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Original Article

Application of Fuzzy logic, watershed Lines and Mathematical Morphology for the Detection of Linear Structure and Urban Fabric: Detection of the Road Network of the City of Douala (Cameroon)

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Abstract - *This paper presents a technique for the extraction of linear structures from satellite images of SAR types and aerial photographs based on the fuzzy logic approach associated with the Watershed method and mathematical morphology. The methodological approach is centered on an extraction-oriented algorithm acting in several steps, namely: textural analysis and fuzzy filtering, application of mathematical morphological operators allowing to highlight the land use forms, the whole, completed by segmentation by Watershed Lines, in order to obtain finer thresholding, highlighting the filillary structure of the study area. This combination of morphological and non-morphological tools is a complement to solve the problem of discontinuity of structures, very often encountered when extracting linear structures in urban areas, by classical methods, or by using only simple morphological operators such as skeletonization. The results obtained allow us to highlight the road network of the city of Douala (Cameroon).*

Keywords - *Fuzzy logic, Linear structures, Mathematical morphology, Urban area, Watershed lines.*

1. Introduction

Fuzzy logic is currently of great interest to researchers, engineers and industrialists, but more generally to all those who feel the need to formalize empirical methods, generalize natural modes of reasoning, automate decision-making in their field and build artificial systems capable of performing tasks usually taken care of by humans. The application of fuzzy logic in remote sensing brings new ways to obtain the desired results.

Remote sensing is a technology and a scientific discipline that allows us to observe and analyze our environment and consequently define, monitor and evaluate natural resource management policies [5]. Based on ground measurements and combined with Geographic Information Systems, it now makes a decisive contribution to the various issues that arise in the areas of environment, health, land use planning, rational exploitation of natural resources or prevention of natural disasters [6]. It also allows applications in many fields such as agriculture, forestry, hydrology and water resources, oceans, geology, cartography, urban planning, cadastre, or strategic intelligence. The demand and need for reliable maps is growing and becoming a difficult problem to solve [18]. In the absence of adequate cartographic tools, decision-makers often have difficulty determining the real boundaries of urban areas and those isolating the different districts [14]. It is, therefore, necessary to develop appropriate and efficient computer tools. The analysis and interpretation of remotely sensed images is an important and sometimes essential tool for photo-interpreters and thematicians in the production of maps. Morphological structures such as the road and hydrographic networks become easily detectable.

Various works, more or less recent, have tackled the problem of automatic detection of road networks in aerial or satellite imagery. These works have more particularly concerned the detection methods and the modeling of a road itself.

The urban perimeter is an essential piece of data in urban analysis for determining the peripheral growth of large cities. It is an essential prerequisite in the urban planning and management process [33]. Beyond these considerations, there is a methodological problem: urban networks are diverse in nature and are, unfortunately, only very partially accessible. The detection of urban networks and their characterization (type of transport, pavement, etc.) are of great interest to developing countries [33]. Noting that within an urban area, one can easily move from a paved road to an unpaved road. This poses a real problem of identification.

Mathematical morphology [4], [20] and [23] is one of the analysis methods used to detect the urban using satellite imagery. It is better suited to this study because it is based on the study of the shape: the objects constituting the city being characterized by it [10]. In this paper, a particular emphasis is put on the detection and extraction of surface or linear objects, such as road networks and cross-country tracks. Multiple remote sensing applications (multi-source image registration, map updating, automatic navigation) require the detection of the road network [28]. The detection of linear structures is of great importance for developing countries, especially when it comes to producing cartographic data [33]. The extent of the surfaces to be mapped and the time required to update them make the development of algorithmic tools for detecting cartographic items an important issue. We are interested here in the use of satellite and aerial data for the detection of linear objects. The cartographic item we are looking for is the different networks present in the radar image of the city of Douala (Cameroon), such as the road network or the hydrographic network. Numerous studies now allow the automatic or quasi-automatic extraction of the road network from high-resolution optical satellite images (SPOT panchromatic images at a resolution of 10 m) and very high-resolution aerial images (50 to 100 cm) [28].

On the other hand, in radar images, the traditional methods used to detect linear structures fail because they are based mostly on differences in averages between areas [26]. Several solutions have been proposed for extracting linear structures in satellite images. The Hough transformation [12] and [17], which allows us to search for parametric curves (straight lines or circles, for example) in an image, has been very popular. However, the application of such a method remains limited by the parametrization, which often restricts the search to line segments.

A Markov field is defined using a priori information about their continuity and, thus, the resulting neighborhood relations between pixels. This approach allows the detection of continuity breaks in an interferogram [27]. Unfortunately, in the case of satellite images, such a technique can only obtain disconnected pieces of roads. Using mathematical morphology, [9] in their article propose a method of extraction of the road network of the city of Douala by neighborhood processing. Unfortunately, this method presented a handicap because of the discontinuity of structures. [11] proposes a method of extracting structures by marked point processes, but this method presented problems of overdetection and omission of linear structures. [13] use texture analysis which exploits the spatial relationships between pixels.

However, this method consumes considerable computational time, and the linear structures do not have a uniform texture. In [21], an approach based on object-oriented image classification is proposed. Robust to noise, but it is difficult to define the desired level of detail. The authors [16] use the wavelet transform to segment the image at different scale levels in their paper. Then, the regions resulting from the segmentation are filtered according to their rectangularity measure based on the ratio between the object's perimeter and its area. Finally, it applies morphological operators for edge enhancement and skeletonization to extract the main axes of the road network.

To achieve a solution approach, the goal of this work is to prove the possibility of extracting such information on an ERS-1 SAR image of the city of Douala in Cameroon, in a region with high cloud cover where it is often impossible to acquire good quality optical images during most of the year. This paper proposes here a detection method based on the combination of morphological filters (erosion, dilation, opening and closing), watershed (EPL) after filtering and edge detection using fuzzy logic tools to the original image to overcome the difficulties encountered by other authors.

The identification of roads with smaller widths (smaller than the pixel size) is difficult firstly because of this size, making it difficult to apply the processing.

2. Materials and Methods

2.1. Data used and Study Site

The image used (Table 1) is an image of the ERS1 satellite.

Table 1. Characteristics of the image used

Satellite	**RHS 1**
Date of registration	23/ 08 /2010
Covered area	100 Km x 100k m
Polarization	V V
Spatial resolution	20m x 20m (original ; 12,5m x 12,5m)
Image size	640x400
Frequency	5,3 GHz *Data used and study site*
Wavelength	5,6 cm
Band	C
Angle of incidence	23°
Longitude	8°30 – 9°50
Latitude	3° - 5°

Fig. 1 Original SAR image of Douala

2.2. Methods Used

Many works allow today automatic or quasi-automatic road network detection on high-resolution optical satellite images. The methods used in our work are based on statistical analysis on the one hand, on the watersheds and mathematical morphology on the other hand.

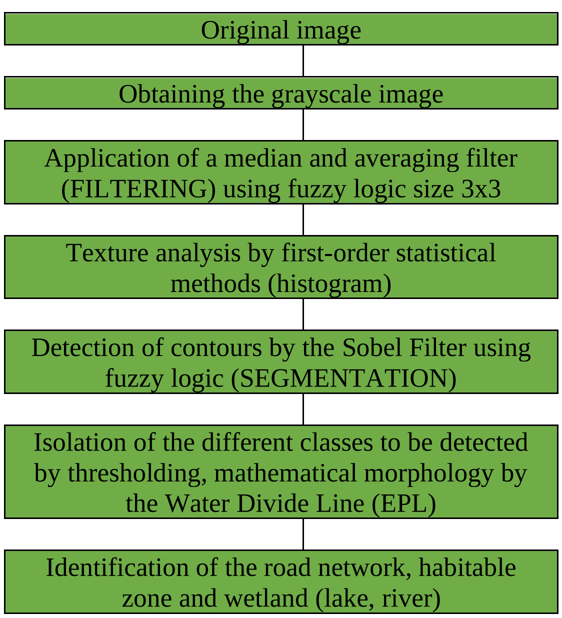


Fig. 2 Algorithm for the detection

2.2.1. Fuzzy Filtering

Fuzzy Logic

The set of techniques used in image processing utilizing fuzzy logic includes those that perceive, represent, and treat pictures, their segments, and their attributes as fuzzy sets. The representation and processing are determined by the problem to be addressed and the fuzzy approach selected.

Fuzzy image processing (FIP) has three main steps:

- Fuzzification of the image
- Modification of the values of belonging
- Defuzzification of the image

The fuzzification and defuzzification steps are due to the fact that we do not have fuzzy hardware.

Therefore, encoding the image data (fuzzification) and decoding the results (defuzzification) are steps to process images with fuzzy techniques [24].

The main strength of fuzzy image processing lies in the intermediate step (membership value modification). After the image data has been transformed to the gray level at the membership plane (fuzzification), appropriate fuzzy techniques modify the membership values. We will use a fuzzy rule-based approach.

