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Linear features' detection in SAR images using Fuzzy Edge Detector (FED)

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Summary: Synthetic Aperture Radar (SAR) images exploitation is of great importance in remote sensing and Earth observation techniques, as well as in military surveillance and reconnaissance missions. One of the most important image-processing techniques is image segmentation. Segmentation subdivides an image into its constituent parts or objects. Edge detection is often an important first stage in many types of image segmentation. It can be used to simplify complex imagery in preparation for subsequent feature identification. Detection of linear structures (road network, airfields e.t.c.) is of great interest in a potential automated recognition system.

A new approach for edge detection in SAR images, which overcomes the necessity of choosing arbitrary thresholds is described in this paper. The Fuzzy Edge Detector (FED) not only discriminates between edge pixels and no-edge pixels, but assigns each image point a degree of being an edge point. This intermediate fuzzy output enables a very flexible post-processing and thus an efficient edge detection processing chain (e.g. non-maximum suppression and edge linking). Additionally, the edge direction information resulting from FED can be used for linear features' identification and extraction. The performance of the proposed edge detector on airborne and spaceborne SAR images that include linear features is presented.

1. INTRODUCTION

Edge detection is based on the concept that an edge is the boundary between two regions with relatively distinct gray level or textural properties and therefore the idea underlying most of the edge detection techniques is the computation of a local derivative operator. Traditionally, edge detection is regarded as a convolution operation. Usually, the edge detectors are divided into two groups based on the support of the convolution kernel. When the kernel has finite support, mask-based edge detectors are obtained, while when the kernel has infinite support, a different class of models (recursively implemented filters) arises. More recently, there have been studies of edge detection with learning models that mimic one style or another. This class includes both artificial neural networks and fuzzy reasoning systems [1].

In the case of SAR images, the speckle phenomenon has to be taken into account. Constant false alarm rate (CFAR) edge detectors deal with speckle noise. A characteristic example of this category of edge detectors is the normalized ratio (NR) to be applied on detected (intensity) data, either in its single-edge version, or the multiedge version [2][3]. More recently, edge detection in complex SAR images with correlated speckle is presented [4].

Features' extraction usually follows the edge detection process and makes use of the contours resulting from edge detection. The methods for identifying linear features can be roughly divided into two major categories: contour-tracing methods and structure-oriented hierarchical methods [5][6][7]. Contour-tracing methods try to directly exploit the edge detection result, having the advantage of resolution (the edge detection resolution), but being limited by the capabilities of the edge detector (e.g. its CFAR) in its performance. Structure-oriented methods use as starting conditions the results of the edge detection and build up structure hierarchies by composing complex structures from less complex structures. For this reason, a knowledge base is used and approximations concerning the comparison of the object form to its pattern are made. Within the framework of this paper the contour-tracing method was used, mostly due to the fact that FED [8] overcomes the necessity of choosing some arbitrary thresholds associated with false alarm rates (FAR). It has to be noted that the goal is to achieve good visual interpretation fulfilling the screening task mentioned in [6].

2. FUZZY EDGE DETECTOR (FED)

FED evaluates pixel by pixel the degree of being an edge pixel and the edge direction of this pixel. Fuzzy dissimilarity is calculated for two symmetrical neighborhoods moving in the opposite sides of each pixel to be resolved as an edge pixel. The bigger the dissimilarity, the higher the estimated degree of being an edge pixel. The dissimilarity measure is based on the difference (ratio) between certain features (statistical or geometrical) within the neighborhoods. FED's output denotes the degree of a certain pixel to be an edge pixel

and the possibility of the according edge to be a vertical, horizontal or diagonal edge.

FED is based on the general edge detection scheme of figure 1 but in all stages incorporates the fuzzy information output, which the edge-enhancing stage produces.

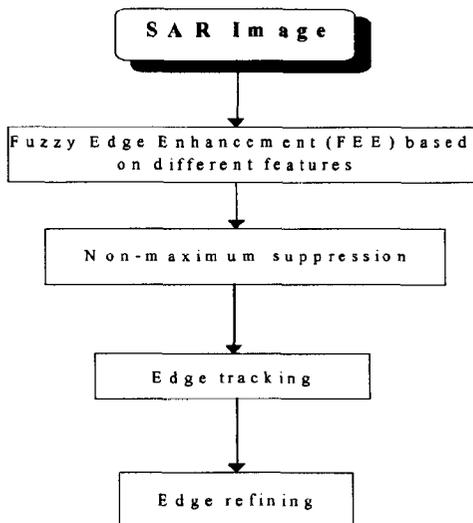


Figure 1: FED's edge detection scheme.

