ROAD EXTRACTION AIDED BY ADAPTIVE DIRECTIONAL FILTERING AND TEMPLATE MATCHING

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ABSTRACT

In this paper, the problem of the detection of road networks from Optical/SAR images is addressed. Our procedure try to overcome problems due for the noisy surround and improve road extraction by implementing a directional filter. The method takes into account four separate steps. The first consists of an automatic procedure to adapt the direction of filtering on the basis of the predominant direction of the roads present into of the image, the second step try and discard the "blobs" that do not possess the usual characteristics of the roads such as elongation, the third step entails the real road extraction by the Hough transform routine. Then, in order to eliminate redundant segments and to avoid gaps between part of the same road we apply an algorithm able to connect each other the extremities of the segments on the basis of tolerances and related to the spatial resolution.

The proposed procedure was tested on a couple of images, one a fine resolution SAR images and a fine resolution optical image. The experiments have shown an increase in the completeness and correctness indexes after the procedure with respect to more standard extraction methods.

1 INTRODUCTION

Automatic or semiautomatic map updating using remote sensing images is an important area of research. A growing amount of remote sensing image is available today from different kind of sensors and a certain level of automation can speed-up the map updating process considerably. The paper presents one solution for one of the most relevant applications of high resolution SAR data: road network detection in dense urban areas. The most difficult task is to discriminate between the road and its surround [1-3], especially in urban environment where the shape of the road is often biased by buildings, vegetation, cars and other urban objects.

In the past 20 years, many approaches have been developed to deal with the detection of linear features on optic or radar images. Most of them start from SAR complex or real data and exploit two criteria: a local criterion evaluating the radiometry on some small neighborhood surrounding a target pixel to discriminate lines from background and a global criterion introducing some large-scale knowledge about the structures to be detected [4].

2 THE PROPOSED PROCEDURE

The conceptual workflow of the proposed procedure is described in fig. 1. The street extraction is made in four steps: the adaptive filtering, the discarding procedure, the extraction routine and finally the alignment procedure.