2.2.2. Filtre médian et Moyenneur Utilisant La Logique Floue

Averaging Filter

This linear operation can be seen as the discrete convolution of the image by a mask. Where I is the intensity of the original image, I' is the intensity of the filtered image, is the neighborhood used, and h is the convolution mask.

$$\mathrm{I}'(i,j) = \sum_{(m,n)\in v} h(m,n)I(i-m,j-n),$$

$$\sum_{(m,n)\in v} h(m,n) = 1 \qquad (1)$$

Median Filter

Noise reduction with the median filter: When an image contains aberrant pixels (for example, a single white pixel in the middle of a black area or isolated pixels randomly distributed in the image that degrade the image quality), it is said to be "noisy". Simple image smoothing can reduce noise because the effect of aberrant pixels is reduced by averaging with its neighboring pixels.

However, the smoothing leads to a reduction of sharpness in the image. The method based on the median filter does not have this disadvantage. It is particularly suitable when the noise consists of isolated points or fine lines. However, it is only applicable to gray scale images, unlike smoothing:

$$G(x,y) = median\{f(n,m) \mid (n,m) \in S(x,y)\} \qquad (2)$$

with S is a neighborhood of (x,y)

This linear operation can be seen as a mask's discrete convolution of the image. Where I is the intensity of the original image, I' is the intensity of the filtered image, is the neighborhood used, and h is the convolution mask.

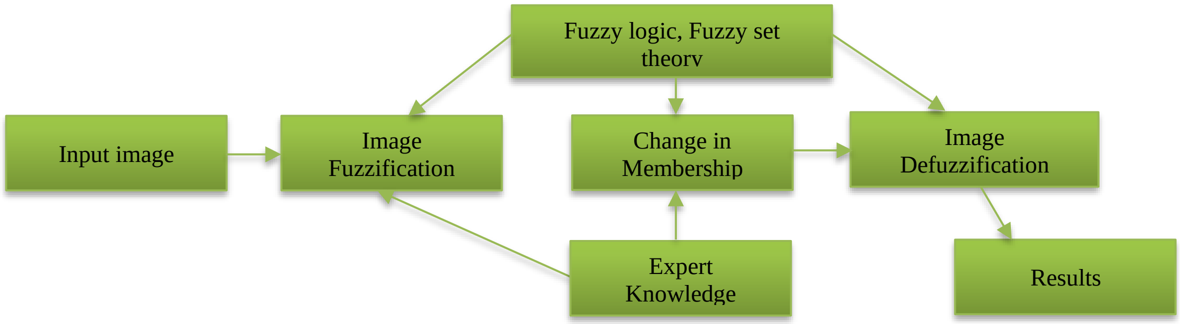


Fig. 3 The general structure of a PIF is shown in the figure

Noise removal algorithms reduce or remove the visibility of noise by smoothing the entire image, leaving the areas near the contrast boundaries.

After converting the image to grayscale, use two filters to smooth the image. This is effective in reducing the Gaussian noise of the images. We use the medium and median filters. The results of these filters will be used to create fuzzy rules.

Now convert the image to double precision data since the evaluation of fuzzy inference systems only supports single precision and double precision data. Therefore, convert the mean and median filtered images into a double array.

Let's define the fuzzy inference system (FIS) for noise reduction noiseFIS; put our choice on the FIS of Mamdani and specify the image gradients, mean and median, as inputs to noiseFIS. Specify a Gaussian membership function with zero means for each input. If the gradient value of a pixel is 0, it belongs to the zero membership function with a degree of 1. Specify a Gaussian membership function for each output and adjust the noise reduction performance in two classes: homogeneous (HO) and details (DE).

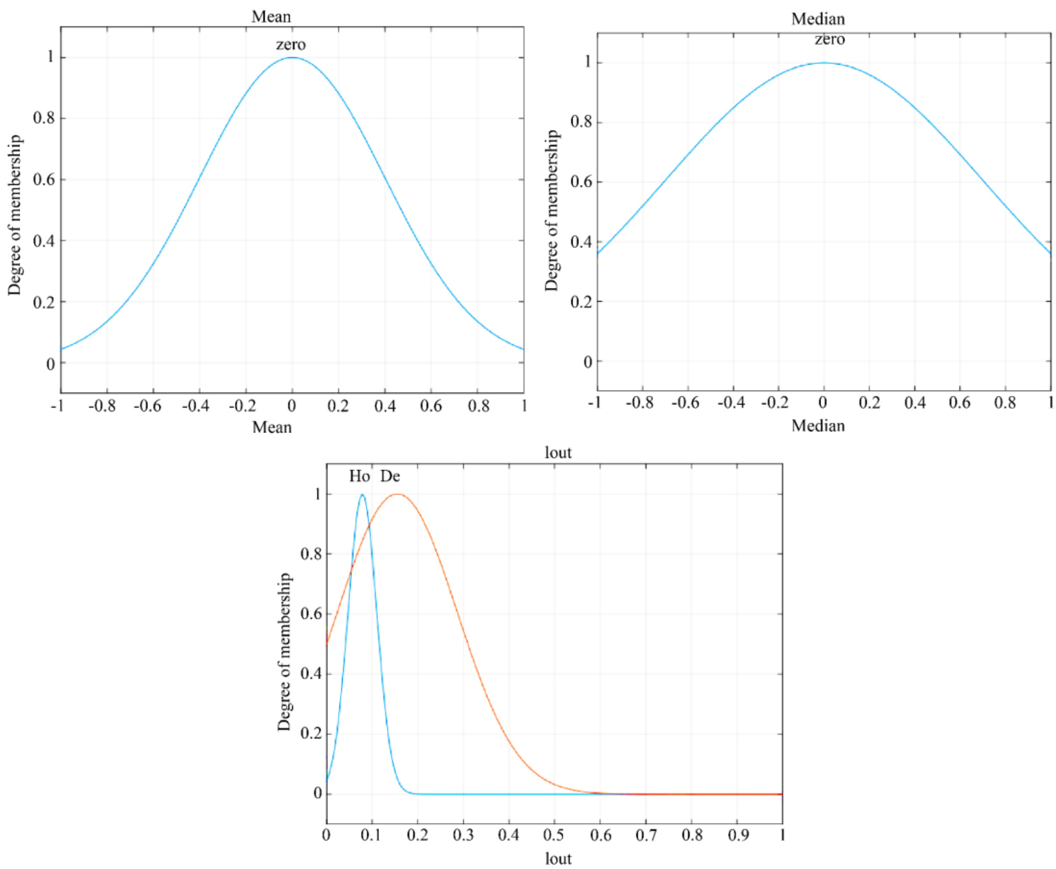


Fig. 4 The membership functions of the inputs and outputs of noiseFIS

Add the following rules for noiseFIS:
r1 = "If the mean is zero and the median is zero, then Iout is Homogeneous".
r2 = "If the mean is not zero or the median is not zero, then Iout is Details"
Now let's evaluate the FIS.

Evaluate the output of the noise reducer for each row of pixels in Img using the corresponding rows of the Averager and median filter as inputs.

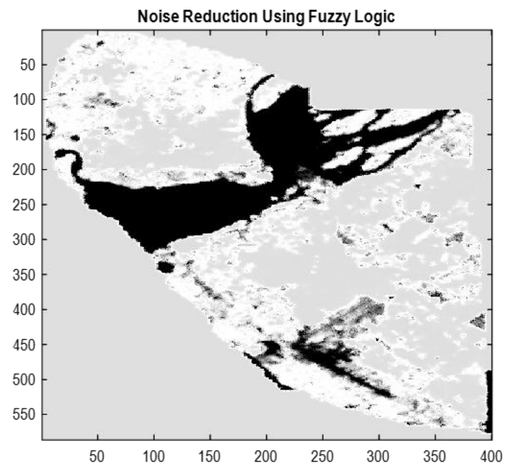


Fig. 5 The reduced noise image

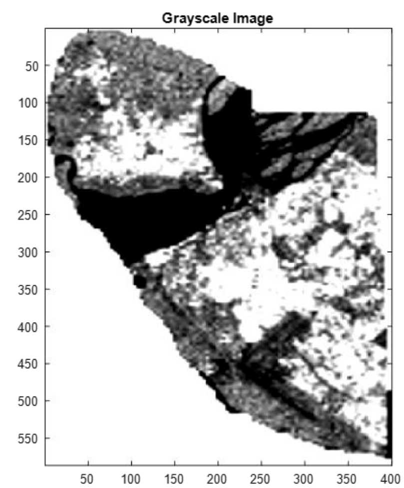
It is now clear that image quality is achieved by noise-free images for better results and greater precision.