2.1 EDGE ENHANCEMENT

The concept of the edge enhancement stage is based on the movement of two symmetrical neighborhoods N_1 and N_2 in the opposite sides of each image pixel $p(x,y)$ to be resolved as an edge pixel following a scanning-window central-edge (SWCE) configuration [4]. The whole operation - for symmetrical 3×3 windows moving in the opposite sides of the pixel to be resolved as an edge pixel - is described in figure 2.

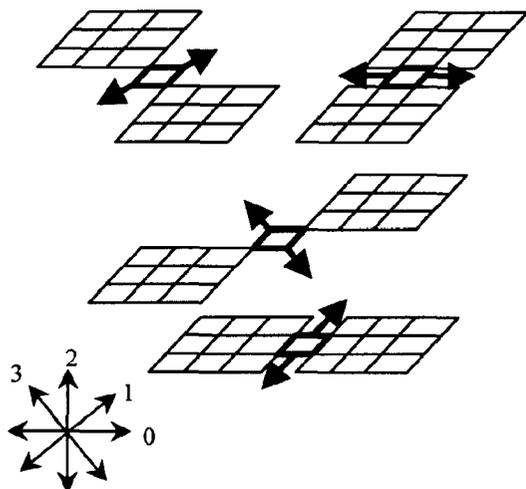


Figure 2: The four possible alignments of the two symmetrical windows moving around the pixel to be resolved as an edge pixel and direction index.

During this movement, the dissimilarity between the extracted features is assessed by fuzzy dissimilarity measures. Important parameters affecting the output of the fuzzy edge detector are:

- different fuzzy dissimilarity measures
- the extracted features in the neighborhoods
- the size and form of the neighborhoods
- the distance between the neighborhoods and the pixel to be resolved.

Finally, the edge properties (the edge strength and the edge direction) and the presence of speckle noise influence the output.

This process results in a description for every pixel, which includes two features:

- A four-dimensional feature vector $\vec{\mu} = [\mu_1 \mu_2 \mu_3 \mu_4]$. The components give the pixel's degree to belong to an edge with certain orientation according to figure 2.
- The degree of the certain pixel $p(x,y)$ being an edge pixel $e(x,y)$ - it is, in fact, the maximum component of the four-dimensional feature vector $e = \max(\vec{\mu})$.

The first step in edge enhancement is to extract the features out of the two symmetrical neighborhoods and then estimate the dissimilarity between them.

2.1.1 Fuzzy Dissimilarity Measures (FDM)

Fuzzy similarity measures estimate the similarity between two objects. We define a fuzzy dissimilarity measure D , by taking the complement of a fuzzy similarity measure S , where α and β are the feature vectors to be compared [9]:

$$D(\alpha, \beta) = 1 - S(\alpha, \beta) \quad (1)$$

In FED's case, the fuzzy dissimilarity measures project the dissimilarity between features to the interval $[0,1]$. This gives for each pixel a degree of being an edge pixel in the certain direction.

We compared the following four fuzzy dissimilarity measures:

$$D_1^k(\alpha, \beta) = 1 - \left[1 - \frac{\sum_{i=1}^n |\alpha_i - \beta_i|}{n \cdot 255} \right]^k, \text{ where } 1 \leq k \leq \infty \quad (2)$$

$$D_2(\alpha, \beta) = 1 - \frac{\sum_{i=1}^n (\alpha_i \wedge \beta_i)}{\sum_{i=1}^n (\alpha_i \vee \beta_i)} \quad (3)$$

$$D_3(\alpha, \beta) = \frac{\sum_{i=1}^n |\alpha_i - \beta_i|}{\sum_{i=1}^n (\alpha_i + \beta_i)} \quad (4)$$

$$D_4(\alpha, \beta) = 1 - \frac{\sum_{i=1}^n \alpha_i \wedge \sum_{i=1}^n \beta_i}{\sum_{i=1}^n \alpha_i \vee \sum_{i=1}^n \beta_i} \quad (5)$$

where $\vec{\alpha} = [\alpha_1 \dots \alpha_n]$ and $\vec{\beta} = [\beta_1 \dots \beta_n]$ are feature vectors to be compared.

