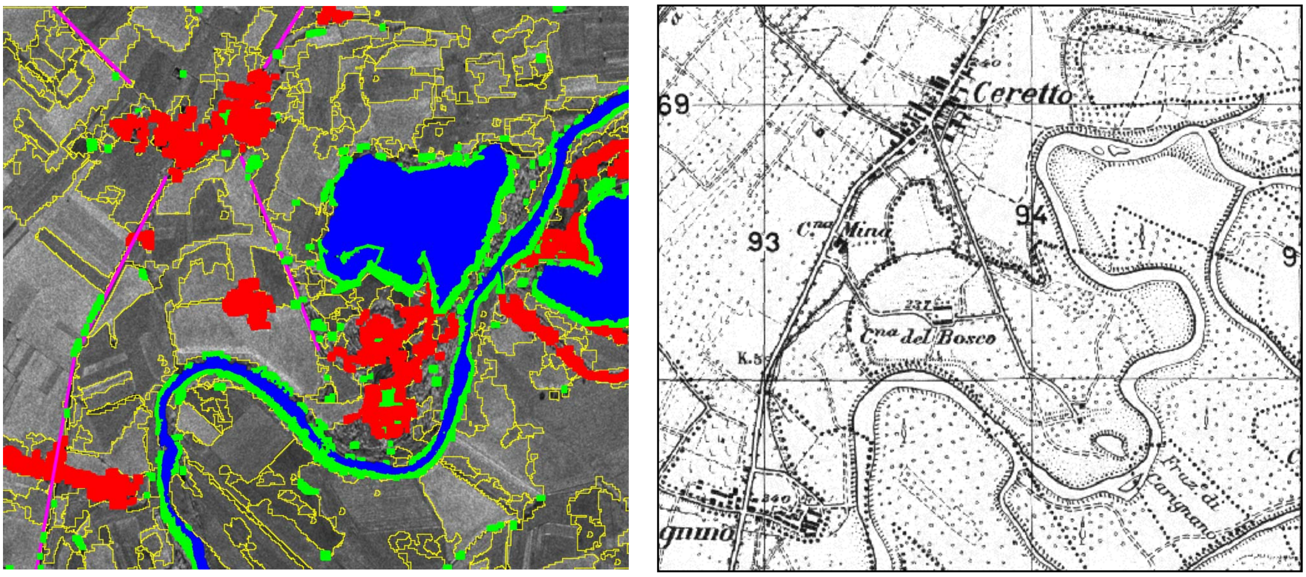

(a) (b)

Figure 4. Final classification map of the scene superimposed with the original SAR data, to be compared with (b) the Regional Technical Map of the same area.

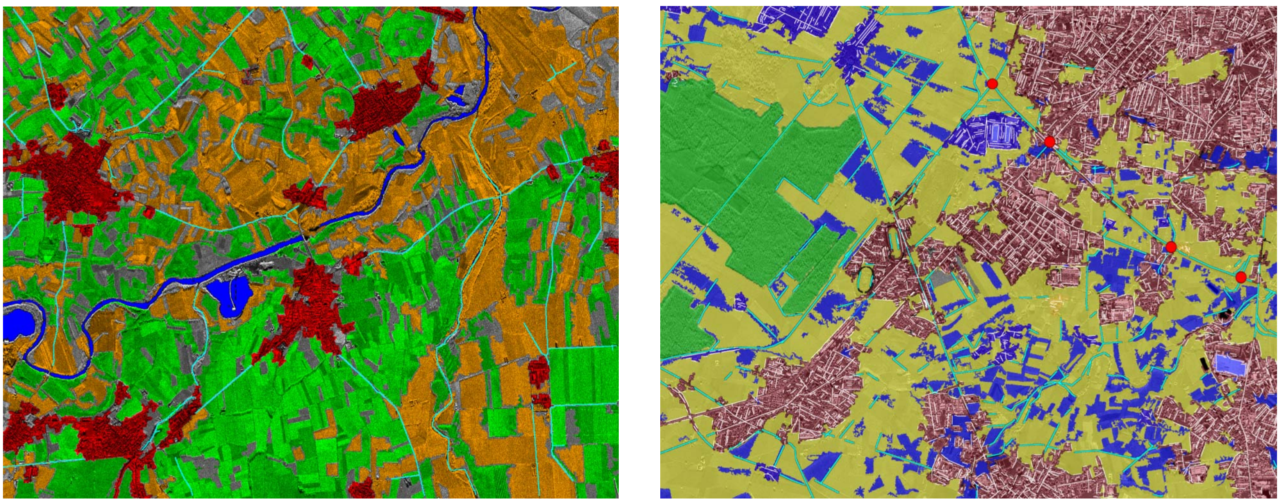

Figure 5. Two Intermap tiles after the complete mapping procedure.