2.2.3. Texture Analysis by First-Order Statistical Methods

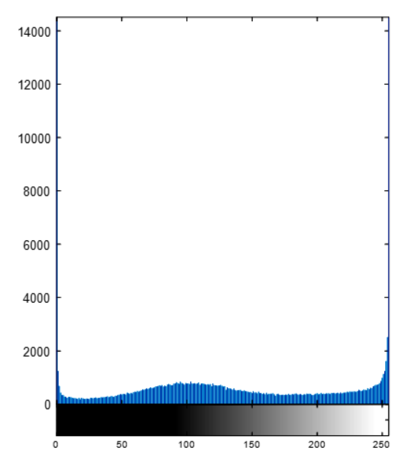
Any interpretation and any data processing of an image are based on two fundamental notions, which are: the texture and the structure. The texture is the set defined in the extension of the textural elements. A textural element of an image is the continuous and repeated zone in which a change of characters is not detectable or detected, with the means at our disposal [7]. In the case of satellite images, a textural element is constituted by the set of resolution elements (whose area is defined by the characteristics of the sensor) that have the same value of luminance or a function of luminance (dimension of the characteristics of the object) and which are related (spatial dimension). Thus, the set of areas of the same textural value corresponds to a texture. The textural analysis is a method that considers the spatial distribution of gray levels around a pixel considered in the image. Several methods of texture analysis have been developed over the years. Of all these methods, the co-occurrence matrix seems to be the most classical. In this method, the element S(i,j,v) of the co-occurrence matrix is the probability of occurrence of the pair of gray levels (i,j), given a displacement vector v along a given direction and orientation. The disadvantage of this method is that it does not consider all directions around a pixel. [30] proposed the texture spectrum approach. This approach is similar to the co-occurrence matrix approach, in the sense of characterizing the stochastic properties of the spatial distribution of the image gray levels, except that it takes into account all eight neighboring pixels around the pixel under consideration instead of a single displacement vector. In order to avoid all these difficulties, the analysis method based on first-order histograms proposed in [3] serves as a model for our approach. Such a histogram indicates the frequency of appearance of a gray level in a considered neighborhood. From the histogram, we can extract parameters with different degree statistics.

This method is based on first-order histograms. Such a histogram indicates the frequency of appearance of a gray level in a considered neighborhood. From the histogram, we can extract parameters with different degree statistics.

We are obliged to transform the original image to the gray level since the median filters apply only to images at gray level.



a)



b)

Fig. 6 Textural analysis by the first-order statistical method. (a) Grayscale image. (b) First order histogram

2.2.4. SOBEL Filtering using Fuzzy Logic

The principle of this filter is that the operator calculates the gradient of the intensity of each pixel.

The operator uses convolution matrices. The matrix (usually of size 3×3) undergoes a convolution with the image to calculate approximations of the horizontal and vertical derivatives. Imgx and Imgy are two pictures that, each point, roughly represent the horizontal and vertical derivatives of each point, respectively. Let me serve I as the source image. These images are calculated as follows:

$$Img_x = \begin{bmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{bmatrix} * I$$

$$Img_y = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix} * I \quad (3)$$

At each point, the horizontal and vertical gradient approximations can be combined as follows to obtain an approximation of the gradient norm :

$$F = \sqrt{{Img_x}^2 + {Img_y}^2} \quad (4)$$

The fuzzy logic approach to image processing allows the use of membership functions to define the degree to which a pixel belongs to an edge or a uniform region.

Step

Convert the image to double-precision data since the evaluation of fuzzy inference systems only supports double-precision or single-precision data.

We convert our grayscale image into a double precision (a double array).

The edge detection algorithm relies on the gradient of the image to locate breaks in uniform regions. Compute the image gradient along the x-axis and y-axis. GImgx and GImgy are simple gradient filters. We obtain a matrix containing the gradients of I along the x and y axis after convolving I and GImgx with I and GImgy.

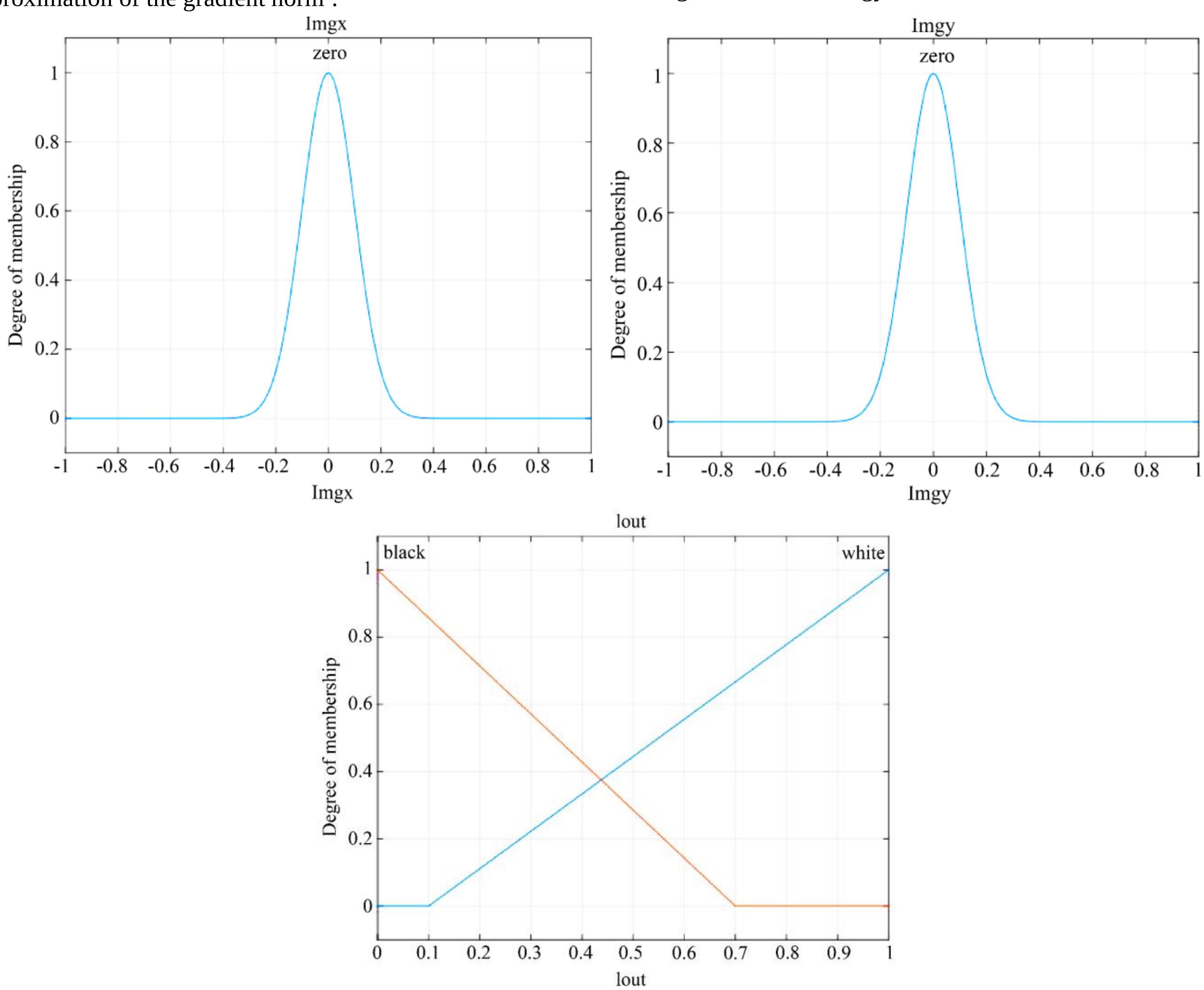


Fig. 7 EdgeFIS input and output membership functions

Define the edgeFIS fuzzy inference system (FIS). We choose Mamdani's FIS for edgeFIS detection.

For this, we specify the image gradients, Imgx and Imgy as inputs to edgeFIS.

Let's specify a Gaussian membership function with zero mean for each input sx and sy indicate the zero membership function's standard deviation for the Ix and Iy inputs. If a pixel has a gradient value of 0, it is a member of the zero membership function with a degree of 1.

For the Ix and Iy inputs, sx and sy indicate the zero membership function's standard deviation. You may alter sx and sy values to modify how well the edge detector performs.

The algorithm becomes less sensitive to image edges, and the intensity of identified edges falls when these parameters are increased. Let's specify the detected image's intensity as the edgeFIS output.

Let us specify the triangular membership functions, white and black, for Iout. As with sx and sy, we can change the values of d1, d2, d3, d4, d5 and d6 to adjust the performance of the edge detector. The triples specify the start, peak and end of the triangles of the membership functions. These parameters affect how strongly edges are identified.

Let's specify the FIS rules.

Add rules so that a pixel is white if it belongs to a uniform region and black otherwise. When an image's gradient is 0 in both directions, a pixel is said to be in a uniform area. If one of the directions has a non-zero gradient, the pixel is on an edge.

Now let's evaluate the FIS.

Let's evaluate the edge detector output for each row of pixels in Img using the corresponding rows of Imgx and Imgy as input.

It is now clear to see the image's sharp edges, which help indicate its high-frequency components.

2.2.5. Mathematical Morphology

Mathematical morphology deals with binary images and uses set theory. This technique allows, among others, to do

- filtering: to keep or remove structures from an image that have certain characteristics, notably shape,
- segmentation: to obtain a partition of the image in its different regions of interest. Generally, we try to separate the objects of the image from the background.

Mathematical morphology is a method of image analysis based on set theory [10], according to the first law of vision, which states that any object hides whatever is placed behind it.