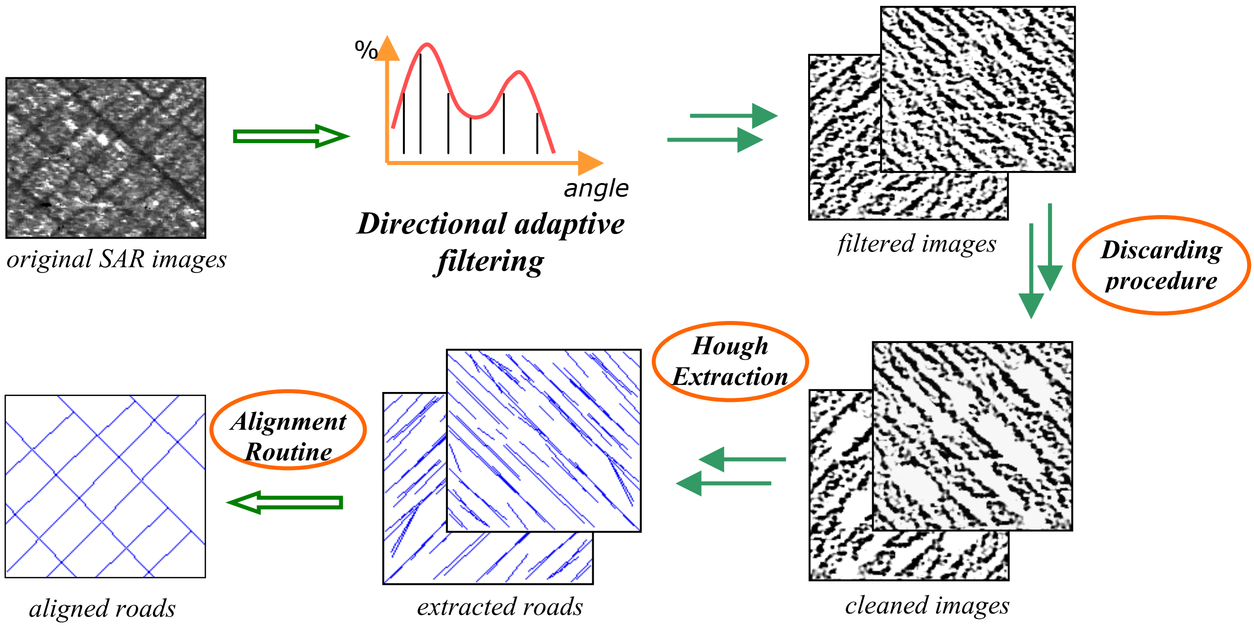


Figure 1: *Conceptual workflow of the proposed procedure*

2.1 DIRECTIONAL ADAPTIVE FILTERING

The initial procedure is to try and perform on the image a preliminary filtering in order to delineate the road contours and facilitate the following extraction step. This task may be done by filtering both horizontally and vertically the image. The major drawback is that roads that doesn't show in horizontal or vertical way are less highlighted than the others. The innovation in the present implementation consists of an automatic procedure to adapt the direction of filtering on the basis of the predominant direction of the roads present into the image. This is done by extracting, using a modified Hough transform [5], the roads and than computing an histogram of all directions present in each sub-zone of the entire image to decide the best filtering direction for it. By this way it is possible to increase the level of contrast independently of the local road direction. The windows dimension in which is computed the histogram of the road directions largely depends on the resolution of the image. A good rule foresees that it must be so large to include a significant amount of segments into it in order to avoid the overrating the direction of just one or few segments very close each other; on the other hands this window must be not so large to contain zone with different predominant directions. A good dimension for urban areas is depicted in the following:

$$D = \frac{20}{\textit{spatial resolution in meters}};$$

After computing the histogram, the algorithm tries and localizes the possible peaks on it. If are present more than just one it'll take in consideration only the predominant two angles. This matches the hypothesis that usually there are one or at least two main streets directions in an urban area. Step by step the windows is moved to occupy all positions into the image and for each zone these directions are computed. The filtering procedure follows.

The algorithm filters the original image with the precomputed directions of each sub zone creating two different images, each of them containing the two different filtering. An example of this procedure is depicted in fig. 2;

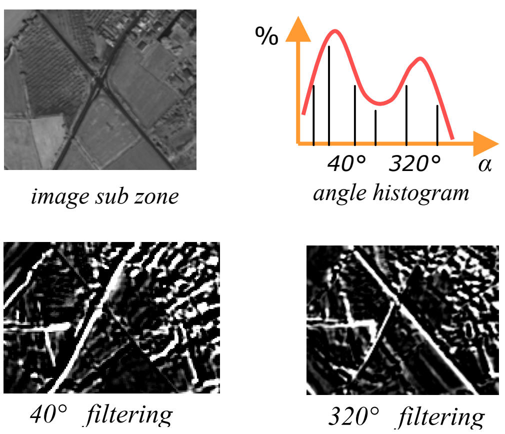


Figure 2: *Example of adaptive directional filtering.*

2.2 DISCARDING ALGORITHM

This algorithm follows the pre-filtering methodology. The method corresponds to providing a pre-extraction step [5] where only possible street candidates are considered and passed to the extraction routines, in this case the Hough transform routine. After discarding uninteresting blobs, the remaining ones have all the characteristics to be streets or part of them. More in detail, the system compares each connected region (or "blob") in the data with prototype linear regions. To avoid maintaining a huge prototype database, the algorithm introduces many additional checks, based on the filling ratio, the blob edges' locations and directions, the choice of an "optimal" window (in both mean position and width) to characterize the blob and, finally, a tracking procedure to connect parts of the same blob. For each "blobs" detected and located, they are compared with a set of 16 basic prototypes. The fine resolution of the data allows us to extract the shape by looking for its two lateral edges. In the end, the algorithm discards from the picture blobs that doesn't show a close similarity with the aforementioned prototypes with the results to facilitate the follow road extraction.

