INT. J. REMOTE SENSING, 1999, VOL. 20, NO. 1, 153–168

A thinning-based method for recognizing and extracting peri-urban road networks from SPOT panchromatic images

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(*Received 24 September 1997; in final form 14 April 1998*)

Abstract. In this paper we describe a method for recognizing and extracting the road network in peri-urban areas using SPOT panchromatic images. A particular combination of image representation–description algorithms is proposed, which recognizes road features—not clearly defined in remotely sensed images and often confused with other features—and extracts them. The method consists of five algorithms—thresholding, morphological, thinning, linking, and gap filling—that are used sequentially. The only human intervention required is the definition of a threshold. The proposed approach produces a raster road network representation that is highly complete and locationally accurate. Some experimental results are given in this paper.

1. Introduction

The application of remote sensing in updating cartographic information is broad. Spatial land cover types, identified by statistical models of pattern recognition theory (Duda and Hart 1973) are often used to update maps. On the other hand, several local and global line detection, as well as image representation, algorithms and techniques (Pratt 1978, Gonzalez and Woods 1992, Lillesand and Kiefer 1994) have been developed for extracting linear networks, such as roads, from remotely sensed images.

The extraction of linear elements from remotely sensed imagery is a quite complex process. The extraction, for example, of the road network also requires its recognition, which is not an easy operation, because road segments are not represented by a constant range of digital numbers in the input images, the shapes of the roads are ill-defined, and pixels with the same digital number often represent land cover types which are not related to roads. That happens because in remotely sensed images, certain types of land cover, e.g. buildings, have similar spectral characteristics with roads and, thus, are indistinguishable, at a pre-processing stage, from the roads.

Consequently, line detection and image representation–description algorithms, available from image processing theory, give noisy results, where: (a) line segments which do not belong to the road network, like the edges of the buildings; (b) discontinuous linear features; and (c) spikes and irregularities are shown.

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International Journal of Remote Sensing
ISSN 0143-1161 print/ISSN 1366-5901 online ©1999 Taylor & Francis Ltd
http://www.tandf.co.uk/JNLS/res.htm
http://www.taylorandfrancis.com/JNLS/res.htm

Road tracking and linking algorithms (Ton *et al.* 1989, Gruen and Li 1995) that have been developed, overcome these defects, by using seed points on roads: (a) as starting points; (b) near roads discontinuities; and (c) near local direction changes. Therefore, semi-automatic methods have been based on them.

Another approach to cope with this problem is the extraction of cartographic primitives. In the relevant research the linear elements of maps or images are considered as primitives and extracted at a first step by digitization or lower level techniques. Emphasis is given then into their interpretation. Examples include: (a) the building of a rule based system for interpreting linear map features (Schenk and Zilderstein 1990); (b) the road network extraction by interpreting two types of primitives: crossroads and road segments (Cleynenbreugel *et al.* 1988); and (c) the implementation of a system for the extraction of a forest road network by using both procedural and knowledge-based modules. The latter defines the road network by eliminating extraneous elements derived from the image (Domenikiotis *et al.* 1995). Although the results obtained by the rule-based systems are encouraging, the complexity of the knowledge required if the system should be expanded to incorporate more linear objects and features, cause serious inconvenience for their broad use.

In this paper we present a thinning based method, that enables us to extract the road network of peri-urban areas from panchromatic SPOT images. These images are the most indicative for distinguishing road networks, because of SPOT's 10-m resolution. Indeed, on lower resolution (20 or 30 m) multispectral images, road network is shown more confused in spite of the increased radiometric potentiality of the respective sensors (Destival 1987). In our method, image processing procedures, such as thresholding, thinning, linking, gap filling are combined in a particular way to take the most advantage from the spectral and spatial resolution of the SPOT panchromatic images. Human intervention is limited to the definition of the lower threshold, making the method almost automatic.

The method is based on three key factors. First, it uses the fact that geographical features that have similar spectral characteristics with the road network but are not part of it, normally, have a different size and shape from the features of the transportation network. Thus, we use a stage in the method that eliminates from further processing the clusters of pixels that have sizes and shapes that are different from those that are typical of road network features. Second, it processes several binary images produced by the original panchromatic, because every one of them represents a subset of the road network with different completeness and refinement. Third it uses the digital numbers of the pixels in the original panchromatic image to expand the linear features that have been extracted in the early stages of the processing. Such an expansion fills the gaps that have resulted from thinning and linking algorithms of the method. This combination of excluding pixels that represent information unrelated to the road network and including pixels that are likely to be part of the network has as the consequence of improving substantially the performance of extraction algorithms. As a result, the road networks that are obtained from this process have a high degree of completeness.