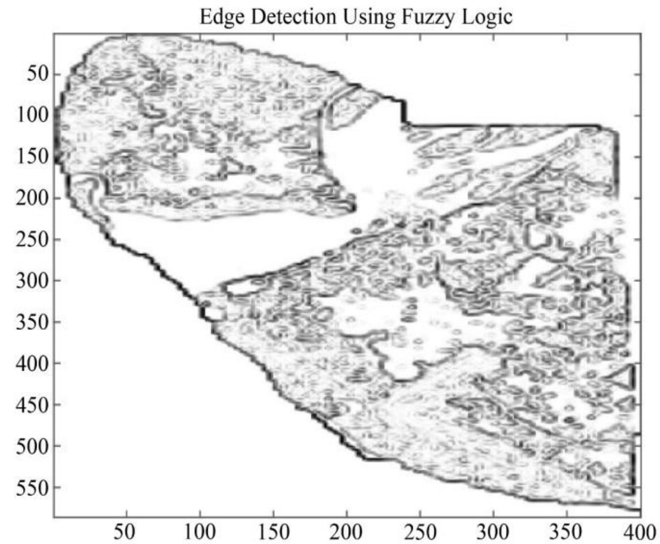


Fig. 8 The contours detected by the sobel filter using fuzzy logic

For example, if object A is located before object B, the eye no longer perceives B, but the difference between B and A. Thus, to express the obvious fact that bodies are generally opaque and not translucent and that we see them in perspective, the mind resorts to the concepts of inclusion, intersection, reunion, etc., that is to say, a morphology and, thus, a description of forms. The objects studied are not directly accessible to measurement, so the analyzer must first construct the set on which the measurement will be based.

This construction is carried out by successive transformations, starting from the raw image, which will gradually bring to light the set to be measured [4]. This highlighting is done thanks to the tools of mathematical morphology, which are: The transformations by Erosion, Dilatation, Opening, and Closing. The basic idea of mathematical morphology is to compare the objects we want to analyze to an object of known shape, called a structuring element. It is defined by simple geometrical forms: round, square, hexagon (figure 9).

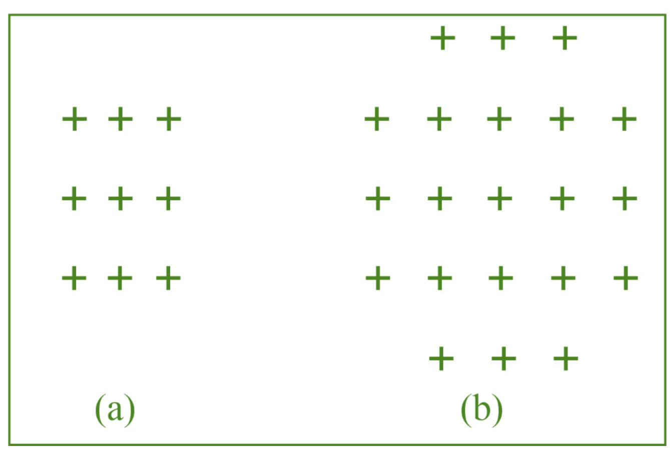


Fig. 9 Illustration of a structuring element a) square; b) hexagonal

Morphological Operators
Be two non-empty sets of $\mathbb{R}^n$, X, and Y. The Minkowski addition is the set operation defined by **:**

$$X \oplus Y = \{x + y \mid x \in X, y \in Y\} \quad (5)$$

In what follows, we fix a structuring element B. For all x ∈ $\mathbb{R}^n$ we note

$$B_x = \{x + y \mid y \in B\} \quad (6)$$

Dilatation
The dilatation of a set X by a structuring element B is defined by :

$$D_B(X) = X \oplus Y = \cup_{x \in X} B_x \quad (7)$$

By using dilatation :
-all objects will "grow" by a part corresponding to the size of the structuring element,
- if there are holes in the objects, they will be filled in,
- if objects are located at a distance less than the size of the structuring element, they will merge

Erosion
What constitutes a structural element B eroding a set X is:

$$(E_B(X) = \{x \in \mathbb{R}^n \mid B_x \subset X\} \quad (8)$$

The erosion is the dual operation of the dilatation in relation to the complementary passage.

$$(E_B(X) = [D_B(X^C)]^C \quad (9)$$

Où X^C is the complementary of X.

By using Erosion:
- objects smaller than the size of the structuring element will disappear,
- the others will be cut by a part corresponding to the size of the structuring element,
- if there are holes in the objects, they will be accentuated,
- the objects connected between them will be separated

Opening and Closing
An erosion followed by an expansion is called an opening, and an expansion followed by erosion is a closure.
Erosion + Dilatation → Opening.
Dilatation + Erosion → Closing.

Fig. 10 Opening-closing by threshold reconstruction

The opening has the property of eliminating all the parts of the objects that cannot contain the structuring element, and the closing has the property of filling everything smaller than the structuring element.

2.3. Extraction of Linear Structures

The linear structure extraction algorithm is given in the following Figure 2: The processing is applied to both aerial photographs and radar images. In the first case, it is important to convert the image into a gray-level image to apply the filtering. Filtering by the Median and Averaging filter using fuzzy logic is then done in order to refine the grayscale image. Texture analysis by first-order statistical methods is then done on the filtered image, accompanied by an edge detection by the sobel filter using fuzzy logic. The combination of morphological operators and a segmentation, by the Watershed method, specified by thresholding, allows delimiting the different classes to be detected.

2.3.1. Methodology

Our methodological approach is an extraction method acting in several steps, the most important of which are: textural analysis and filtering. The application of morphological operators (Erosion, Dilation, Closure and Opening) allows us to highlight the forms of land occupations. Finally, the application of the segmentation by Water Divide Line (EPL) refines the result sought (the layout of roads). This complementarity allows for solving the problems of discontinuity, over-detection and omissions, which are very often encountered during the extraction of linear structures by automatic methods based on textural analysis by mathematical morphology. The images used are SAR (Synthetic Aperture Radar) images from the ERS1 satellite of the European Space Agency (ESA). In the absence of more recent images, we applied our theoretical concepts to an image of the Douala region (Cameroon), recorded on August 23, 2010. In order to reduce the computation time and highlight the relevance of the chosen methodology, we worked on a portion of the image of size 640 x 400 pixels. Only the parameters on the fly were used. The characteristics of this image are given in Table 1. The second application is made on an aerial photograph of the cross-country terrain of the city of Douala (Cameroon). The linear structures of these images were extracted from an algorithm implemented in the MATLAB software.

2.3.2. Watershed Method

The watershed [29] and [31] is the primary method for mathematical morphology segmentation. It uses the description of images in geographical terms. An image is represented by a numerical function f. It is therefore perceived as a relief if we associate the gray level of each point with an altitude. The concept of EPL is closely related to that of regional minima. Flooding is generally used, sometimes called immersion. In this concept, the image is seen as a topographic relief where the light structures are the peaks of the relief, and the dark structures correspond to its valleys. Let's imagine that this topographic surface is perforated at the locations of the minima. Let's then slowly immerse this surface in a lake (an area of water assumed to be infinite for the convenience of the experiment). The water will flow through the holes (the local minima), so the water level rises at a constant speed and is uniform in all the catchment areas.

It should be noted that the water can only enter the valleys through its minima. When the waters from two different minima meet, a dike is built to prevent them from mixing. Only the DIKES will emerge when the entire topographic surface has been submerged, delimiting the watersheds to the number of local minima of the function f. At the end of the immersion, all the dikes constitute a set of closed contours called: Watershed Lines [8]. Figure 11 below illustrates this.

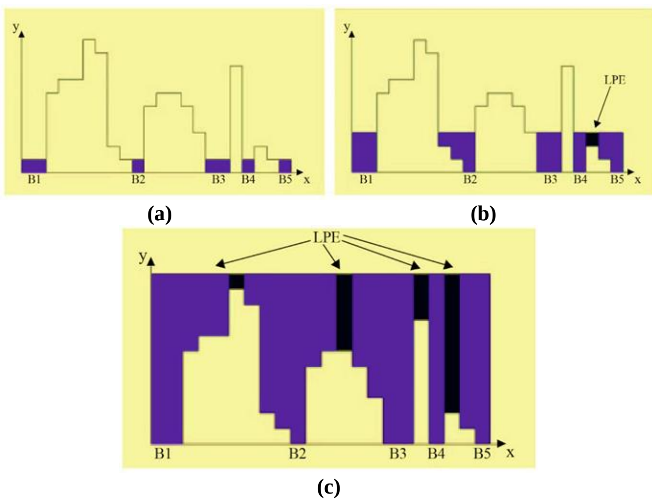


Fig. 11 EPL or LPE construction process:(a) Flooding of the relief from its minima, (b) Building a dam when two watersheds meet, (c) Final watershed

Unfortunately, since real images are usually quite noisy, the EPL algorithm is instead applied to the gradient image of the image to be segmented. The gradient is used to distinguish between homogeneous and heterogeneous areas. The more a pixel is located in a heterogeneous area, the more its gradient; therefore, its elevation will be important. Thus, the homogeneous areas of the image become regional minima in the gradient image. The EPL will coincide with the peaks of the gradient image, i.e. the contours of the original image. This results in a strong over-segmentation in Figure 3. To remedy this problem, only one gradient minima must appear on each region to be segmented. This is equivalent to flooding the topographic surface constituted by the image gradient, not from its minima but from the M markers [19]. This EPL is generally referred to as marker-controlled EPL. The principle of homotopy modification of the gradient is to impose the markers of the regions to be segmented as minima of the gradient, removing all other unwanted minima. This gradient is then flooded with all markers. One and only one EPL is then present between each marker, and it tends to lie on the contours of the objects to be segmented, which have already been pre-detected by the gradient.