Dissimilarity measure D_1^k incorporates a scaling factor k , which can control the contrast and therefore is capable of “adjusting” to a certain SAR image.

Dissimilarity measure D_2 together with dissimilarity measure D_4 constitute two promising edge detection tools for SAR images, as they incorporate despeckling properties (using the ratio between the two opposite regions it is possible to deal with multiplicative nature noise) [2].

2.1.2 Feature extraction

Up to now, the basic fuzzy tools for edge detection have been outlined. The major factor, though, determining the performance of a potential edge detector are the features to be extracted from N_1 and N_2 and used inside the dissimilarity measures. For this purpose some first features have been investigated with respect to their edge detection properties as well as taking under consideration some of the SAR image properties (presence of speckle noise). Those features are:

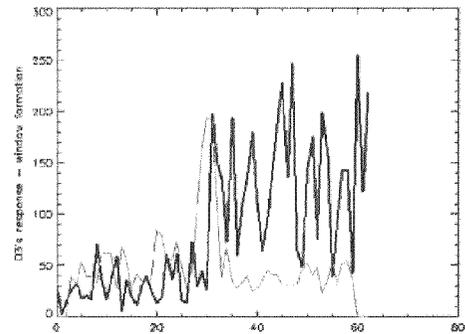
- *The M-dimensional vector of the sorted pixels within the neighborhoods:* the pixels are sorted from maximum to minimum.
- *The mean value of the neighborhoods:* this feature has good performance in the presence of speckle, due to the smoothing properties.
- *The median of the neighborhoods:* this feature has good performance in the presence of impulse noise [10].
- *The minimum and the maximum of the neighborhoods:* feature sensitive to “salt and pepper” noise.

In addition to this, texture measures could be used as features but this has not yet been verified.

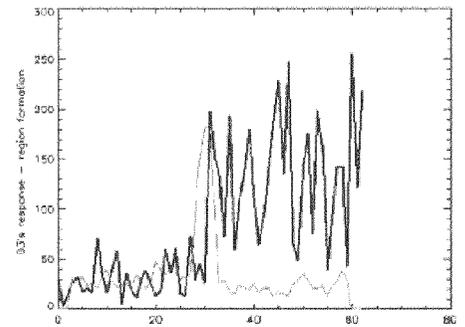
2.1.3 Form, size and distance of the neighborhood

One major concern is the symmetrical neighborhoods within the pixel’s area of investigation. The *form* of neighborhoods N_1 and N_2 on each side of the pixel is of

great importance for the capabilities of a potential fuzzy edge detector, concerning the edge orientation description. The neighborhood of the pixel can be divided e.g. a) into two contiguous regions by cutting out a line along the desired direction, or b) two windows in the opposite sides of the pixel (figure 2). Those two forms of neighborhood were particularly investigated within the framework of this paper. For understanding better the impact of these parameters, a speckled step-edge has been simulated [11] and then FEE with the two different forms has been applied. Figure 3 outlines the results.



(a)



(b)

Figure 3: FED’s response to a speckled step edge using 7×7 area of investigation, sorted pixels as feature and dissimilarity measure D_3 , for (a) region and (b) window formation.

The responses of figure 3 reveal a bigger sensitivity of edge detection to speckle noise if window form is applied. This is due to the smaller number of pixels used inside the symmetric neighborhoods for feature extraction.

The *neighbourhood size* is also a parameter under investigation, taking under consideration the nature of SAR images (presence of speckle, ambiguities, etc). Smaller neighbourhoods produce sharper responses to an edge (better resolution) with bigger sensitivity to the presence of noise, while bigger neighbourhoods have better immunity to noise, sacrificing resolution [2]. Figure 4 summarises the results.