The concept of the method is based on the Thinning operation. Thinning algorithms can be classified into two categories. The first category includes the algorithms that generate the 'skeletons' of the features by identifying pixels on them that have special geometrical or logical properties, and the second category includes the algorithms that determine the 'skeletons' of the features by 'peeling' the outermost layers of the features.

The algorithms of the first category can be further classified into those that are based on the Blum (Gonzalez and Woods 1992) and Pavlidis (Pavlidis 1982) formal definition of the medial axis transformation, and those which require the computation of the appropriate logical properties, such as the distribution of pattern points (Mahmood, *et al.* 1991, Ahmed 1995).

The algorithms of the second category are based mainly on the approach of iteratively 'peeling' the outermost layers of the features until the features are reduced into thin lines. They allow the efficient use of parallel image processing machines and they are called parallel algorithms. In the recent literature, many parallel thinning methods and techniques are reviewed and compared (Roland *et al.* 1987, Chen and Hsu 1988, O'Gorman 1990, Guo and Hall 1992, Steven *et al.* 1995). Those methods and techniques differ in terms of size and/or shape of thinning operators that they use, the thinning criteria and conditions, and the thinning implementation requirements (e.g. devices for restoring templates (Roland *et al.* 1987), defining critical pixel(s) (Steven *et al.* 1995) etc.). In this paper, we use a parallel thinning method.

2. The proposed method

On a remotely sensed grey-level image, the road network of peri-urban regions can be considered as a set of linear continual patterns on a complicated irregural and non-periodic background representing various land uses such as crops, vegetation, buildings and parking areas. Because of the variety of the land-use classes in such areas, and the sub-pixel spectral mixing according to class proportions, the digital values range for both linear patterns and background is similar. Therefore, the extraction of the road network requires road network *recognition* and *thinning* operation.

Road network recognition cannot be based absolutely on morphological techniques which assume geometric background patterns (Su and Ahmadi 1994), nor on a one-level thresholding (Gonzalez and Woods 1992), which assumes that pixels of the road network and background in the image can be distinguished by their grey-level values. The method that we have developed is based on the observation that the level of recognition of the road segments that result from a thresholding procedure depends on the threshold value that is used to separate the pixels of the road system from the pixels that represent other land cover types. The lower the threshold value, the more segments of the road network appear in the resulting binary image, the more pixels representing other land cover types are classified as 'roads', the more confusion exists in determining the roads. The higher the threshold value, the more specific certain parts of the road system become, the more parts of the road network segments are missing (not classified as road segments).

Our method exploits that characteristic and determines the segments of the road system by creating several binary images, each resulting from the original panchromatic image using a different threshold value, and then by processing the images morphologically, to determine as precisely as possible the road network features.

Analytically the method consists of five major algorithms. Figure 1 shows us graphically the proposed procedure. Every algorithm characterises a step of the method.

The first is the *thresholding algorithm* which produces the binary images. The second is the *morphological algorithm* which excludes all pixels that were classified as road pixels by the first algorithm but are unlikely to represent road features due to characteristics of shape and size of pixel clusters that include them. The third

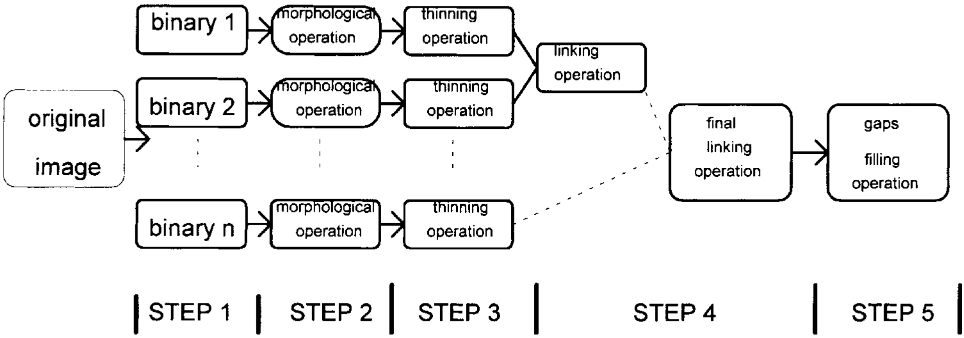


Figure 1. The proposed method.

algorithm is the *thinning algorithm* which refines the road segments by determining axes on them. It is executed on the morphological corrected images. The fourth algorithm is the *linking algorithm* which links parts of the refined road segments found on the different binary images. Finally, the fifth algorithm is the *gap filling algorithm* which completes gaps of the network by the use of the maximum local value of the original image.