To obtain the gradient image, a morphological gradient [2], [1], and [22] is computed on each spectral band of the image. The definition of the morphological gradient is given by the following relationship (10):

$$G(A) = \boldsymbol{\delta}B(A) - \boldsymbol{\varepsilon}B(A) \tag{10}$$

Where δB and εB are the Dilation and Erosion by a structuring element B (of 3 × 3 square shape), and A is the image. The final elevation image is obtained by combining the elevations of the different spectral bands using the Euclidean norm. If the gradient of the i th band is denoted Gi and NB the number of bands, the final gradient is defined by the following relation (11):

$$G = \sqrt{\sum_{i=0}^{N_B} {G_i}^2} \tag{11}$$

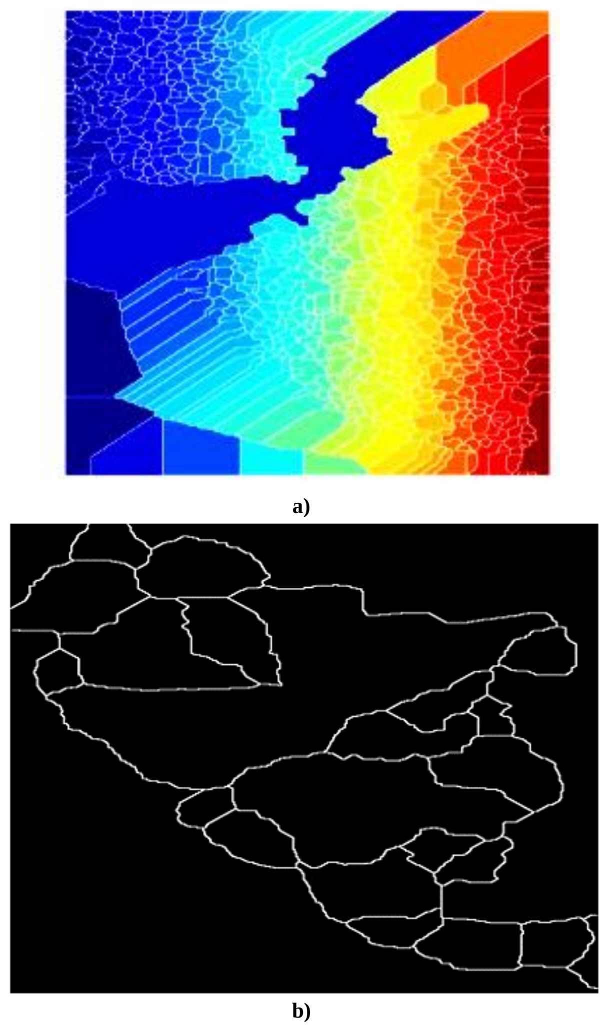


Fig. 12 (a) EPL image of the original image of the city of Douala, 640 x 400 (b) road network of the original image of the city of Douala, 640 x 400

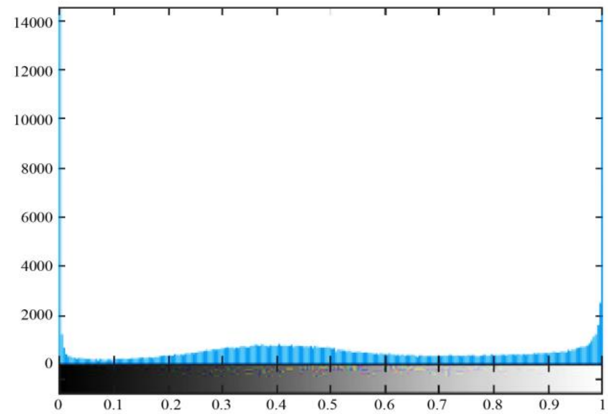
3. Results and Discussion

Results

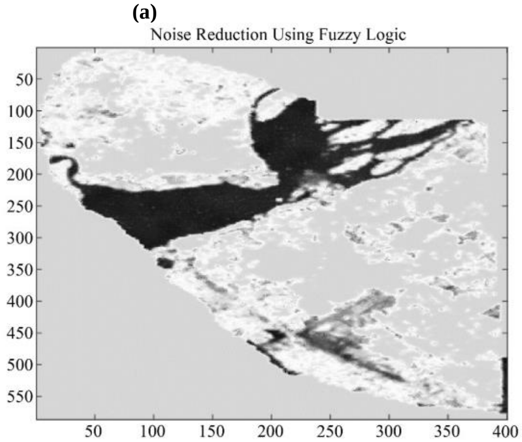
The processing applies to both aerial photographs and radar images. In the first case, it is important to convert the image into a gray level image to apply the filtering using fuzzy logic. Filtering by the Median filter and the averaging filter using the fuzzy logic is then done to refine the grayscale image. Texture analysis by first-order statistical methods is then performed on the filtered image, accompanied by an edge detection by the sobel filter using fuzzy logic. The combination of mathematical morphological operators and a segmentation, by the Watershed method, specified by thresholding, allows delimiting the different classes to be detected.

3.1. Detection of Road Networks

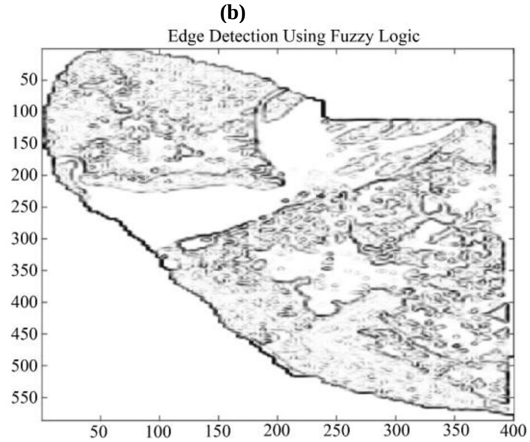
(a)



(b)

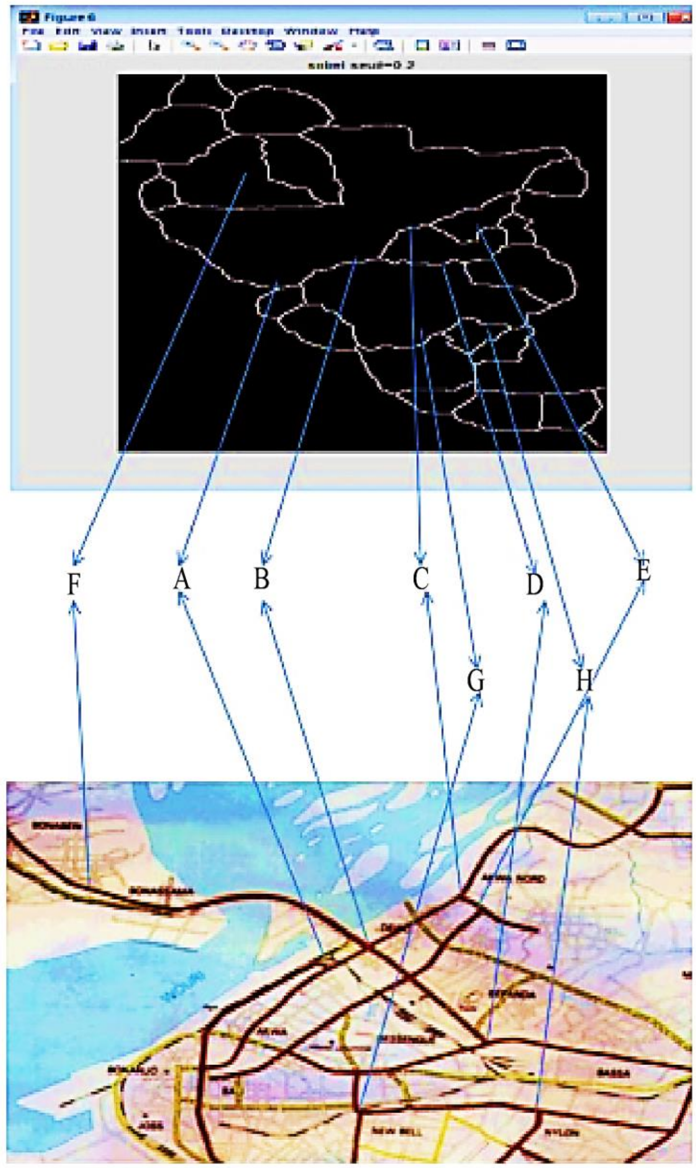


(c)



(d)

(e)