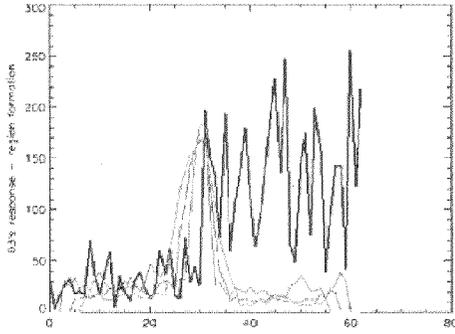
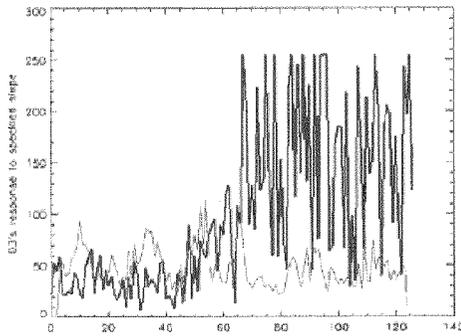
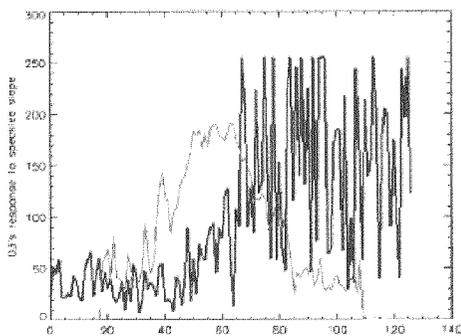


Figure 4: FED's response to a speckled step edge using, sorted pixels as feature and dissimilarity measure D_3 for different region sizes (from a 7×7 area size having light blue color, up to a 15×15 area size having orange color).

Finally, the *distance* between the neighbourhood and the pixel to be resolved has to be considered. The bigger the distance, the broader the response of the edge detector becomes. One possible advantage of enlarging the distance is the better resolution of a slope edge. In this case, the distance may overcome the transition area and resolve better the edge, having of course broader response. Figure 5 summarises the results for a speckled slope edge.



(a)



(b)

Figure 5: FED's response to a speckled slope step edge (30 pixels transition area) using 7×7 area of investigation, region form, sorted pixels as feature and dissimilarity measure D_3 having (a) 0 and (b) 15 pixels distance between the pixel to be resolved and the symmetrical neighborhoods.

In figure 5(a) FED's response presents no edge enhancement of the slope edge or even the transition area for 0-pixel distance, while introducing the 15-pixels distance in figure 5(b) results in big edge enhancement of the transition area (slope edge). It also gives maximum response in the center of the transition area located in the 62nd line of the artificial edge. Nevertheless, equally big responses are produced in the vicinity of the maximum response, making the task of the non-maximum suppression stage harder.

2.2 NON-MAXIMUM SUPPRESSION

The maximum of each vector $\vec{\mu}$ is assigned to the edge map. As the maximum lies in the interval $[0,1]$, the edge map constitutes a 3D-surface.

Non-maximum suppression keeps for each edge only those pixels, which have maximum degree of being an edge. We use the fuzzy information resulting from FED to erase all pixels with less edge degree to the considered edge. The whole process is based on Canny's non-maximum suppression technique [12].

First, the edge direction has to be estimated. Instead of using gradient interpolation, the two most possible edge directions are used to approximate the actual edge direction. The estimated edge direction splits the 8-pixel neighborhood of $p(x,y)$ into two halves. In each half the edge degrees of the two closest pixels to the normal of the edge direction define together with $p(x,y)$ a plane. These two planes (each in every side of the edge direction) locally approximate the 3-D surface of the edge map. The value e of the center pixel is one common point of both planes. If it is the maximum value of all the five considered pixels, it is regarded as a local maximum point and $p(x,y)$ is kept as an edge pixel $e(x,y)$.

The output of this operation is, in fact, an extraction of FED's maximum response to an edge, located in the actual position of the edge. The whole procedure is described in figure 6.

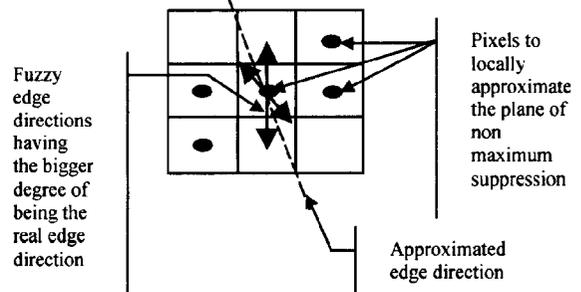


Figure 6: Non-maximum suppression scheme.

2.3 EDGE TRACING

After the non-maximum suppression stage, the edge map still presents some discontinuities along an edge line. An edge-tracing algorithm is applied to get continuous edge lines. We propose an edge-tracing scheme, which is divided into two major functions:

- *The endpoint searching function:* it evaluates if a certain $e(x,y)$ is actually a nominal endpoint. The tracing process starts from these points. This function incorporates also a refining property as edge pixels, representing forbidden profiles (e.g. junction points, thick edges), are erased. Figure 7 presents usual examples of valid and invalid endpoint pixels.