2.1. *The thresholding algorithm*

This is a very simple algorithm that is used to select a set of pixels that satisfy a user-specified condition. The algorithm gets as input the digital panchromatic image and a threshold value, and generates a binary image that contains values from the set {0, 255}. If the grey-level value of a pixel in the input image is less than the threshold value then that pixel is characterized as 'inactive' and is assigned the value '0' in the output image. If its value is equal to or greater than the threshold value, then that pixel is characterized as 'active' and is assigned the value of '255'.

2.2. *The morphological algorithm*

The binary images that result from the application of a threshold value, contain a classification error which is caused by the inclusion of pixels that represent land cover types other than roads into the set of pixels that represent roads. Examples of such land cover types are certain kinds of agricultural cultivations, built areas, and barren land that has specific moisture. This happens because the grey-level values of the erroneously classified pixels are similar to those of the pixels that represent parts of the road network and, thus, the corresponding pixels cannot be differentiated using radiometric information.

The morphological algorithm is based on the fact that roads are linear features and, thus, their width is substantially smaller than their length. Other land cover types, such as agricultural cultivations, urban built areas and barren land, have a substantially different pattern in terms of shape, size and ratio of width to length. This difference provides the means to separate clusters of pixels that represent roads from those that represent other land cover types.

The algorithm takes as input a binary image which has resulted from the original panchromatic image by applying a threshold value and deletes all clusters of 'active' pixels that have greater width than the width of a specific structure (e.g. crops, building, storehouse). In our application we specified that the maximum width of a road should be approximately 30 m on the ground (3 pixels on the image). The algorithm detects features that are wider than roads by convoluting the binary image using a 3 × 3 pixel window. If all pixels of the 3 × 3 window which is centered at a given pixel in the image are 'active' then they are turned to 'inactive'. In this case, the outer frame of the 3 × 3 window (a 5 × 5 window) is also examined and 'active' pixels found there are turned to 'inactive' too. The result of the convolution is a binary image that does not contain clusters of 'active' pixels that are 3 × 3 pixels or larger.

This algorithm is very efficient (linear order) in terms of removing features that have width larger than that of a typical concrete structure. It achieves this goal without having to compute the basic geometric properties of the features shown on an image (Gerhard and Martin 1993) or to use time consuming morphological transformations that are employed by other algorithms (Daya Sagar *et al.* 1995). As long as the assumption about the maximum width of a road remains valid, all structures that are wider than the maximum road width and are classified as 'roads' by the thresholding algorithm will be removed from the set of 'active' pixels.

The structures that have been erroneously classified as 'roads' and are less than three pixels wide will not be removed from the set of 'active' pixels by this procedure. Those structures are mainly represented as scattered spots through out the resulting binary image.

Another characteristic of the morphological algorithm is that it may remove from the image certain sections of the transportation network (mainly those segments that are adjacent to relatively large concrete structures). This erroneous removal, however, does not affect the final results because its effect will be corrected at later stages of the method (linking and gap filling algorithms).

2.3. *The thinning algorithm*

The main goal in developing a thinning algorithm is to determine the 'skeleton' of features shown on a binary image as accurately and as completely as possible. This goal can be achieved by algorithms that satisfy the following five conditions (Chin and Wan 1987, O'Gorman 1990):

1. Parts of the feature that are connected in the image must be connected in the 'skeleton' of the feature (connectivity preservation)
2. The 'thinned' result must be minimally 8-connected
3. The endline locations of the feature must be maintained as much as possible (no excessive erosion)
4. The 'skeletons' that result from the thinning procedure must approximate the medial lines (or axes) of the feature (medial line approximation), and
5. Extraneous spurs in the resulting 'skeleton' must be avoided (boundary noise immunity)

The thinning algorithm that is used in this method is based on the above five conditions. It works iteratively and, in each iteration, it removes 'active' pixels that are on the outer boundary layer of features that are thinned. The removal of 'active' pixels is made using eight (8) templates (figure 2). The algorithm checks if a given 'active' pixel in the binary image matches any of these templates and, if it does, then it removes that pixel from the set of 'active' pixels. Specifically, templates (a)–(d) are used to remove pixels that are at the top, left, bottom, and right edges of a feature

0	0	0
x	255	x
x	x	x

(*a*)

0	x	x
0	255	x
0	x	x

(*b*)

x	x	x
x	255	x
0	0	0

(*c*)

x	x	0
x	255	0
x	x	0

(*d*)

x	0	0
x	255	0
x	x	x

(*e*)

0	0	x
0	255	x
x	x	x

(*f*)

x	x	x
0	255	x
0	0	x

(*g*)

x	x	x
x	255	0
x	0	0

(*h*)

Figure 2. Thinning templates. (Note: An 'x' denotes the fact that the corresponding pixel can take any of the two values that are permissible in the binary image (0 or 255). However, two or more pixels that are denoted with an 'x' in each template must take the value of 255 in order for the thinning algorithm to operate properly.)

