Fuzzy Hough Transform and Adaptive Directional Filtering for Road Extraction from Aerial Images

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Abstract - In this paper the problem of extracting roads from a synthetic aperture radar image (SAR) is taken into account for implementation. Here the procedure deals with filtering, which is used to detect the predominant directions of roads. Next it is followed with a discarding algorithm, to avoid the protruding elongation over the roads. After that the real roads are detected by a Hough transform routine. Finally after extracting the roads the gaps are avoided using alignment routine. Here two test images are taken. The experiments have shown an increase in the completeness and correctness indexes after the procedure followed and expected to give a more exact result over the other researches. Not only linear roads but the curved roads of other SAR images can be detected using this proposed procedure.

Keywords - SAR , Hough transform, alignment routine.

1. INTRODUCTION

Urban road network extraction from space borne SAR image has been one of most important applications in remote sensing technology. For example, it is greatly helpful of urban transportation mapping, planning and management and city GIS database etc. During recent two decades, some approaches for automatic or semiautomatic detection of road from the optic or radar images have been developed. However, due to some difficulties such as roads irregularity, multiplicative speckles, and complicated distribution of various objects in the urban area, these approaches do not seem to be well tractable to process the radar image, especially for distinguishing linearly featured objects, e.g. water body and roads. In the past 20 years, many approaches have 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 . In this field of application, one of the key points is the characterization of the street network inside a city. This task requires classification/interpretation tools clever enough to discriminate between the streets and their surroundings in first place, but also some data fusion tools. This helps for instance to solve the problems due to the so called cardinal effect of SAR images, i.e. the different Visibility of linear features depending on the sensor's viewing angle. Combining streets extracted from different images is a feasible solution to this problem. Similarly, it may be useful to combine street networks extracted on the same image by means of different street detectors, each one with its own advantages and drawbacks. This paper presents a novel method for automatic road network extraction from high resolution images. The method uses image processing for finding road candidates and knowledge of road networks for elimination of false roads. It operates in three major steps. Firstly, it extracts lines from the original image using a line operator such as a morphological operator. A split-and-merge operation is applied to the extracted lines to generate smooth line segments. A hierarchy of line images is generated by applying several thresholds of line length to the extracted line images. Progressing through the levels of the hierarchy will result in an increasingly dense distribution of line segments. Lines are grouped according to their similarities in geometry and radiometry. The grouping of line segments starts from the top of the hierarchy (with sparse distribution of line segments) to create the main structure of the road network. It then proceeds through the levels of the hierarchy to the lowest level (most densely distributed set of line segments) to add more detailed road segments in the grouping. Finally, knowledge of road networks is applied to remove non-road segments to form a complete road network.

2. SYSTEM MODEL

The Road extraction is made in four steps:

1) The adaptive filtering
2) The discarding procedure
3) The extraction routine
4) The alignment procedure

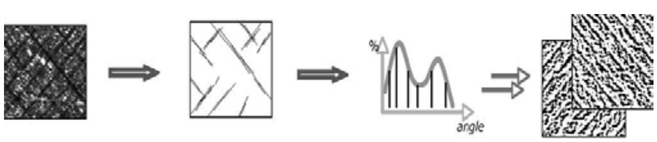
2.1 ADAPTIVE DIRECTIONAL FILTERING

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 a road that doesn't show in horizontal or vertical way is 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 the roads and then 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:

$$D = \frac{20}{\text{Spatial resolution in meters}}$$

After computing the histogram, the algorithm tries and localizes the possible peaks on it. If there 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 are moved to occupy all positions into the image and for each zone these directions are computed. The filtering procedure follows.

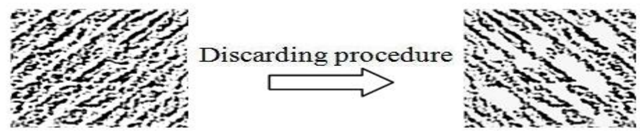


SAR Image filtered road histogram final image

The algorithm filters the original image with the pre computed 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.1; 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 blob that doesn't show a close similarity with the aforementioned prototypes with the results to facilitate the follow road extraction.

2.2 DISCARDING ALGORITHM

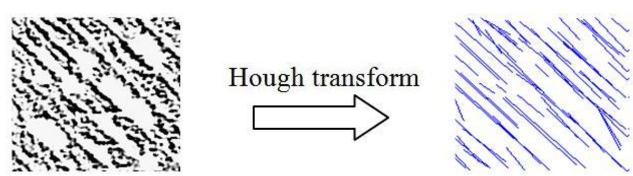
This algorithm follows the pre-filtering methodology. The method corresponds to providing a pre-extraction step where only possible street candidates are considered and passed to the extraction routines, in this case the Hough transform routine. After discarding uninteresting blobs, the remaining ones 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 don't show a close similarity with the aforementioned prototypes with the results to facilitate the follow road extraction.



