ROBUST ROAD EXTRACTION FOR HIGH RESOLUTION SATELLITE IMAGES

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ABSTRACT

Automatic road extraction is a critical feature for an efficient use of remote sensing imagery in most contexts. This paper proposes a robust geometric method to provide a first step extraction level. These results can be used as an initialization for other algorithms or as a starting point for manual road extraction. Results of the extraction are vectorized for GIS integration and for a better interaction with human experts that can refine the results. The algorithm is fast, has very few parameters and is only slightly affected by the image properties (resolution, noise). The algorithm is available in the open-source Orfeo Toolbox.

Keywords: Remote sensing, Road extraction

1. INTRODUCTION

Road extraction is a critical feature for an efficient use of high resolution satellite images. There are many applications of road extraction: update of GIS database, reference for image registration, help for identification algorithms and rapid mapping for example. Road network can be used to register an optical image with a map or an optical image with a radar image for example. Road network extraction can help for other algorithms: isolated building detection, bridge detection. In these cases, a rough extraction can be sufficient. In the context of response to crisis, a fast mapping is necessary: within 6 hours, infrastructures for the designated area are required [1]. Within this timeframe, a manual extraction is inconceivable and an automatic help is necessary.

A high resolution satellite image typically has a resolution of 0.5 to 1 m and four spectral bands. Using the result of a fusion, a product combining four spectral bands at the higher resolution can be obtained. This is usually the case for the Quickbird satellite from DigitalGlobe and will be the standard product for the future Pleiades constellation from CNES.

One of the most important key features of satellites is their ability to cover an important area, thus gathering a huge amount of data. One Pleiades scene will cover an area of 20×20 *km*. A manual exploitation of these data, even just for road extraction is not possible. An operator would need to visualize more than 1000 screens to process these data at full resolution. An efficient automatic algorithm leading to a good (even if not perfect) solution would facilitate the work of remote sensing experts.

Since 1990, different methods have been proposed to provide automatic or semi-automatic road extraction in remote sensing images. In [2], an exhaustive bibliography on automated road extraction is provided. These methods include snakes [3], higher order active contours [4], dynamic programming [5] or probabilistic approaches [6]. However, to our best knowledge, none of these algorithms satisfies the operators, mainly because of computation time. In most situations, road extraction is still manual.

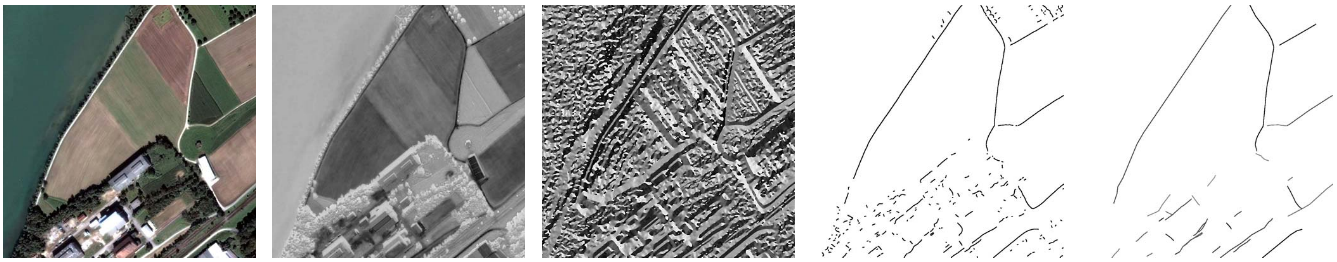
The main problem of these methods is the difficulty to provide the best parameters for a given image. Given a new image, the user often has to try different combinations before obtaining a satisfactory result. The computation time is also often a problem. As the resolution of optical sensors increases, size of images increases as well, thus increasing the computation time necessary to process a scene. Information provided by the color is also often misused, most algorithms focusing on the panchromatic data.

The aim of this paper is to provide a simple, fast, robust and efficient algorithm to extract roads. The algorithm provides a vectorized result. The only entry parameter is the color of the road or the spectrum if more spectral bands are available. Results are not expected to be perfect but rather to be a good initialization for more complex algorithms or for human refinement.