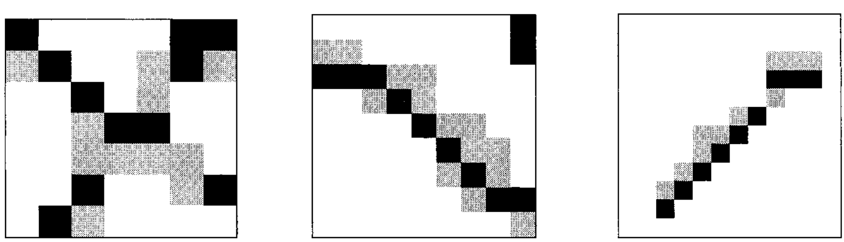
while templates (e)–(h) are used to remove pixels that are on top-right, top-left, bottom-left, and bottom-right edges of such a feature.

Thus, in a given iteration, the outer layer of a feature that is thinned is removed. Successive iterations 'peel' a feature and leave only the pixels that comprise its 'skeleton'.

The above procedure preserves most of the conditions specified above for the correct 'skeletonization' of a feature. Specifically, the requirement that at least two of the pixels denoted with an 'x' in each template (figure 2) must have the value of '255' in order for the central pixel to be deleted, preserves, in most cases, the local connectivity condition (condition 1). Also, the same requirement satisfies the minimal endline location erosion and minimal connectivity conditions (conditions 2 and 3). Finally, the use of each template in each iteration minimizes biases in the determining the medial line of a feature because features are 'peeled' gradually from their outer boundaries to their interior (condition 4) (figure 3, Scheme 2).

One of the limitations of the thinning algorithm is that, in cases where there is a transition from one part of linear feature which is at least two pixels wide, to another which is at least one pixel wide. It creates gaps in the 'skeleton' of the relevant feature (violation of the first condition) (figure 3, Scheme 1). We have not attempted to fix this limitation at this stage because it will be fixed by the linking and gap filling algorithms.

As far as the elimination of extraneous spurs that may result from the thinning algorithm is concerned (condition 5), we have tried to avoid them by using as input,



Scheme 1 Scheme 2 Scheme 3

Figure 3. Examples of the thinning algorithm application: Scheme 1, violation of the first condition; Scheme 2, medial line approximation; Scheme 3, features without noisy boundaries.

the output of the morphological algorithm as well as many binary images (figure 3, Scheme 3). This way, we have avoided use of cleaning templates to reduce noise in the boundaries of features, as it is often done in research and applications (Roland *et al.* 1987, Steven *et al.* 1995).

3.4. *The linking algorithm*

The segments of the road system that resulted from the application of the thinning algorithm on the different binary images can not be unified using an 'add images' operation because such an operation would violate the unit-width requirement (condition 2). This violation would occur when parts of the road segment are not aligned perfectly with each other in two binary images. Consequently, after the 'add images' operation, it is likely that the resulting binary image would contain segments that are more than one pixel wide.

The linking algorithm uses as input two images that have resulted from the thinning algorithm. One of them, the most comprehensive, serves as the basis which must be completed (figure 4(*a*)). The other serves as an auxiliary which would provide information for completing the first one (figure 4(*b*)).

The algorithm scans the two images simultaneously using a 3×3 window in each of them. In each step of the iteration, the algorithm examines whether the central pixel of the window in the first image is an endline pixel. This is the case when that pixel is 'active' and one of its adjacent eight (8) pixels is 'active' too (figure 4(*a*)) or two consecutive adjacent pixels are 'active' (figure 4(*b*)).

Then the algorithm checks the corresponding window in the second image. If one or more non-central pixels in that window are 'active' and, in addition, are not adjacent to each other nor adjacent to pixels that are 'active' in the boundary of the first image, then those non-central pixels are turned into 'active' in the first image.

The algorithm operates iteratively. In each iteration, if its conditions are satisfied, it adds new 'active' pixels at the endpoints of the road segments. This process continues until no further extensions can be made on the road network in the first image. It must be noted that the preconditions of the linking algorithm guarantee that the extensions made in the road network in the first image are connected to at least one segment of the road network (connectivity preservation). Also, they preserve the unit-width requirement, they reduce the problem of excessive 'erosion' at the endlines of the road segments, and satisfy the medial line approximation requirement.