Filtered images Cleaned images

2.3 WHY FHT IN ROAD EXTRACTION?

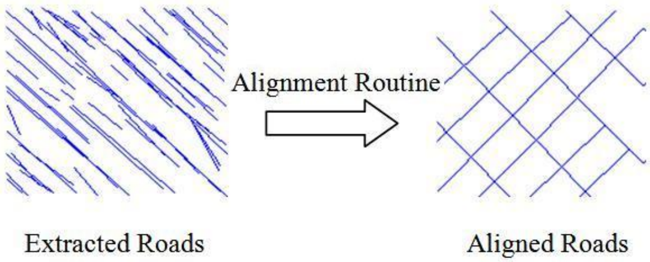
For road extraction purposes, we applied a routine aimed at detecting straight objects in the scene. In particular, road extraction on both images was performed using the fuzzy Hough extractor. The fuzzy Hough Transforms looks for lines or segments in many directions, possibly with different widths and 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).



Cleaned images Extracted Roads

2.4 ALIGNMENT ROUTINE

Next step is the Alignment procedure where the extracted roads are further aligned to a direction in which the correctness of the extracted roads can be reached.



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

The parameters involved in this process are:

1. The maximum allowed distance between two extremes of segments that are to be connected;

2. 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;

3. The maximum angle tolerance between segments to be connected together; the maximum allowed perpendicular distance between two parallel segments that will be fused together;

4. 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).

5. The minimum allowed length for the unconnected segments.

3. EXPERIMENTAL RESULTS

This paper illustrates 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 axes 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.

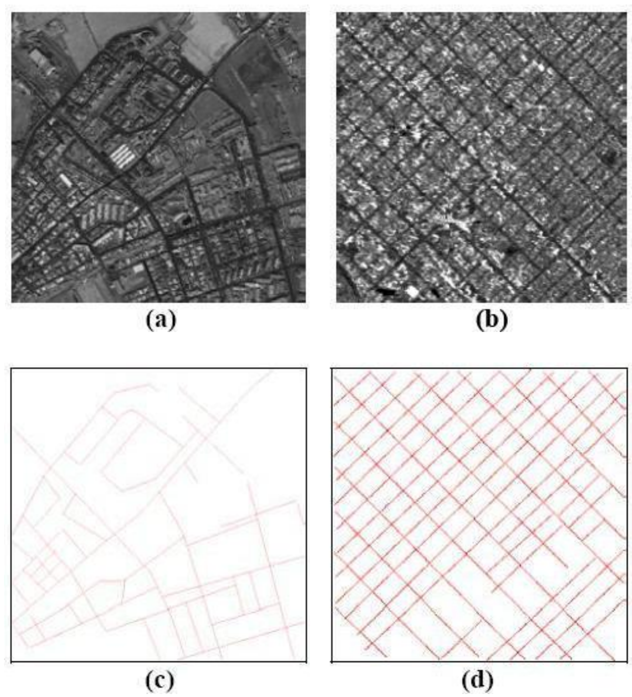


Figure 3: (a, b) AIRSAR images (c, d) Extracted roads

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.

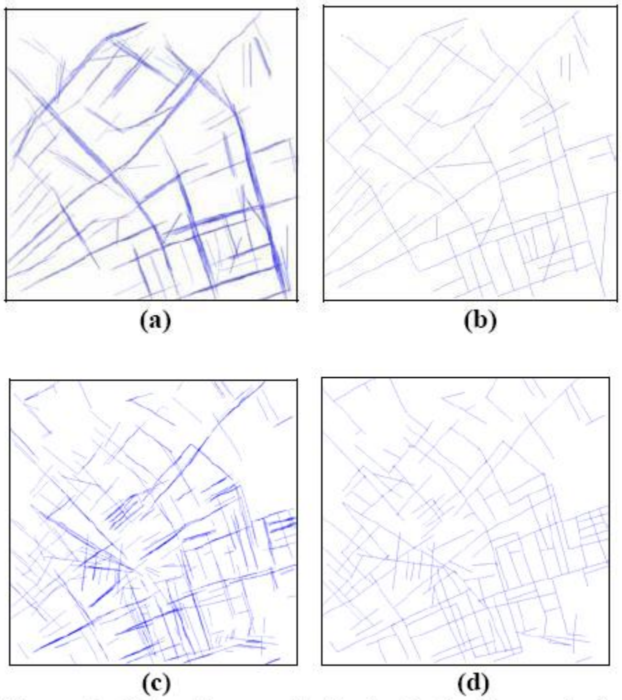
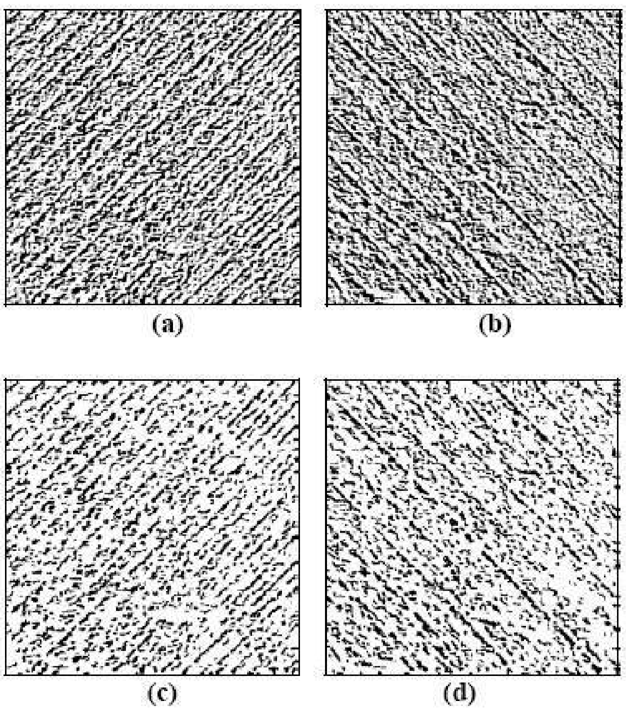