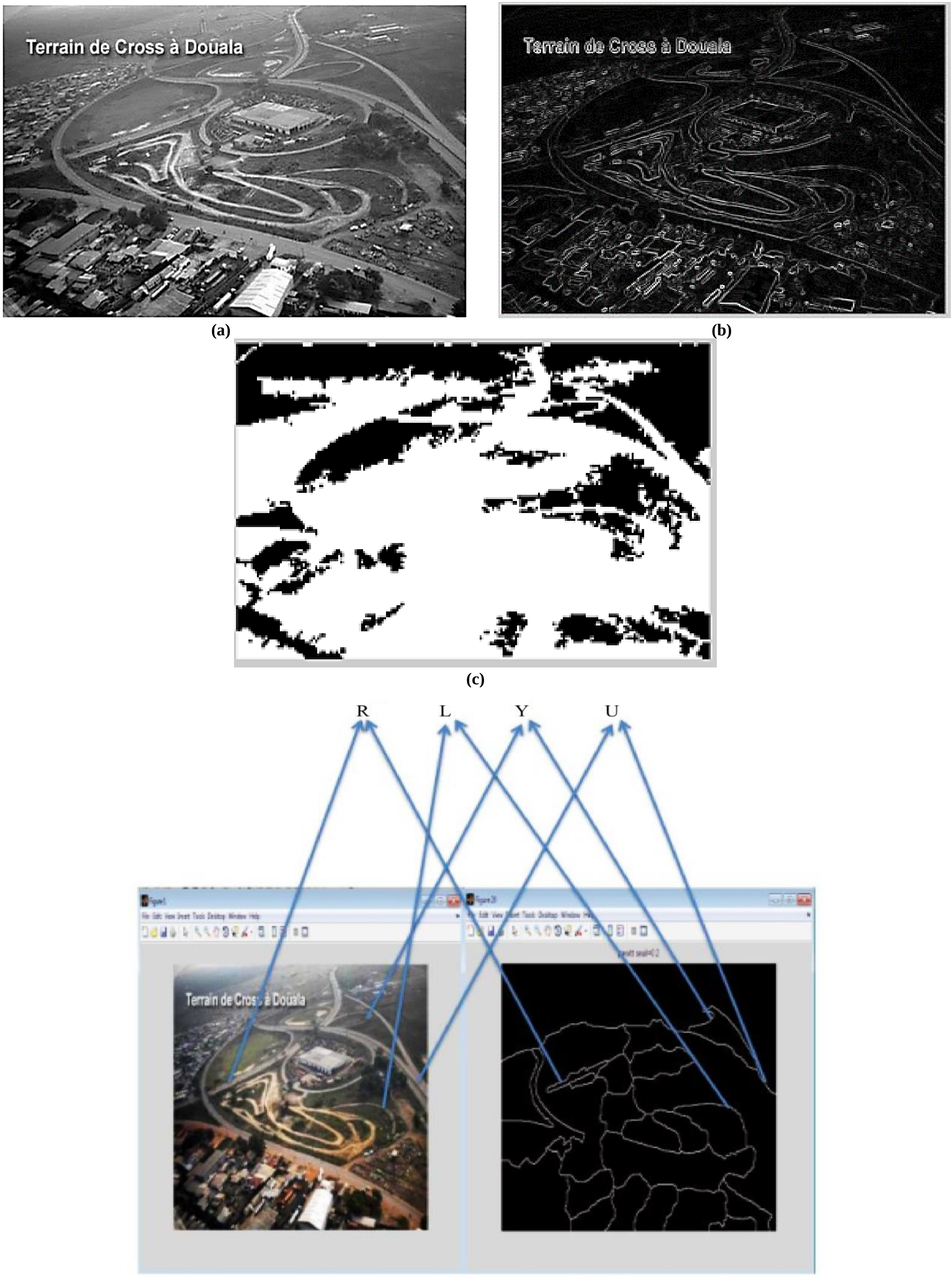


(f)

Fig. 13 (a) grayscale image, (b) histogram, (c) median and averaging filter using fuzzy logic, (d) sobel filter using fuzzy logic, (e) opening-closing by thresholded reconstruction, (f) road network (F, B, C, E, G)

- **F: Bonassama Street**
- **B: Deido traffic circle**
- **C: Akwa-North entrance junction**
- **E: Bonabassem intersection**
- **G: Unity boulevard**

A comparison with the road network map of the city of Douala (Figure 13 f)) shows that not all roads were detected. This is due, on the one hand, to the fact that there are roads that are less than the width of a pixel. On the other hand, some roads are hidden by the roofs of houses, which are usually made of metal, and therefore have a high radiometric level. It can be noted that the application of the EPL has highlighted not only the road network but also all the linear structures of the image. It can be seen that the edges of the image that are not roads but have been delineated by the sobel mask using mathematical logic, as shown in Figure 14b) stand out on the image of linear structures.



(a) (b)

(c)

(d)

Fig. 14 (a) gray level image, (b) sobel filter using fuzzy logic, (c) opening-closing by thresholded reconstruction, (d) road network

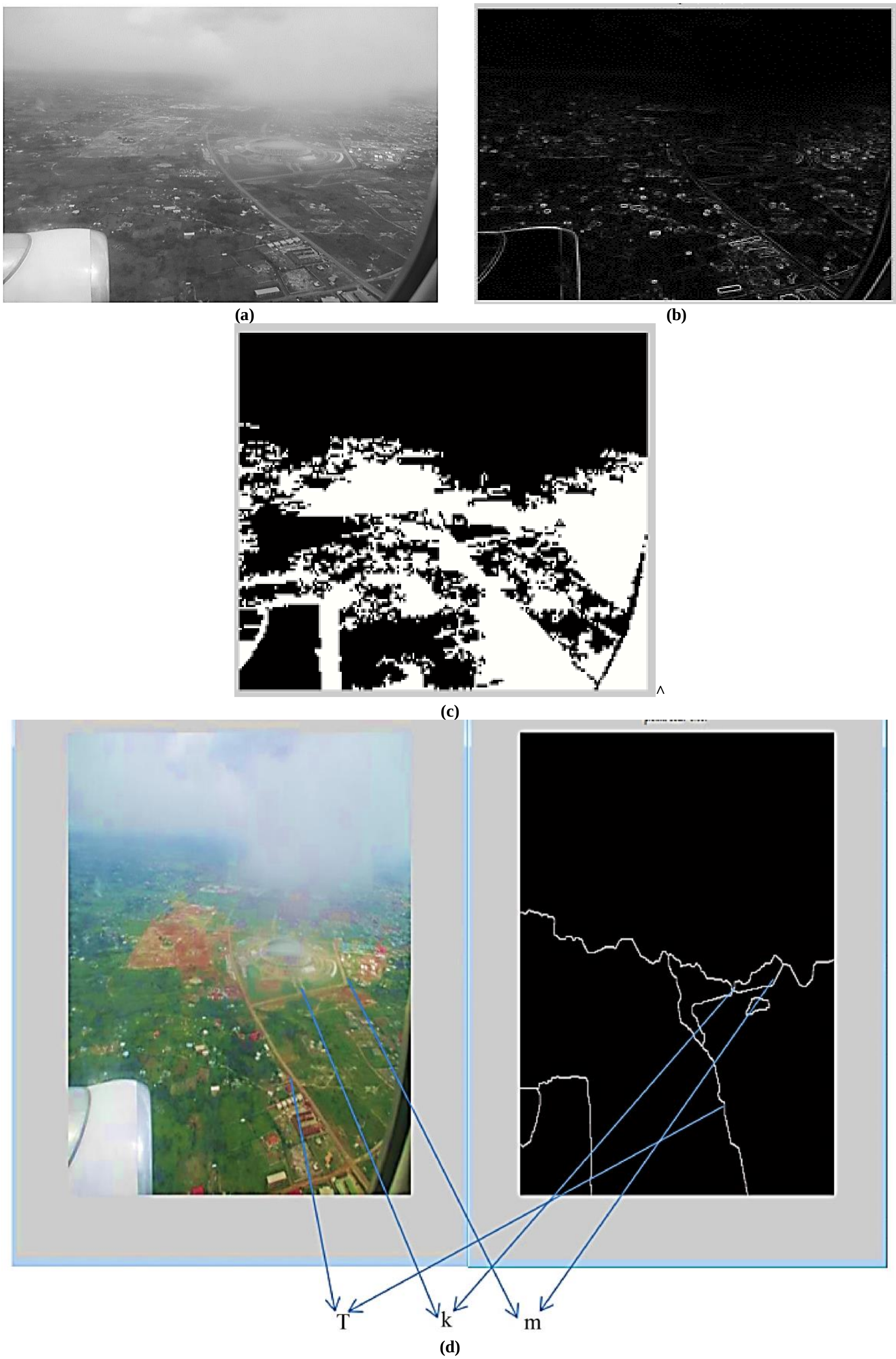
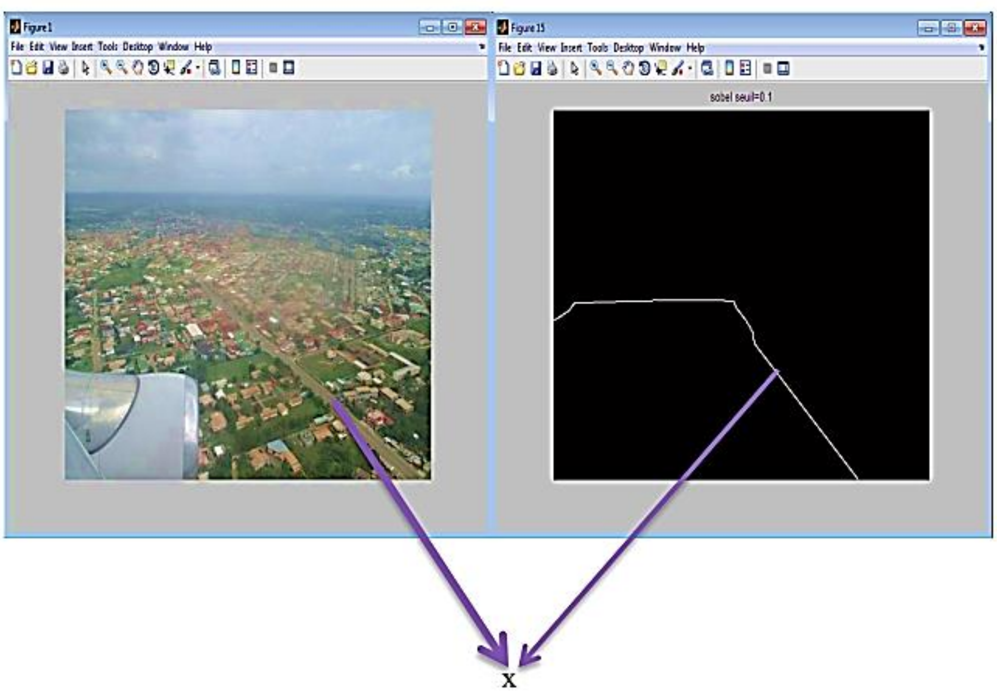


Fig. 15 (a) grayscale image, (b) sobel filter using fuzzy logic, (c) opening-closing by thresholded reconstruction, (d) road network.