It must be noted that the algorithm does not transfer in the first image parts of the network which appear only in the second image and are not linked to any parts of the network of the first. This limitation can be handled, to some degree, by choosing as base image the one that contains as many non-connected pieces of the road network as possible. Experiments on the panchromatic SPOT image of Attica, Greece, showed that the binary image resulted from the lower threshold plus 10 brightness values upwards, is always the most recommended.

Figure 5 demonstrates how the linking algorithm works. Schemes 1 and 2 show

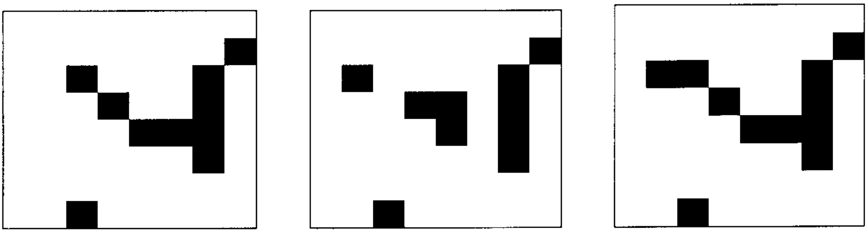
255	0	0
0	255	0
0	0	0

(*a*)

255	255	0
0	255	0
0	0	0

(*b*)

Figure 4. Sample templates defining endlines of road axes.



Scheme 1 Scheme 2 Scheme 3

Figure 5. Example of the linking algorithm result after one iteration: Scheme 1, base image (result of the thinning algorithm); Scheme 2, auxiliary image (also result of the thinning algorithm); Scheme 3, output image.

the base and auxiliary images, respectively, that are input into the algorithm. Those images have resulted from the thinning algorithm applied on the different thresholded binary images. Scheme 3 shows the output of the algorithm.

3.5. *The gap filling algorithm*

This algorithm completes the road network which was obtained from the linking algorithm by adding segments that do not appear on any image produced by the thresholding algorithm. The gap filling algorithm is based on the fact that in peri-urban areas the grey-level values of the road segments are substantially higher than the values of the adjacent land cover types. This difference in the grey-level values enables us to distinguish visually roads from the other land cover types in panchromatic images. The information which is portrayed by this difference, however, cannot be detected by the thresholding algorithm because, often, the absolute grey-level values of the roads in the panchromatic image are smaller than the specified threshold value and, thus, those roads are not represented in the binary images. Even when we use low threshold values in the thresholding algorithm, still, we would miss certain road segments as a result of the morphological algorithm.

The gap filling algorithm works iteratively and fills small gaps in the roads that have resulted from the linking algorithm by taking into consideration the grey-level values of the pixels of the original panchromatic image. Specifically, the algorithm determines whether a pixel is an endline pixel of a road segment using the same procedure as the one described in the linking algorithm and, if it is, the algorithm examines the eight (8) peripheral pixels of the 3×3 window which is centered on the endline pixel to determine which one has the highest grey-level value in the original panchromatic image. If that pixel is not 'active' nor adjacent to an 'active' pixel in the binary image then the algorithm turns it to an 'active' pixel and continues to process the next endline pixel. Otherwise, the algorithm searches to find the peripheral pixel of the same 3×3 window that has the second highest value. If that pixel is not 'active' nor adjacent to an 'active' then the algorithm turns that pixel to an 'active' one and continues processing from the next endline pixel. Otherwise, it continues to examine the pixel with the third highest value. If that pixel is not 'active' it turns it to an 'active' and continues processing from the next endline pixel of the image.

In the case in which there is a gap between two segments endlines that are separated by one pixel, the algorithm fills the gap by turning into 'active', the intermediate pixel. The gap filling algorithm is effective in filling up, pixel by pixel, gaps of the road system without creating extraneous spurs or violating the thinning requirements. The algorithm includes 'ring correction' when, at a given endline location, the pixels with the high grey-level values form a small scale circle. The basic weakness of the algorithm is its inability to fill gaps when certain segments of the road not being detected by the thresholding and linking algorithms do not match any endline pixel in the binary image which is input in the gap filling algorithm.

Figures 6 demonstrate partially how the gap filling algorithm works. Pixels shown in black colour indicate pixels that are part of the road network which resulted from the linking algorithm, and pixels that are dark grey are pixels which were turned to 'active' by the gap filling algorithm. Pixels shown in lighter tones of the grey come from the original grey-level value which is also represented.