Figure 4: *Extraction results for the Optical image in fig. 3(a): (a) segments extracted with adaptive filtering, (b) after alignment procedure; (c) segments extracted without adaptive filtering; (d) after alignment procedure .*



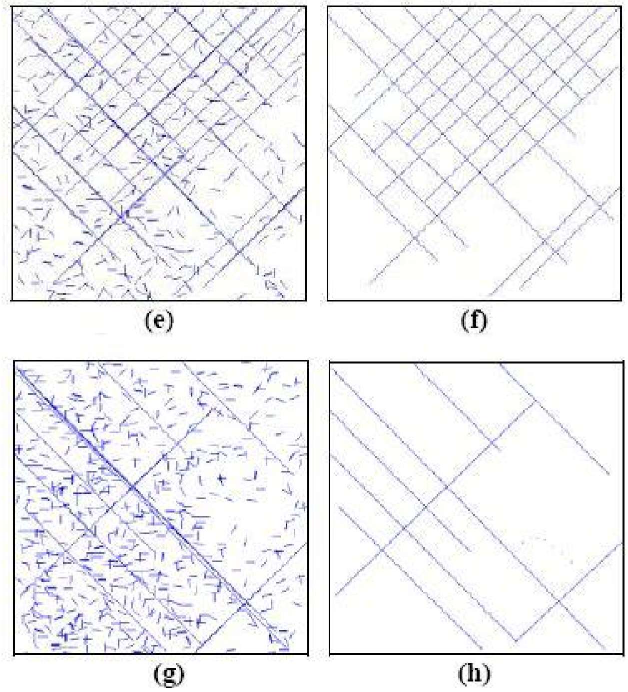


Figure 5: *Extraction results for the SAR image in fig. 3(b): (a),(b) after the adaptive directional filtering; (c),(d) after discarding routine; (e) after Hough Transform; (f) after alignment; (g) Hough transform on an image without adaptive filtering and (h) after alignment procedure.*

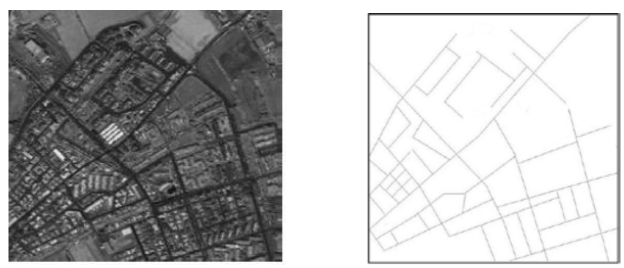


Figure 6: Extraction results of Pavia, Italy

In Fig. 6 The extracted roads of Pavia, Italy is shown after adaptive directional filtering. 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.

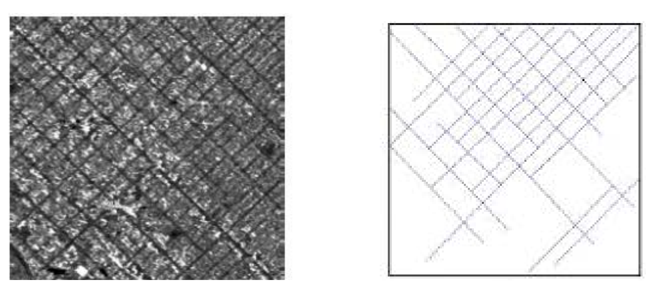


Figure 7: **Extraction results Santa Monica, CA**

In Fig.7 the extracted Roads of AIRSAR image of Santa Monica is shown.

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 compare both the visual understanding and the correctness index of the road network.

4. CONCLUSIONS

In particular, three points are worth stressing. The proposed locally adaptive directional filtering highlights curvilinear roads and enhances road patterns in urban areas, even where they are characterized by multiple dominant directions. Results show that this procedure increases the percentage of detected road candidates. The region selection procedure introduced after the directional filtering helps and reduces the computational load of FHT by providing a refined input and discarding uninteresting area where roads are not likely to be located. Finally, a simple set of rules based on perceptual grouping concepts is able to provide, even acting only locally, a set of segments more similar to the actual connected network. Proposed results show that this step ameliorates the visual understanding and increases the quality index of the extracted road network. In Future not only linear roads but also the Curved roads of Aerial Images can be extracted using Fuzzy Hough Transform and Adaptive Directional Filtering.

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