ROAD NETWORK EXTRACTION IN URBAN AREAS BY MEANS OF FEATURE-LEVEL FUSION

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1. INTRODUCTION

The availability of VHR SAR images depicting in detail urban areas allow starting and considering the use of these data for cartographic feature extraction. This has been proved already by means of airborne data [1] [2] but has to be further improved in order to achieve the quality that is currently available from optical VHR data.
One of the main problems for road extraction in SAR data is the complexity of the scene and the fact that buildings along the roads may mask them, or reduce their visibility. Combination of more views has been suggested as a way to partially overcome the problem [3][4].
This work presents the results of the preliminary analysis of TerraSAR-X data over the town of Pavia, Italy, in the framework of the LAN0044 project "Urban objects' characterization via SAR data inversion".

2. METHODOLOGY

Linear feature extraction from SAR data is a tough challenge, especially from VHR SAR data. Multiple extraction procedures are expected to provide different results. The drawbacks of one approach might be compensated by the advantages of another, i.e. the idea is that data fusion at feature level might improve the overall results. This is also the topic of this work; to fuse results from line extractors at some point and to get even better results than what is available in technical literature.

II.A – Line extractor 1 has been tested before in an already existing road extraction approach developed mainly for rural and sub-urban areas [5].

1) Linear feature extraction: The first step consists of a line extraction using Steger's differential geometry [6], which is followed by a smoothening and splitting step.

2) Uncertainty estimation of linear features: The linear features are evaluated based on its attributes [7]. The theory of the evaluation originates from Bayesian probability theory. We estimate uncertainties for each linear feature that it belongs to three predefined classes; ROADS, FALSE ALARMS or SHADOWS. The uncertainty evaluation is based on attributes such as length and intensity. ROADS are assumed to appear as dark, long lines in SAR images, which is mostly true in rural and sub-urban areas. FALSE ALARMS represent the group of short, brighter linear features frequently appearing in urban or forest areas. SHADOWS often show a slightly darker intensity than ROADS. Posterior probability density functions for each attribute were estimated from training data collected from a TerraSAR-X scene of a different sub-urban scene. The line extractor is normally applied to less complex scenes than the one used in this work. A significant over-segmentation occurs, especially in built-up areas. To reduce and to get a more reliable result, all line features assigned to FALSE ALARMS are sorted out. SHADOWS are kept while roads are often occluded by shadows. In the end parallel segments are deleted. Longest and highest evaluated linear features are kept.

3) Fusion: The fusion of the linear features from both scenes is carried out as described in [7], but this time without considering any global context information.

II.B – In high resolution SAR images, roads appear as dark, elongated areas, with bright lateral edges and also looking for pair of parallel edges. A combination of these ideas is integrated into a multi-scale feature fusion framework. It is divided in four main steps:

1) Multiple feature extraction: In order to search for road pixels, the first step in this procedure is the computation of a few spatial features in a circular window around the current pixel (fig. 1). Of course, each of these features will be a function of the window radius. These features highlight dark elongated areas in the pixel neighbourhood. If they are good candidates for road areas, a high contrast is also expected between and the average total radiance along all 180

directions.
The proposed features capture different but consistent characteristics of roads, which locally may always be considered as modelled by dark straight segments. Therefore, they lead to almost the same findings, but possibly (fig. 1) with different false recognitions. This point may be used to combine them and provide better extraction results.