2.3 ROAD EXTRACTION ROUTINE

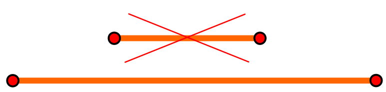
For road extraction purposes, we applied a routine aimed at detecting straight objects in the scene. In particular, road extraction on both images was performed using the fuzzy Hough extractor proposed in [6]. The fuzzy Hough Transforms looks for lines or segments in many directions, possibly with different widths and lengths. It's therefore suited for straight roads, large highways, and most of the urban areas. Moreover, this routine is sensitive to possible width fluctuation in large roads; such fluctuation usually produces false positives and small, randomly oriented line elements. In that paper it was noted that it is difficult to have extraction routines well-suited for any situation, and this is especially true in our test site, due to the complex structure of the town center. Within our test area, the Fuzzy Hough Transform (FHT) was the most effective approaches, because of the complex shape of many roads coupled with clearly visible linear features. FHT is an adaptation of the well-known Hough Transform to a fuzzy input. In the examples FHT is applied to the results from the previous step (pre-filtering + discarding routine).

2.4 ALIGNMENT ROUTINE

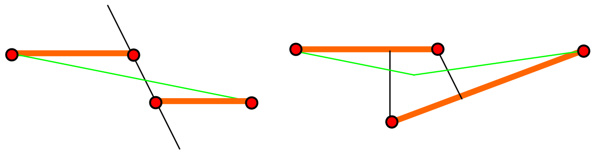
This step was added to the whole method to improve the characterization of the road networks. So, the proposed procedure is based on perceptual grouping concepts and allows connecting segments where reasonable, based on their mutual positions.

The program is based on the following processing steps:

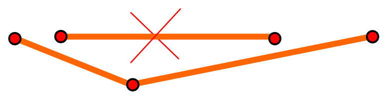
1. First of all, segment pairs very close one to the other are reduced to the longest one.



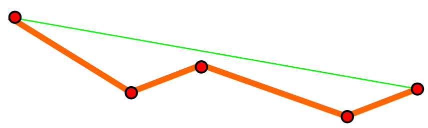
2. Then, segments that are sufficiently similar in their directions and with extremes nearer than a give threshold, are joint into one.



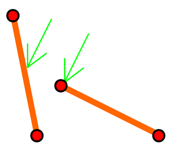
3. The third step requires that a new search for overlapping segments is carried out, due to the reduction of the segment by the previous analysis.



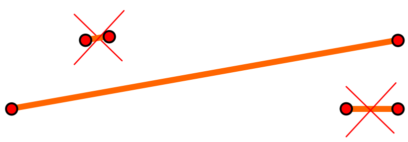
4. A fourth step is then applied, so that (long) chains of segments are simplified to the best approximating set.



5. Then, a proximity check is carried out, and segments that nearly touch one another, or that intersects but near one of the extremes, are redrawn to touching pairs.



6. Finally, the last step foresees the possibility to remove segments with a length lower than a threshold.



The parameters involved in this process are:

- the maximum allowed distance between two extremes of segments that are to be connected;
- the maximum gap between the extremes of the incoming segments and the potential intersection point of the other segment for the former to be extended until intersection;
- the maximum angle tolerance between segments to be connected together; the maximum allowed perpendicular distance between two parallel segments that will be fused together;
- the tolerance value, i.e. the maximum displacement between the extracted trail and its representation in linear segments (curves are represented as sequences of linear segments, which implies a certain degree of local displacement in some locations, and this parameter sets an upper limit to such displacement).
- the minimum allowed length for the unconnected segments.

3 EXPERIMENTAL RESULTS

We illustrate the proposed method on a couple of images, one a fine resolution SAR images and a fine resolution optical image. Both images represent an urban environment and are depicted in fig. 3 with the corresponding ground-truth manually obtained from the amplitude image. Note that only the main axis of the network roads visible in SAR/Optical images are plotted. The SAR, fig. 3(a), is acquired by a sensor with a resolution of 1 m/pixel, the optical one, fig. 3(b), is acquired by the Ikonos sensor with a resolution of about 1 m/pixel. The overall extraction routine provides the results in fig. 4(b) and 5(f) for the two test areas, to be compared with the output without adaptive filtering in fig. 4(d) and fig. 5(h). An intermediate step is also provided in fig. 4(c) and fig. 5(g), where the proposed methodology is applied without the adaptive filtering.