(a)

(b)

(c)

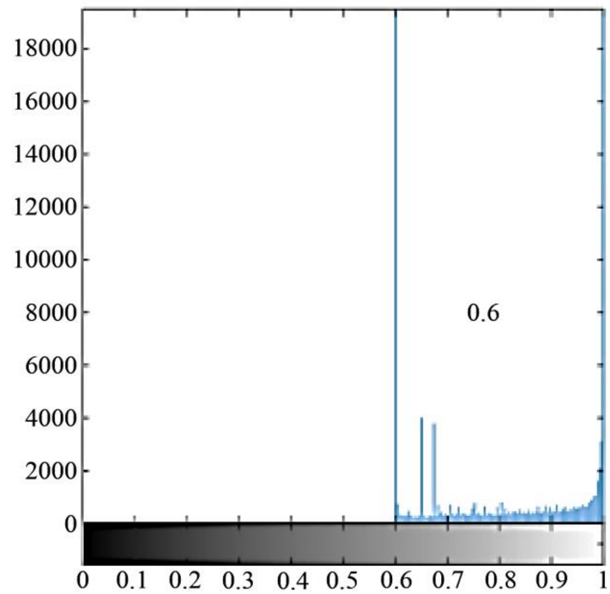


(d)

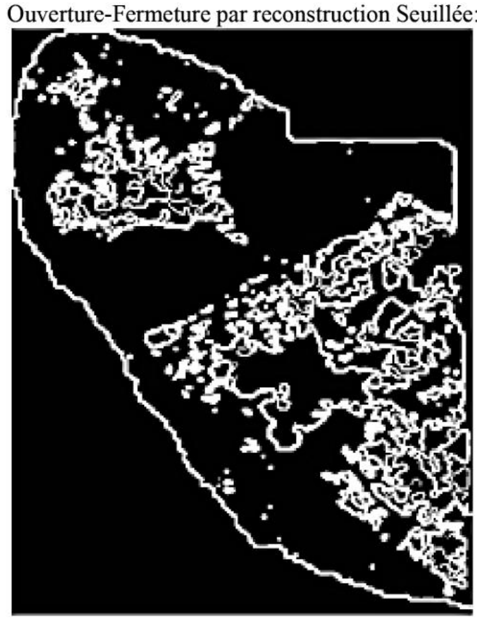
Fig. 16 (a) grayscale image, (b) sobel filter using fuzzy logic, (c) opening-closing by thresholded reconstruction, (d) road network

3.2. Detection of Habitable Areas and Wetlands

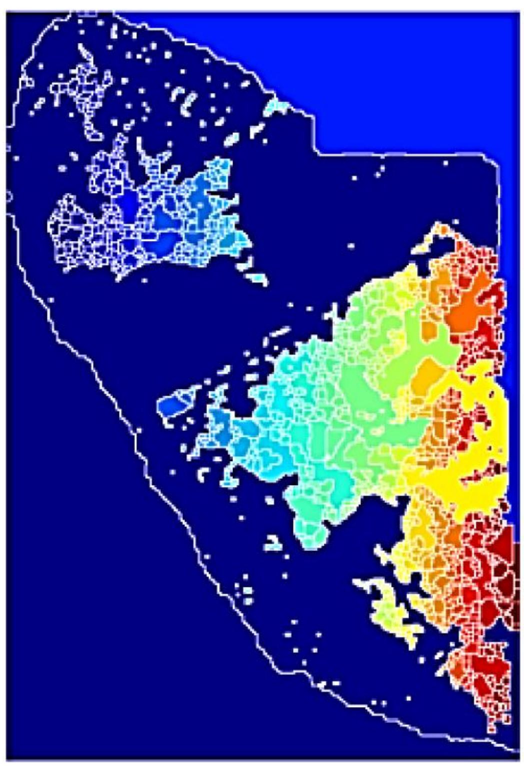
The same algorithm is used but with a few modifications. The detection of agglomerations (living area) is characterized by the gray level of the sheet, which is very high. We allow to take into account this in the histogram.



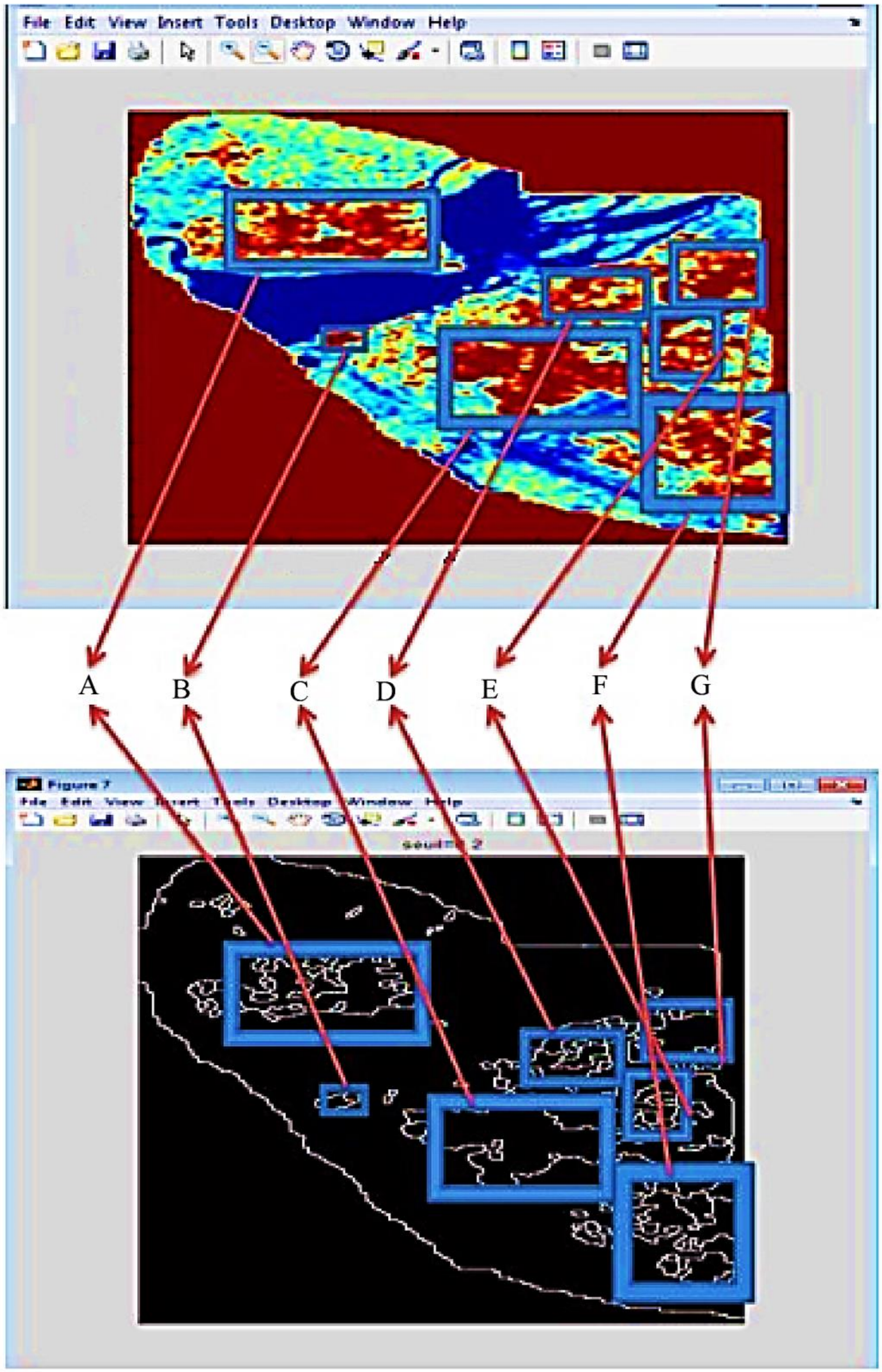
a)



b)