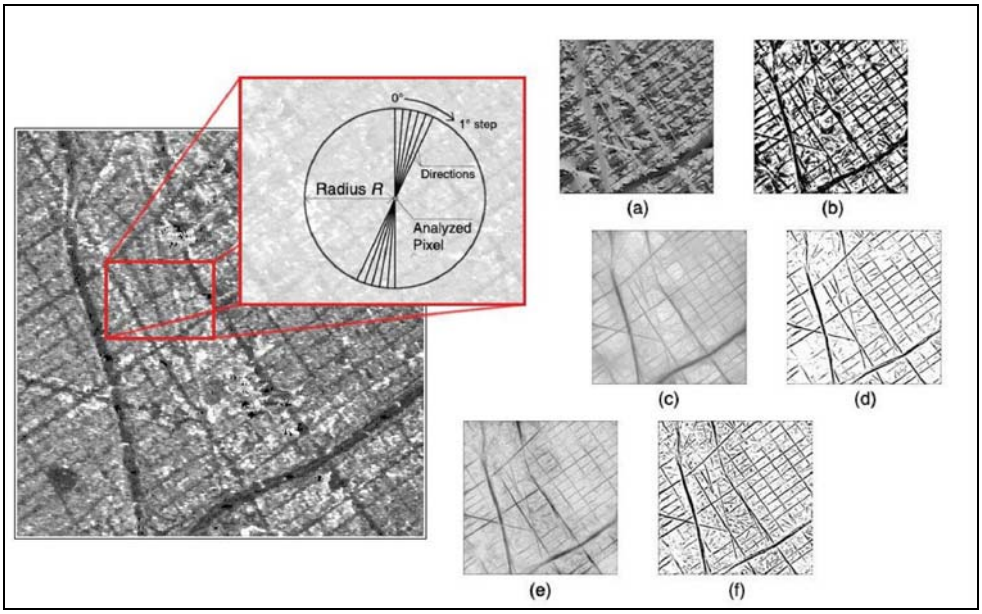

Figure 1 Feature extracted from a sample SAR image: (a) ; (c) ; (e) ; (b, d, f) corresponding binarized values.

2) Feature binarization: The following step in road candidate extraction is a semi-automatic feature binarization. Binarization would require the selection of a threshold. This threshold may set globally, but a much more efficient algorithm is to set it locally, looking for the neighbourhood of the position under test. By this choice, only positions with feature values significantly similar to (or different from) their neighbourhood are labelled and retained.

3) Multi-scale fusion: In order to exploit multiple scales, the previous steps are performed on different sub-scale of the under test image. At the end, a binary feature ma is computed as a logical AND across binarized features at all scales:
The final feature map is therefore the result of a multi-scale feature fusion which allows detecting different features of candidate road regions at multiple scales and using multiple detectors.

4) Candidate area selection: The last step of the processing chain for multi-scale feature fusion detection is the selection of candidate regions in the binary multi-scale feature map. To his aim, a spatial and a spectral criterion are employed. The spatial check discards small area regions that, according to the ground spatial resolution of the sensor, could not be elements of the road network. To this aim, only regions with area greater than 16 pixels are considered.
The second check is instead based on spectral information, and discards areas whose average radiance value is much higher from the mean value of the overall data set. To this aim, the average area value is computed, and it should be smaller than.

After carefully determining the candidate regions for the road network, we need to vectorize the result, translating selected paths into segment chains. This is done in two steps, the first aimed at a shape regularization for each candidate region, which may be composed by multiple connected road segments and the second step aims at the extraction of the segment chain best fitting the region shape, possibly including multiple branches.

II.C – Road element fusion
Finally, the results coming from extraction of linear features using the two above mentioned approaches are compared and fused, using a two steps' approach.

1) first of all, gestalt rules are applied to reduce the complexity of the linear features and select real road candidates [8];
2) then, a Markov Random Filed procedure [9] based on the exploitation of road junctions is exploited looking for the "best" network passing through these junctions.

Combinations of road candidates extracted from different views of the same area (ascending and descending passes) are also considered, again by means of the same feature-fusion procedure.

(a) *(b)*

Figure 2 – Original TerraSAR-X images over the city of Pavia, Italy; (a) Pavia 063 – (b) Pavia 076

3. TEST SITE AND RESULTS

The procedure was tested on two sets of TerraSAR-X recorded over the town of Pavia (fig 2). The data was recorded in X-band, HH polarization, and geocoded to a UTM map grid with WGS84 earth ellipsoid and pixel spacing of 1 m. Both data sets were recorded in High Resolution spotlight mode, and were provided after geocorrection and spatial enhancement, which means in the mode to achieve the best possible spatial resolution, at the cost of a worse speckle noise degradation of the data radiometry.

Results of different combinations of extractors and images from descending/ascending passes are presented in Fig. 3. Each result is equipped with quality coefficients, such as correctness and completeness (Tab. 1). The ground truth used for the computation of coefficients can be seen at the bottom of Fig. 3.