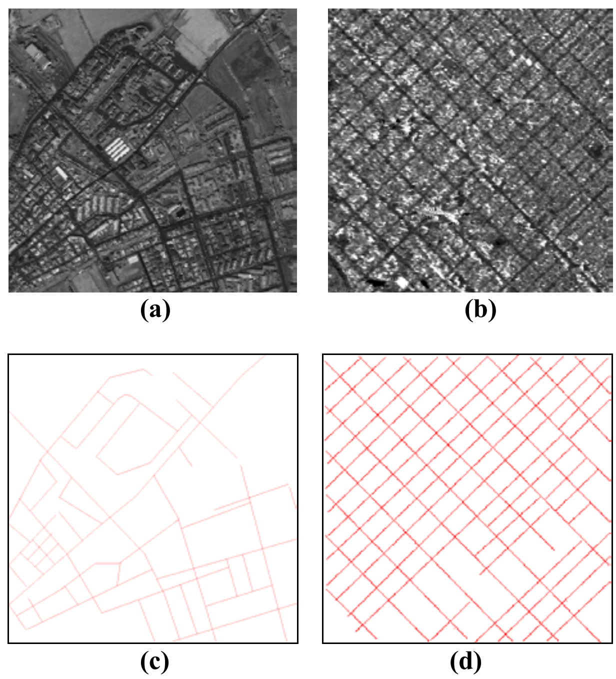


Figure 3: *(a, b) original images; (c, d) manual ground truth*

This strengthens our guess that the proposed procedure improves the original results. Furthermore, fig. 4(b) and fig. 5(f) do not present as many small segments as fig. 4(a) and fig. 5(e). The roads appear “cleaner” and more continuous, and a lot of little spurious segments have been deleted.

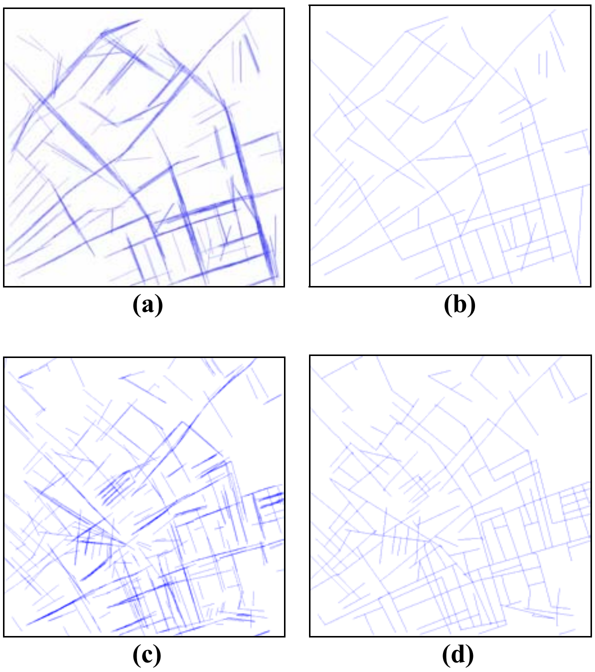
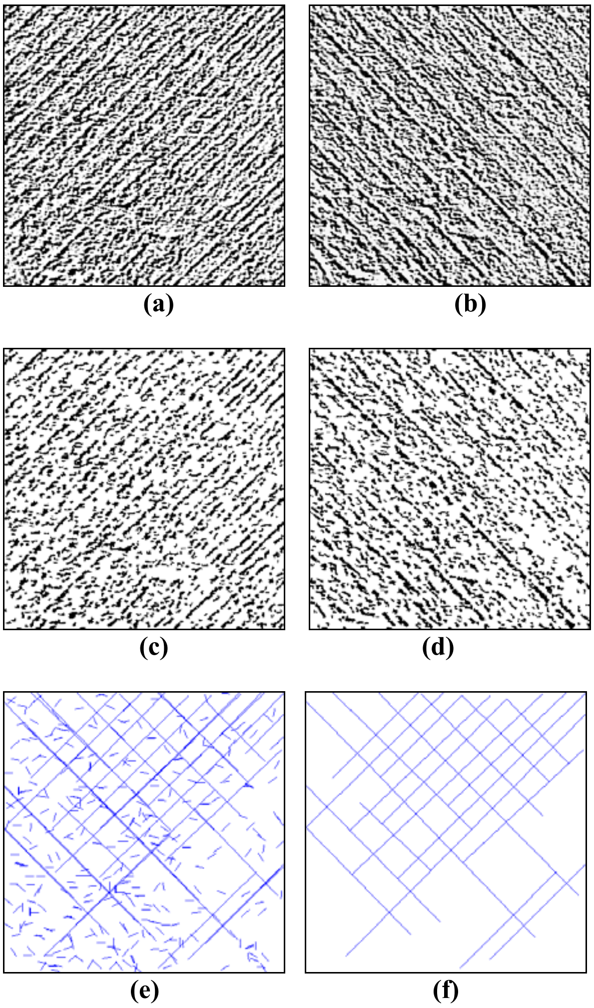