2. ROAD DETECTION

The color of the road provides a rich information which often enables to distinguish between roads and vegetation. This color information, usually in four or more spectral bands can be interpreted as a vector. However, most algorithms prefer to work with scalar data. One efficient way to convert this spectral information to a scalar data is to use the spectral angle with respect to a reference pixel. The spectral angle is defined as:

$$\mathrm{SA} = \cos^{-1}\left(\sum_{b=1}^{n_b} r(b).p(b) \Big/ \sqrt{\sum_{b=1}^{n_b} r(b)^2 \sum_{b=1}^{n_b} p(b)^2}\right), \quad (1)$$



(a) (b) (c) (d) (e)

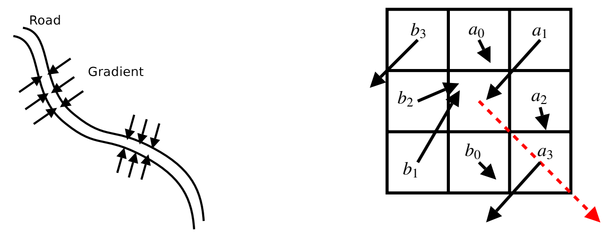
Fig. 1. Original image (a), Distance according to spectral angle (b), Gradient directions (c), line detector (d) and after vectorization (e).

b being the spectral band, r is the reference pixel and p the current pixel.

There are two main advantages to using this representation. The first one being that the following algorithm is working on the spectral angle image and does not depend on the number of bands. Thus the road extraction process can be applied to multispectral images with any number of bands. The second advantage is that choosing the reference pixel, we will be able to extract either tarred roads or dirt tracks. The spectral angle is taken between the reference vector pixel and the current vector pixel. The resulting image contains all the roads in the darker color. Figure 1 (b) shows the distance between each pixel and the reference pixel.

On this spectral angle image we apply a line detection method based on a constrained gradient. This method was described in [7]. A gradient filter is first applied to the image. Each pixel contains gradient direction and gradient intensity values. An example of gradient directions is illustrated on figure 1 (c). Then, knowing that the road is darker than pixels around, we know that the gradient direction will be opposite on each side of the road, as illustrated on figure 2 (a). To use this property, we compute the scalar product between opposite gradient vectors around a pixel. The higher (in absolute value) scalar product which is also negative gives us the direction of the road. On figure 2 (b), the highest scalar value is obtained between pixels a_1 and b_1, leading to the dotted red direction vector with the computed length. The spectral angle provides an important property that the original algorithm did not have: as we know that the road is darker, we can keep only the pixel where the neighbor gradient vectors point toward the pixel.

To improve the line following, pixels which do not have the maximum scalar value across direction are removed (Fig. 3).



(a) (b)

Fig. 2. Gradient representation and the roads: (a) gradient direction towards the roads; (b) computation of the direction and scalar values for each pixel.

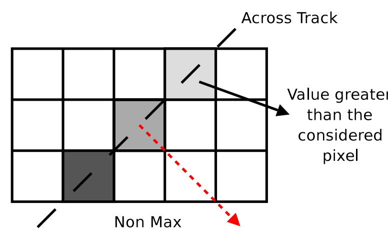


Fig. 3. Removal of non maximum scalar values across direction: one of the neighbor pixel across the road direction has a greater value than the current pixel which is removed for the path construction.

3. VECTORIZATION

Vectorization of the extracted roads is decisive for an efficient use in GIS systems. From the previous step, we had obtained an image with pieces of roads, often irregular as illustrated on figure 1 (d).

After the previous part, paths can be extracted from the image. To get a better localization, path vertices can be located at non integer positions (Fig. 4). Their position is obtained with the weighted barycenter of few pixels on the given direction. However, paths obtained with this process contain too many vertices: about as many as the length of the path. They are also usually too short due to the noise on the gradient image. Few steps are necessary to refine these paths according to general road properties.

Many vertices can be removed as they are usually aligned. Figure 5 illustrates this step. d is the distance between one vertex and the proposed new path. If the distance between all old vertices and the new proposed path is lower than one pixel, the new path is accepted.

One result of the vectorization process is that paths can present a sharp angle at their extremity due to the noise on the gradient image. This sharp angle will be damageable for the

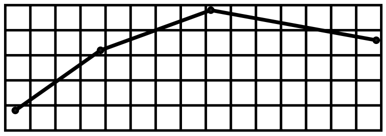


Fig. 4. Vector coordinates are non integer, allowing a better accuracy.

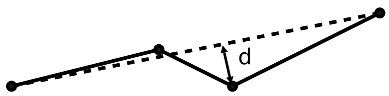


Fig. 5. Simplifying paths.

next step. In general roads contain smooth curves and do not have sharp turns. To comply with this property we split paths which contain a sharp angle between two segments. An angle is considered as sharp if it is above $\pi/8$. The exact value does not influence much results of the algorithm.