4. Experimental results. Method evaluation

The proposed method was applied to a number of images in order to optimize and automate the batch procedure described in figure 1. The value of the lower threshold is the only input required by the user, every time the method is applied. Three more thresholds are calculated automatically by increasing the input value by a step of 10. Experiments showed that method is not hardly dependent on the value of the lower threshold. For each image, there are no significant changes in the results for a range up to ± 10 digital brightness values of the lower threshold. This is due to the morphological correction followed.

In this section, three typical examples will be given. These represent areas which are currently under development procedures and are found in the outskirts of Athens, Greece. They are characterized by a dense irregular road network with complicated patterns. Other land cover classes like buildings and vegetation are also represented. A SPOT panchromatic scene captured on 22 April 1989 was processed after its enhancement by the high boost filter (Gonzalez and Woods 1992). Pictures 7, 9, 11 show portions of the SPOT image. Pictures 8, 10, 12 show the final results overlaid on the satellite image.

We observe that the majority of the road network has been detected correctly. Only a few linear features, which can be seen in the SPOT image and can be interpreted as roads, were not detected by our method. This occurred because no pixels of those linear features were presented in the binary image used as 'base' by the linking algorithm. Consequently, no end-lines were detected by the same algorithm in the region, in order to complete them by the use of auxiliary images, resulted from the appropriate thresholds. Also, we observe that the small segments of the detected roads do not correspond to the road network but in other land uses, such

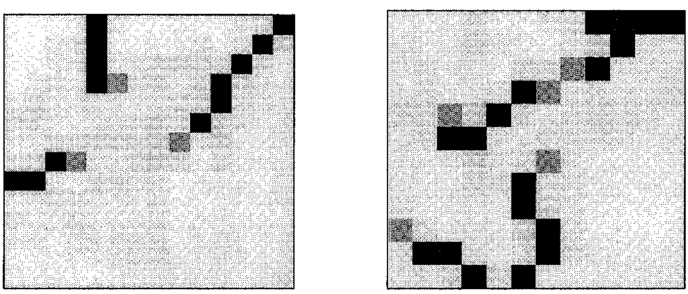


Figure 6. Examples of how the gap filling algorithm works.

Figure 7. A portion of SPOT image.

as parking areas, buildings, etc. Those segments are small in length, have circular shape, and are observable in the images with the most irregular and complicated road network (e.g. figure 7). A set of rules would remove them, but not without effect on the detected road network, arbitrary developed, and not according to a region planning project.

In order to estimate the effectiveness of our method in determining the road network and its accuracy, we compared the results of the first example, where road network seems to be more irregular and complicated, with a topographic map. Therefore we have adopted the following procedure. First, we have digitized the axes of the road network from a 1: 50 000 scale topographic map. That map had been compiled using air photographs which were taken in 1988, that is, a year earlier than that in which our satellite image was taken. Then, we expressed both the digitized network and the roads into the same co-ordinate reference system, the 1987 Hellenic Geodetic Reference System.

Since a precise comparison of the results of our method and of the digitized road network would be inappropriate (the axes of the digitized road segments have an uncertainty), we decided to create buffer zones 10 and 15 m wide about the axes of the digitized roads. The width of those zones was chosen to be 10 and 15 m, respectively, because it matches the accuracy of measurements that can be made reliably on a 1: 50 000 scale map.

Next we computed:

- the percentage of the road network which was detected using our method

Figure 8. Extracted roads.

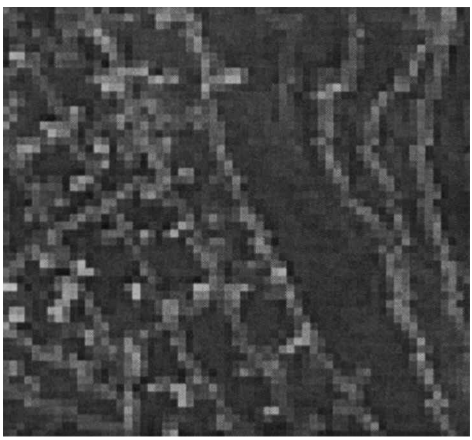


Figure 9. A portion of SPOT image.

- the percentage of coincidence of the roads of the two data sets (the one which resulted from our method and the one which resulted from digitizing)
- the percentage of the roads that have been determined by our method and are within 10 m from the digitized axes of the roads and
- the percentage of the roads which have been determined by our method and are within 15 m from the digitized axes of the roads.

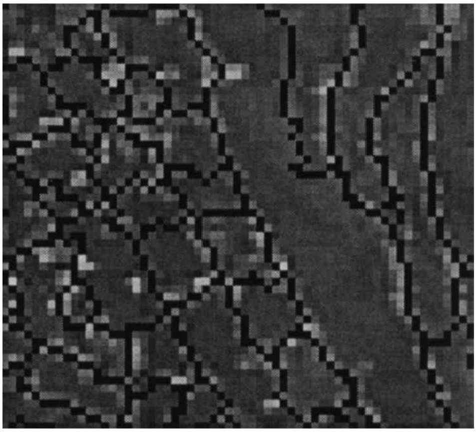


Figure 10. Extracted roads.