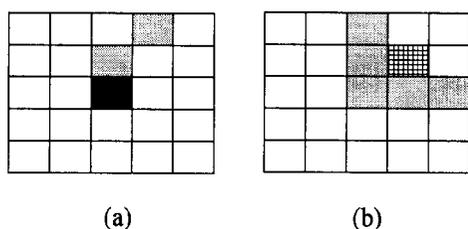


Figure 7: (a) valid endpoint pixel to be used by the edge linking function. (b) Invalid endpoint pixel to be erased from the edge map e .

- *The tracing function:* within the 8-pixel neighborhood of each endpoint, possible successors are selected taking into account the edge direction (and the pixels excluded due to this direction) and the fuzzy directions of the endpoint. The successor is selected by calculating the similarity of the feature vectors between the endpoint and the possible successors. To this end, a similarity measure S is applied. We used in our experiment the similarity measure $S_2 = 1 - D_2$. The whole concept is explained in figure 8.

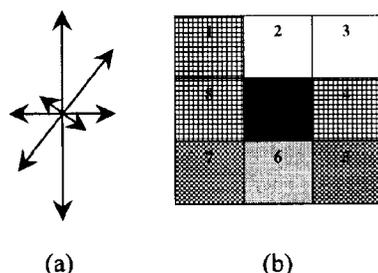


Figure 8: Successor pixels resolved with the use of the fuzzy information (figure 8(a)). The edge consists of pixels 4 and the center pixel and therefore pixels 5 and 7 are excluded due to the direction of the edge. Pixels 1,4,8 are excluded due to the weak edge direction degrees of the direction index shown in figure 8(a). Pixels 2 and 3 are the possible successors of which the one with the bigger similarity of its feature vector to the endpoint feature vector is chosen.

The whole tracing process is based in the fuzzy output and is applied iteratively. That means that, once the endpoints have been chosen, they are processed according to their degree of being an edge. In this way, first the pixels, having the higher degree of being edge pixels, are traced in order to be linked and then the rest in successive groups.

2.4 EDGE REFINING

After the edge-tracing stage, a final refining stage is iteratively applied in order to erase edge pixels, which violate rules of one-pixel-thick edge line, and short line segments, which are not connected to any other edge segment and also have low degree of being edges.

The aforementioned refining processes can be realized through morphological operations such as thinning and pruning [10], having as a parameter for pruning, the length of the sorted segments to be eliminated.

3. EXTRACTION OF LINEAR FEATURES

Extracting linear features from SAR images can serve two tasks as far as reconnaissance is concerned. These are the screening process and the thematic data exploitation [5]. A complete detection of all objects of interest is the objective of the screening process and therefore FED's fuzzy output can be directly used without thresholding. Instead, length and direction filtering processes help to exclude spurious responses and structures produced by the presence of speckle noise. The level, up to which these unwanted structures are eliminated, depends on the resolution of the SAR image itself, the resolution of the edge detector and the expected length of the structures to be extracted.

In order to extract linear features out of FED's output, the fuzzy information concerning the edge direction can be used. For this reason, the information resulting from FED was decomposed in:

- The fuzzy edges (three dimensional array including for each pixel the four feature-vector resulting from FEE, cf. 2.1)
- The edge map e (indicating the maximum degree of dissimilarity for each pixel).
- The direction array (indicating the direction along which the maximum degree of the certain pixel has occurred according to figure 2).
- The non-maximum suppression (NMS) stage output.
- FED's final output (refined edge-tracing process output).

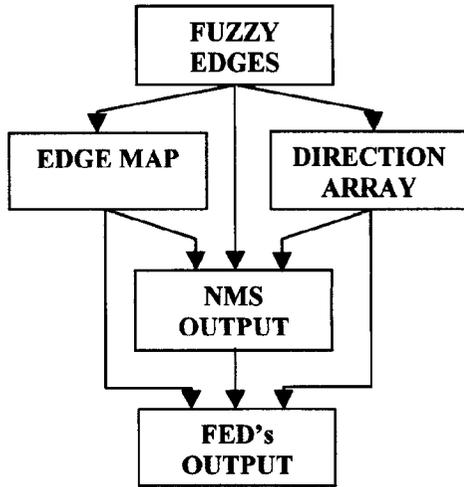


Figure 9: Interaction between the different forms of information.