To allow the detected paths to go over tree shadows or vehicles on the road which impact the gradient, a relation between paths must be considered. The relation is described on figure 6. Within a given search distance d, which depends on the resolution, a link can be found between two paths. To be accepted, these paths have to comply with some conditions: angles between the first path and the link, α_1, the second path and the link, α_2, and the last segment of both paths, $\alpha_1 - \alpha_2$ have to be within a certain range. For a 0.7 m resolution image, the search distance considered is 40 pixels and the angle was chosen to be within the $[-\pi/8;\pi/8]$ interval.

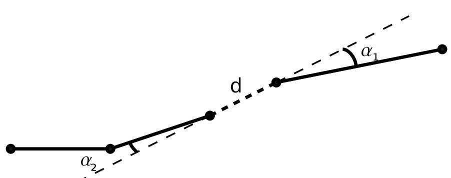


Fig. 6. Linking paths.

After this step, some very short paths are still present on the image. They usually correspond to noise and do not provide much information so they are removed.

The last step associates a confidence value to each path according to the spectral angle value along the path. One path can have a low spectral angle value all along, thus the algorithm will be confident that this path is a road. Some other paths can have higher spectral angle value leading the algorithm to be less confident. The confidence value is presented by the color of the path: darker color for low confidence and brighter color for high confidence.

4. RESULTS

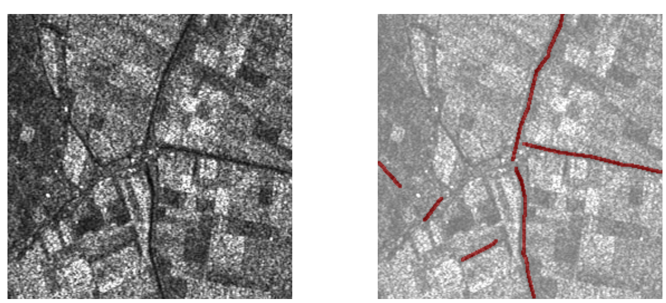
All the results are obtained within the Orfeo Toolbox (OTB) framework [8]. The OTB is an open source set of tools for remote sensing data exploitation. This algorithm is included in the latest release of OTB and follows the principles of reproducible research.

The algorithm is applied on two extracts from a 1000×1000 Quickbird image. We compare the results with those obtained only with the line detector from [7]. The algorithm is fast. On a standard PIV 2.8 GHz, processing a 1000×1000 image takes less than 3 s. This short time enables interactive processing during visualization at full resolution on a screen size.

On figure 8 (c), we can see that the new algorithm provides improved results. Roads are better defined and without staircase effects. Segments have an information about how confident the algorithm is: the dark segments are those for which the algorithm is not very confident (the segment on trees for example). The railroad track in the lower right corner is not mistaken for a road. In two places, the algorithm successfully finds the road hidden by tree occultations.

On figure 8 (f), focus was on extracting the main roads with the reference pixel taken from one of these roads. The algorithm manages to make the difference with the secondary roads from the top right of the image. Most main roads, or at least portions of them are extracted. Few false alarms appear on some buildings.

The same algorithm can be applied to radar images. As we have seen before, the computation of the spectral angle leads to a representation of the road in darker color. In radar images, as roads usually present specular reflections, they also appear in darker color (Fig. 7 (a)). We applied the same algorithm directly on the radar image instead on the spectral angle image to obtain the results presented in Fig. 7 (b). These results are good despite of the noise. Radar images contain a multiplicative noise so the gradient filter is not the most adapted. A ratio of means, as in [9], will probably give better results.



(a) (b)

Fig. 7. Road extraction result on a radar image: the same algorithm is applied without the spectral angle computation.

Fig. 8 (a) Original image **Fig. 8 (b)** Line detector **Fig. 8 (c)** Final algorithm

Fig. 8 (d) Original image **Fig. 8 (e)** Line detector **Fig. 8 (f)** Final algorithm

5. CONCLUSION

The presented algorithm is automatic with very little interaction from the users. The main one is the color (or spectrum) of the road in which the user is interested in. The only parameter which has a significant impact on the results is the search area to link paths. This parameter can be easily related to the image resolution. We have seen that the algorithm, originally designed for optical images, can successfully extract roads on a radar image. Moreover, this algorithm is fast, allowing interactive computation. And finally, this algorithm uses most of available properties of roads in high resolution satellite images: spectral information (with the computation of the spectral angle) and the shape (first with the gradient and then with the vectors).

Of course, results are not perfect but could be refined by more complex methods. These methods, usually more costly in terms of computation time, could be applied only in the selected area.

6. ACKNOWLEDGMENTS

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7. REFERENCES

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