In general, both line extractors manage to recognize the main road axes, but still there remain faults in discovering smaller roads in dense urban areas. Especially the first approach meets problem in these regions (see Fig. 3c-d). Due to frequently gaps and over-segmentation MRF often fails to connect the line segments. However, the big highway crossing was nicely detected. For this reason, line extractor 1 was only applied to the rural parts of the scene before the fusion of the two line extractors took place (Fig. 3g).

Table 1 – Completeness and correctness of the results presented in Fig. 3

	Completeness	Correctness
(a) Extractor 2 on Pavia 063	0.4961	0.2062
(b) Extractor 2 on Pavia 076	0.5286	0.4018
(c) Extractor 1 on Pavia 063	0.3690	0.3118
(d) Extractor 1 on Pavia 076	0.2178	0.4120
(e) Fusion of extractor 2 on Pavia 063 and Pavia 076	0.7119	0.2475
(f) Fusion of extractor 1 on Pavia 063 and Pavia 076	0.5004	0.2388
(g) Fusion of extractor 1 on Pavia 063 and Pavia 076	0.6061	0.2311

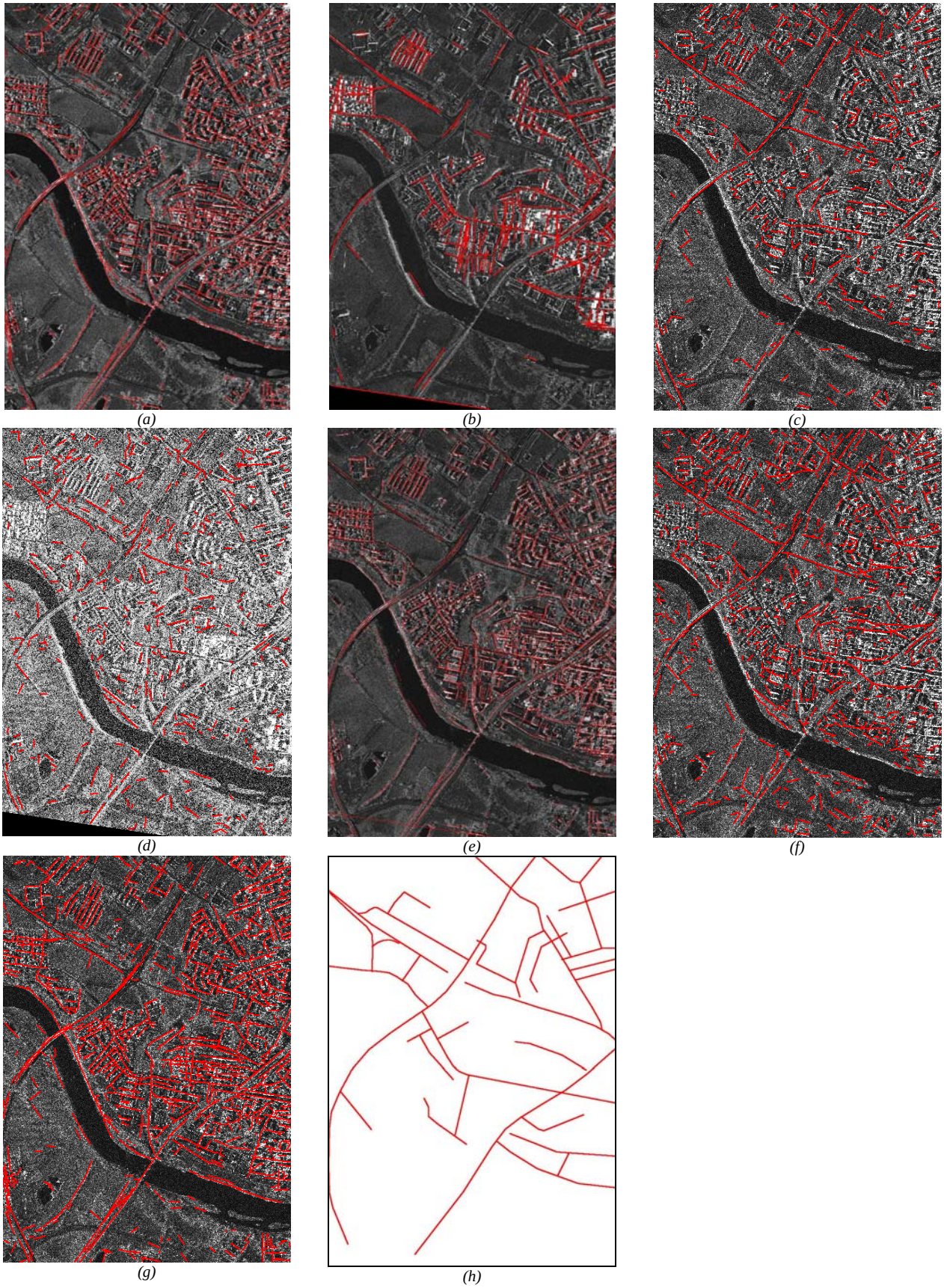

Figure 3 – Road extraction results after MRF with different line extractors as input (a) Extractor 2 on Pavia 063 (b) Extractor 2 on Pavia 076 (c) Extractor 1 on Pavia 063 (d) Extractor 1 on Pavia 076 (e) Fusion of extractor 2 on Pavia 063 and Pavia 076 (f) Fusion of extractor 1 on Pavia 063 and Pavia 076 (g) Fusion of extractor 1 (only applied to rural regions) and 2 on Pavia 063 (h) Ground truth

4. CONCLUSIONS

In this paper we have tested two different approaches for feature extraction in order to get the best combination of both. Second, a data set of anti-parallel views has been exploited. As expected the two approaches showed different behavior and a combination of the two line extractors improves the road extraction. The usage of anti-parallel views showed even better results, which indeed is a motivation for further work on multiple SAR views.
The results so far showed the potential of combining approaches coming from different research groups. An interesting task for the future is the development of a fusion, which involves information about the advantages and the drawbacks of the two approaches.