Figure 4: *Extraction results for the Optical image in fig. 3(a): (a) segments extracted with adaptive filtering, (b) after alignment procedure; (c) segments extracted without adaptive filtering; (d) after alignment procedure .*



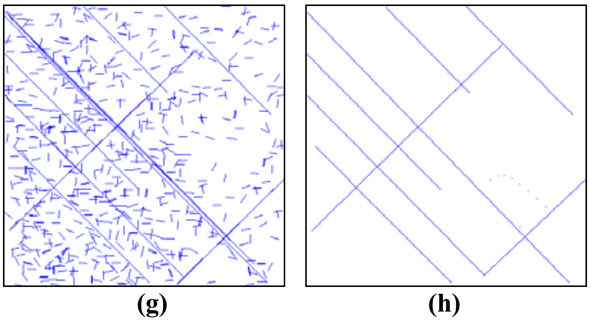


Figure 5: *Extraction results for the SAR image in fig. 3(b): (a),(b) after the adaptive directional filtering; (c),(d) after discarding routine; (e) after Hough Transform; (f) after alignment; (g) Hough transform on an image without adaptive filtering and (h) after alignment procedure.*

A similarly interesting analysis may be done looking at the corresponding quantitative evaluation of the roads, shown in Table I. We offer a comparison of the correctness and completeness indexes [11] for the networks in fig. 4 and 5.

The completeness index represent the fraction of ground truth length extracted while the *correctness* index is the fraction of segments' length belonging to actual roads.

We should keep in mind, however, that the ground truth is not extremely precise, so the values in Table I has a *relative* more than an *absolute* meaning. We observe that the correctness increases from left to right, as we could expect, in almost all cases. Completeness instead is bigger for the networks extracted with the original algorithm. However, this is mainly due to the fact that small spurious roads are present in such images and consequently a lower number of false detections are obtained.

	fig. 4(a)	**fig. 4(b)**	**fig. 4(c)**	**fig. 4(d)**
Correctness	0.64	0.68	0.65	0.32
Completeness	0.89	0.81	0.33	0.31

	fig. 5(e)	**fig. 5(f)**	**fig. 5(g)**	**fig. 5(h)**
Correctness	0.78	0.95	0.63	0.98
Completeness	0.78	0.63	0.61	0.34

Table 1: *quantitative evaluation and comparison of the results in fig. 4 and 5.*

4 CONCLUSIONS

This paper has presented a road detection method that includes in a multi-scale framework a data fusion procedure. It takes into account both a pre-extraction and a post-extraction approach to improve the road network.

In particular, adaptive filtering not only highlights at the same level roads at very different angulations but increases the percentage of real roads while reducing missing ones. Another advantage is that the discarding procedure reduces the computational time of the Hough transform routine. The alignment step releases a set of segments closely connected each other with the double scope to ameliorate both the visual understanding and the correctness index of the road network.

5 REFERENCES

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