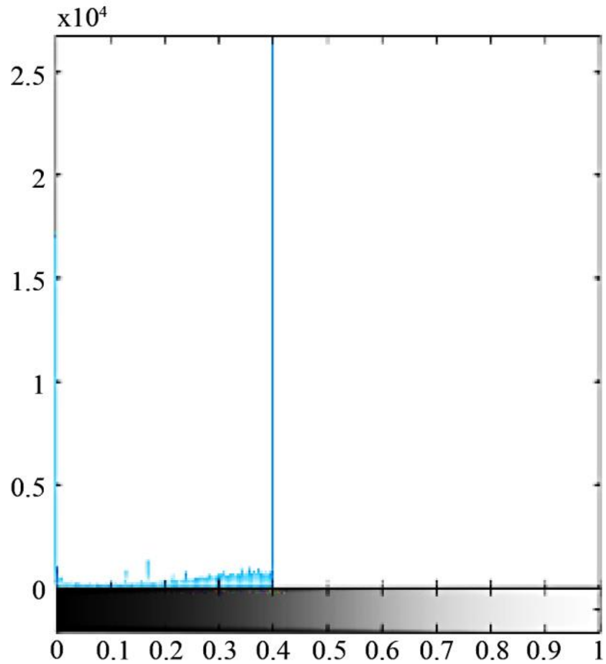
c)



d)

Fig. 17 (a) histogram, (b) opening-closing by thresholded reconstruction, (c) LPE, d) road network

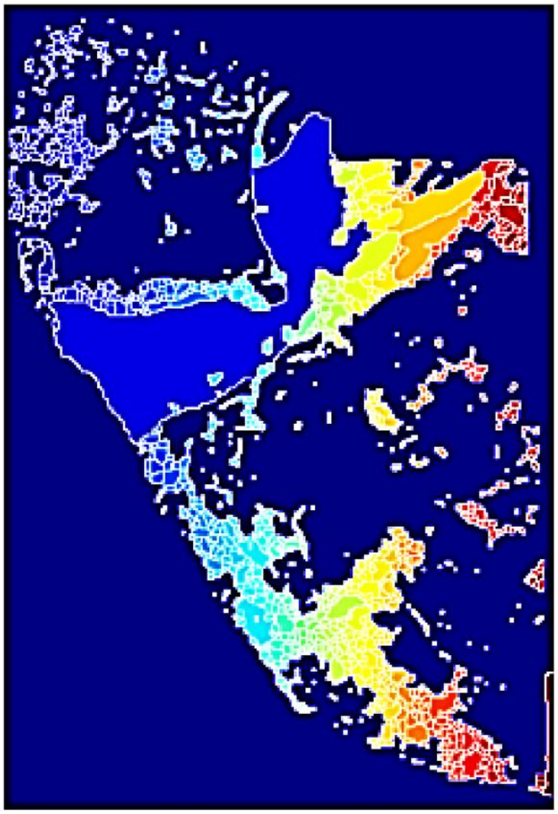
As for detecting swampy areas characterized by a very low level of water gray.


x10^4
2.5
2
1.5
1
0.5
0
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

(a)


Ouverture-Fermeture par reconstruction Seuillée:

(b)



(c)

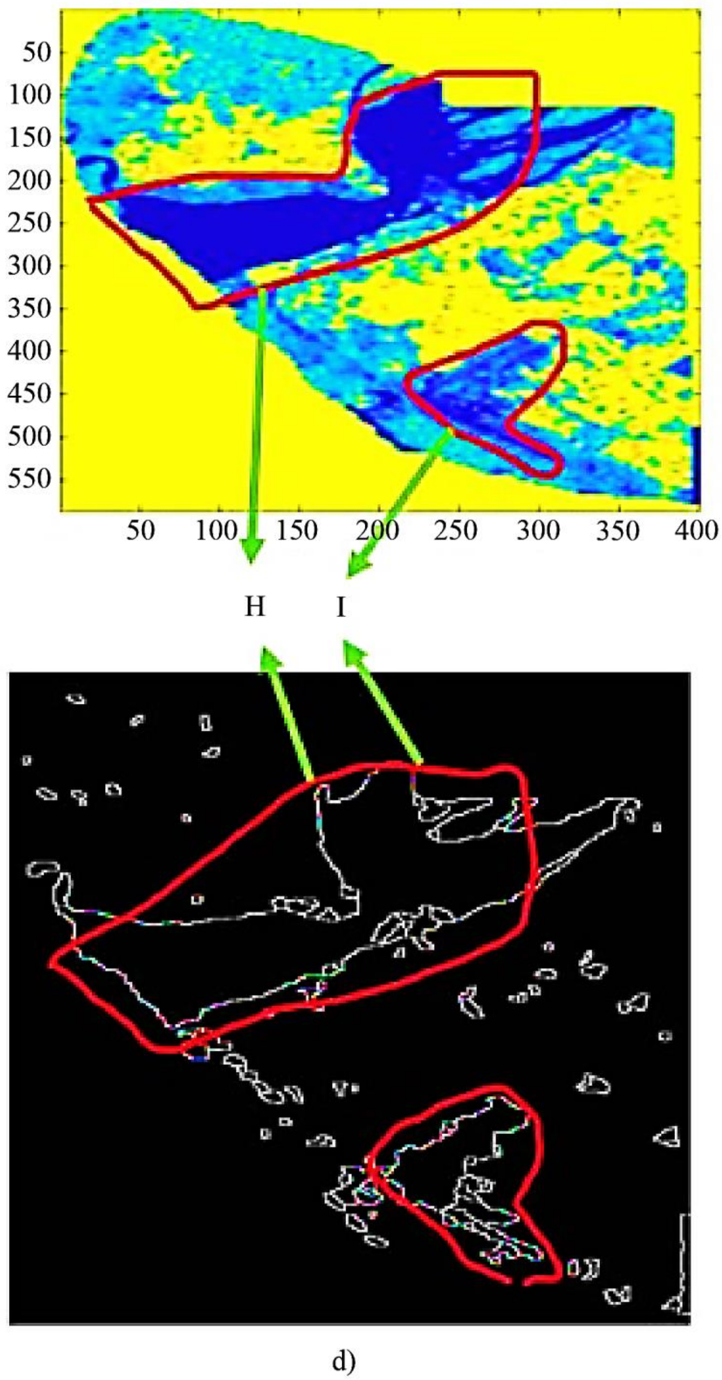


Fig. 18 (a) Histogram, (b) Opening-closing by thresholded reconstruction, (c) LPE, (d) Road network

3.3. Discussion

The families of local and global extraction approaches cover most of the linear structure detection approaches. These methods treat linear structures as invariant objects independently of the observation scale. But in reality, the notion of scale is one of the most important notions in signal processing in general and image processing in particular. The image in Figure 14 represents the cross-country track in Douala (Cameroon). It is a photograph that gives an aerial view of this area. The application of the linear structure detection algorithm allows us to convert it first into a gray level image (figure 14a). In order to avoid over-segmentation or under-segmentation, the filtering by the Median filter is done.

A simple smoothing of the image allows for reducing the noise) because the effect of the aberrant pixels is reduced thanks to the averaging with its neighboring pixels. However, the smoothing allows to obtain a reduction of sharpness in the image. The filtering by the Median filter is particularly suitable when the noise is made up of isolated points or fine lines. However, it is only applicable to gray level images, unlike smoothing.) Applying the fuzzy sobel filter allows for calculating the gradient of the intensity of each pixel. This indicates the direction of greatest change, from light to dark, and the rate of change in that direction. All edges of the objects in the study area can then be seen. Next, an evaluation of the edge detection by the watershed is performed. It is applied to the gradient image of the image to be segmented. Thus, the homogeneous areas of the image become regional minima in the gradient image. The EPL will coincide with the peaks of the gradient image, i.e. the contours of the original image.

In order to avoid over-segmentation, only one gradient minima should appear on each region to be segmented. This is equivalent to flooding the topographic surface constituted by the image gradient, not from its minima but from the markers. The application of the morphological operators Opening and Closing allows the elimination of the peninsulas and to detection of the regional maxima in the image. The regional maxima are then superimposed on the original image, and the same operations of Closing and Opening are repeated. This iteration detects all regions in the image, which are separated using EPL. Thresholded reconstruction opening-Closing eliminates unnecessary features while preserving the contours. The results of the linear structures of the study area obtained in Figures 13f, 14d, 15d and 16d are characteristic of the different thresholds applied.

A comparison with the road network map of the city of Douala (Figure 13f) shows that not all roads were detected. This is due, on the one hand, to the fact that there are roads that are less than the width of a pixel. On the other hand, some roads are hidden by the roofs of houses, which are generally made of metal, and therefore have a high radiometric level.

The algorithm used for the detection of the road network will now be applied to a SAR image of the Douala region (Cameroon). The detection of the agglomeration (inhabited area and maricagious area) will be done by taking into account the intensity of the gray levels after different filtering. The original image is given in Figures 17 and 18.

4. Conclusion

In this article, we have presented a method for detecting linear structures using fuzzy logic on filtering and then combining it with the Watershed algorithm. If it is true that this algorithm allows to bring out the linear structures without discontinuity, it appears that the detection of the edges of the image is a limit of this approach. We believe that the integration of classification using machine learning or deep learning could allow us to remedy this problem. Work is continuing in this perspective.

Conflicts of Interest

According to the authors, there are no conflicts of interest with the publication of this paper. Additionally, the authors have adhered strictly to all ethical standards, which include plagiarism, informed consent, misconduct, data fabrication and falsification, double publishing and submission, and redundancy.

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