REFERENCES

[1] Han, C., Zhou, Z., Junjie, Z., Chibiao D. (2006): Road Extraction from High-Resolution SAR Image on Urban Area. *Proc. of IGARSS 2006*, July 31 2006-Aug. 4 2006, pp. 1454–1457.

[2] Bolon, P., Chanussot, J., Issa, I., Lambert, P. (1999): Comparison of prefiltering operators for road network extraction in SAR images. *Proc. of ICIP 99*, 24-28 Oct. 1999, Vol. 2, pp. 924-928.

[3] Soergel, U., Schulz, K., Thoennessen, U., Stilla U. (2003): Determination of optimal SAR illumination aspects in build-up areas. *Proc. of IGARSS'03*, Vol. 6, 21-25 July 2003, pp. 3662-3664.

[4] Dell'Acqua, F., Gamba, P., Lisini, G. (2003): Road map extraction by multiple detectors in fine spatial resolution SAR data. *Canadian Journal of Remote Sensing*, Vol. 29, n. 4, pp. 481-490.

[5] Wessel, B., Wiedemann C. (2003): Analysis of Automatic Road Extraction Results from Airborne SAR Imagery. *Proceedings of the ISPRS Conference "Photogrammetric Image Analysis" (PIA'03)*, International Archieves of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Munich 2003, Vol. 34, pp. 105-110.

[6] Steger, C. (1998): An unbiased detector of curvilinear structures. *IEEE Trans. Pattern Anal. Machine Intell*., Vol. 20, pp. 549-556.

[7] Hedman, K., Hinz, S., Stilla U. (2007): Road Extraction from SAR Multi-Aspect Data Supported by a Statistical Context-Based Fusion. *Proc. of. Urban Remote Sensing Joint Event*, CD-ROM.

[8] Dell'Acqua, F., Gamba P., Lisini, G. (2006): Improving urban road extraction in high resolution images exploiting directional filtering, perceptual grouping and simple topological concepts. *IEEE Geoscience and Remote Sensing Letters*, Vol. 3, Nr. 3, pp. 387-391.

[9] Negri, M., Gamba, P., Lisini, G., Tupin, F. (2006): Junction-Aware Extraction and Regularization of Urban Road Networks in High Resolution SAR Images. *IEEE Trans. on Geoscience and Remote Sensing*, Vol. 44, Nr. 10, pp. 2962-2971.