Figure 9 shows the interaction between these five different forms of information, while figure 10 indicates the hierarchy according to information content between the forms. It has to be noted that the edge map and the direction array are two forms of the same information with the edge map giving the edge strength and the direction array giving the edge direction.

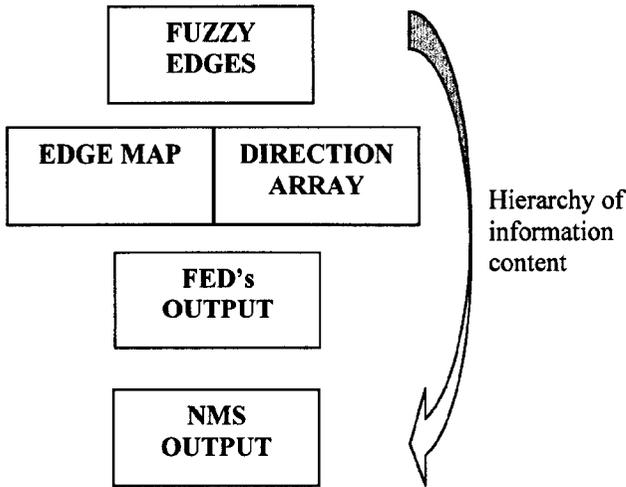


Figure 10: Hierarchy of information content among the different forms of information resulting from FED.

Once these forms of data have been produced, the procedure of figure 11 is proposed. A direction and length filtering process is applied in FED's non-maximum suppression output. This process has as parameters the length of the linear segments to be extracted, the direction to be investigated each time and the edge strength above which edge segments considered important will be extracted. For this reason, the direction array is used, in order to exclude pixels having other directions.

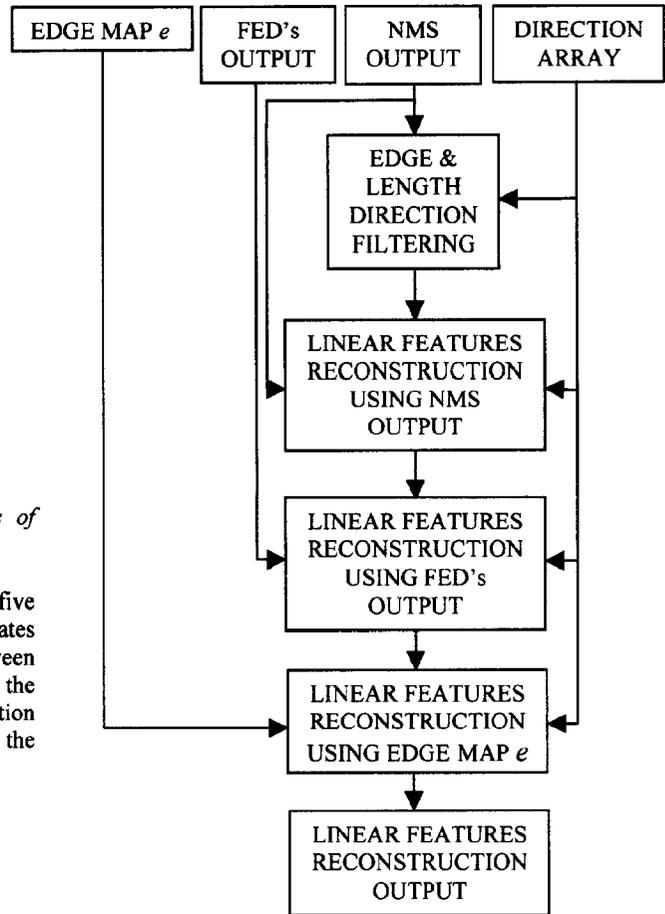


Figure 11: The proposed linear features extraction scheme.

The linear segments resulting from the direction and length filtering are considered the "seed segments" from which the linear features reconstruction process begins. The process uses as inputs the seed segments, the direction array and sequentially the NMS output, FED's final output and finally the edge map e . The used parameters are once again the edge direction and the edge strength.