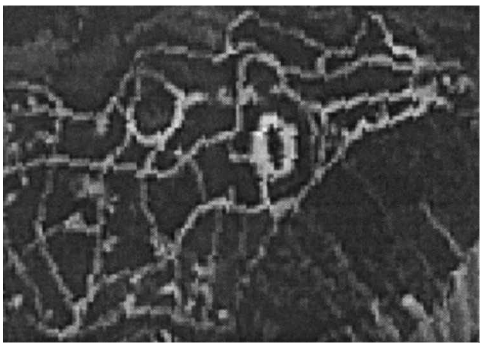


Figure 11. A portion of SPOT image.

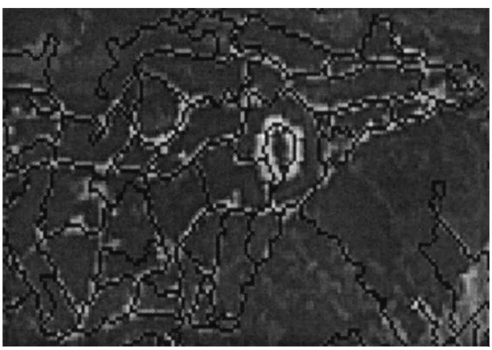


Figure 12. Extracted roads.

The results of the above computations are the following:

Of the digitized road network, 92% has been determined by our method. The remaining 8% has not been detected either because of limitations in our method or because of limitations in the information represented in the panchromatic satellite image. Indeed, if we observed figure 13, which shows an overlay of the digitized road network and the panchromatic satellite image, and figure 14, which shows an overlay

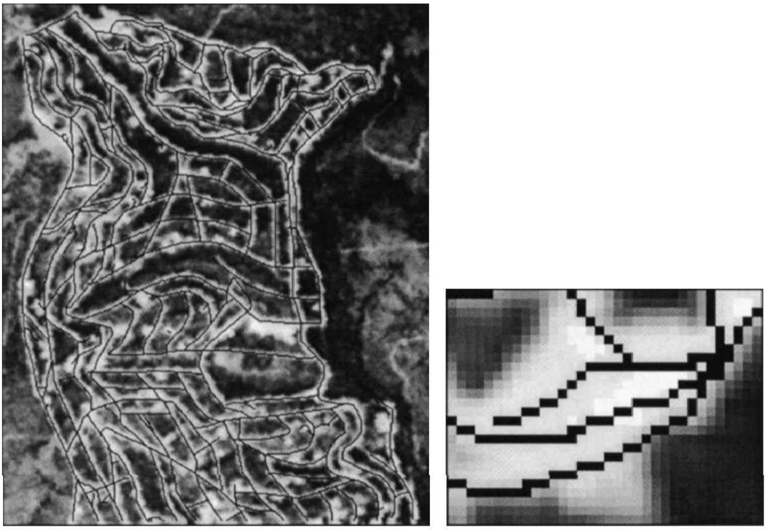


Figure 13. Digitized network overlaid on the panchromatic image. Scheme 1, detail of Picture 7.

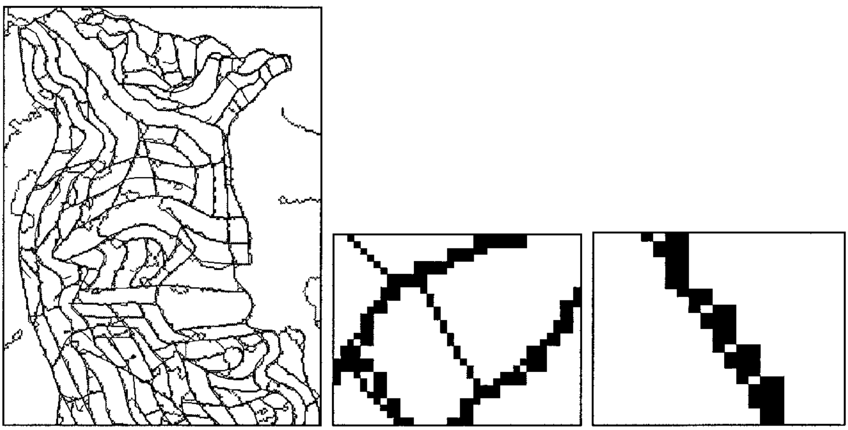


Figure 14. Road determined by our method and road axes resulted from digitizing. Schemes 1 and 2, details of Picture 8.

of the roads determined by our method and the digitized road network, we would observe that areas where the road network is dense and roads have wide embankments, they appear by almost the same grey value in the satellite image (Scheme 1 detail of figure 13). Consequently, it is highly unlikely that any image processing method would be able to determine correctly the road in those areas without additional information given by the user.

In figure 14, which shows an overlay of the digitized road network and the roads determined by our method, we can estimate that the percentage of the roads which cannot be detected by our method is 4%. An example of two roads which are not detected by our method is given in the Scheme 1, detail of Picture 8. It must be noted that in this scheme, the width of the roads determined by our method is greater than one pixel because each pixel in that picture corresponds to an area which is 3×3.5 m large and not 10×10 m, as it was the case in the satellite image.

Of the roads which have been detected by our method, 55% coincide with the axes of the digitized network, which have an accuracy of 0.1 pixels of the SPOT panchromatic image. This percentage is significant, given the fact that the two data sets used in the comparison come from entirely different sources and have been compiled using different methodologies.

Of the roads which were determined by our method, 69% are within 10 m from the digitized axes. This means that 14% of the detected roads are represented with an accuracy which is greater than or equal to one pixel (resolution of the SPOT panchromatic image). This deviation from the digitized network emanates mainly from limitations in our method, although we should always have in mind that the contrasted data do not come from the same source and do not refer to the same time period. Thus, roads that have an embankment in one side would be represented as being wider in the satellite image and consequently the thinning algorithm will determine roads that systematically deviate from the actual ones (Scheme 2, detail of figure 14).

Of the roads determined by our method, 87% are within 15 m from the digitized roads. That means that 17% of the detected roads are represented with an accuracy which is greater than or equal to 1.5 pixels (resolution of the SPOT panchromatic image). This deviation from the digitized network can be attributed mainly to the radiometric and geometric resolution of the satellite image. As in the case of the 10 m buffer zones, the presence of embankments is the main cause for these deviations too.

The remaining 13% which is classified as roads, although it is not, is attributed to.

(a) The inability of our method to distinguish between roads and certain parking areas or buildings. In that case, the roads appear to be circular
(b) The existence of road segments which are shown in the satellite image but not in the topographic map (figure 15: details of our method result overlayed on the satellite image and the result of our method overlayed on the digitized map)

5. Conclusions

In this paper a method was developed for the extraction of the road network in peri-urban areas using SPOT panchromatic image. Aerial imagery may be used too. A batch procedure must be executed, which combines in a particular way the results of the developed algorithms: the thresholding; the morphological; the thinning; the

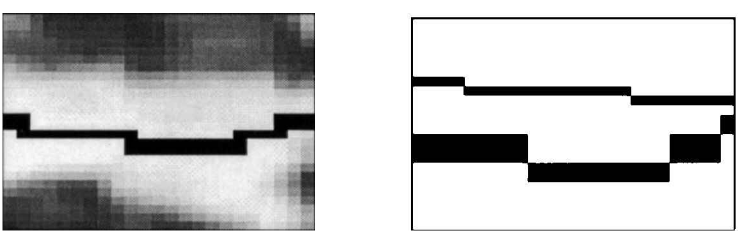


Figure 15. Roads segments not shown in the topographic map.

linking; and the gap filling algorithms. The method is almost automatic, since the lower threshold is the only parameter required by the user. Concerning its characteristics we can conclude the following.

- The method is not strictly dependent on the lower threshold definition (it may be ranged ±10 digital brightness values)
- It is robust in case of gaps and other distortions because of the use of different thresholds and of the gap filling algorithm
- It handles successfully road direction changes even if these are significant
- It can successfully extract roads with various width, shape, and grey-level values
- It excludes efficiently buildings and other land cover classes with similar brightness

The precision of the method is adequate for updating maps at the scale of 1∶50 000. Vectorization of the results must follow for this purpose.

The experiments carried out under this research showed that the more a region is developed according to an urban plan, and the road network respects road regulations, the more the method performance increases. However, it is recommended that the potential of the proposed method be tested in other environments having modern residential developments features. The method developed in this research needs also to be used when higher spatial resolution multispectral data are available.

Acknowledgements

The research upon which this paper is based was funded and supported by the Laboratory of Remote Sensing of the National Technical University of Athens. The authors are grateful to their colleague Dr P. Lolonis who kindly provided maps and helpful comments on a draft copy of this paper. The authors extend their thanks to the anonymous reviewers whose insightful opinions helped to refine this paper.

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