The whole procedure is based on the concept that once linear seed segments are identified, linear features' reconstruction should be able to identify bigger linear segments even if they don't possess the same direction properties locally. Therefore, the reconstruction takes place sequentially in forms of increasing and more complex information according to figure 10. In this way, a hierarchical sequential reconstruction takes place but instead of the symbolic level this happens in the actual contour level. Because of this, the initial edge detection resolution is kept, but on the other hand, deviations and misconstructions due to speckle and low resolution of the image itself can not be avoided.

3.1 EDGE DIRECTION & LENGTH FILTERING

The edge direction and length filtering is applied on FED's non-maximum suppression output and additionally uses the direction array. The parameters affecting its performance are the direction and the length of the edge segments to be extracted and additionally, the edge strength of the segments to be extracted.

The *directions* used are those resulting from the direction array and correspond to the four possible edge directions, FED is incorporating to resolve edges (figure 2). The direction filtering is done sequentially along these four directions. Nominal points are considered the points that fulfil the requirement of being edge points (edge map entry) and having the certain direction (direction array entry).

The *length* of the edge segments is considered as a degree of freedom. The selected edge segments define the "seed segments" from which the linear features reconstruction will begin. The demand for small length segments will produce many seed segments and additionally, also non-linear features will be extracted, as they can be considered linear locally. This fact can be a potential advantage in the case of structures changing direction slowly, such as rivers. On the other hand, this big amount of "seed segments" will help the reconstruction process. Long length segments, are difficult to be extracted, mostly because of the random structures produced due to speckle. On the other hand, only strongly linear features will be selected and the reconstruction process will be more reliable.

The whole edge direction and length filtering process is proceeding in the following way. First, pixels fulfilling the requirements of the specific direction and edge strength are marked in the edge map. The edge strength value can be set to a very low value (~ 0.1) and therefore long edge segments expanding through different edge strengths will not be excluded. On the other hand, such a low value will allow weak edge segments to present and make the detection of the actual linear features more difficult and the whole process more computational demanding. Once the pixels have been marked, the length of the segments is assessed and those exceeding a given range are considered to be the "seed segments".

3.2 LINEAR FEATURES' RECONSTRUCTION

Once the edge direction & length filtering process has been completed, all segments having constant direction and a certain length are considered to be marked. Nevertheless, bigger segments can not be completely revealed because locally the edge direction is changing due to the shape of the feature itself and to the presence of speckle. Therefore, the linear features' reconstruction process, following this stage, should be able to overcome the difficulties resulting from the

aforementioned phenomena. Within the framework of this paper, a contour-tracing approach has been implemented as a first attempt to solve this problem.

The process should be able to trace the contour upon which lies the "seed segment" and connect the segments between them, following the edges already extracted by FED. In order to proceed more reliably, the hierarchy of information presented in figure 10 is used. Sequentially, the non-maximum suppression entries, FED's final entries and finally the edge map entries are used in order to reconstruct the missing segments between the "seed segments". The parameters affecting its performance are the direction and the edge strength of the edge segments to be extracted.

The *edge strength* of the edge segments is considered a factor of importance for the edge segment handling. Edge segments having higher degree of being an edge are considered more important and are, therefore, processed first. As mentioned before, edge segments excluded due to the weak edge strength, can be reconstructed if they fulfil the requirement of connectivity with large or strong line segments.

Although this contour tracing process is reconstructing features which many times have high irregular shape and cannot be considered to be linear, this is something to be expected. It has already been mentioned in [7] that linear man-made structures like airfields and roads present high complexity and the linear approximation can not fulfil the reconnaissance task. Additionally, it is within reconnaissance needs that auxiliary segments to the linear features such as road turns and airfields' taxiways are to be revealed. Finally, the resolution of the sensor and its nature (airborne or spaceborne) affect greatly feature extraction.

The output of the linear features' reconstruction process includes also unwanted structures depending on the number of the "seed segments" in its input. These random structures (mostly created by speckle) can be excluded either by choosing bigger edge segment length, or higher edge strength value during direction & length filtering.

4. EXPERIMENTAL RESULTS, DISCUSSION AND CONCLUSIONS

The linear features' extraction process was applied in an X-band Shuttle Radar Topographic Mission (SRTM) data set of Bayern/Germany (Munich airport area). The data set is a 4-look amplitude data set, processed by the German Aerospace Center (DLR) and it is not geometrically calibrated and not geocoded (figure 12(a)).

Dissimilarity measure D_3 , sorted pixels as feature to be extracted out of the symmetric regions and relatively small areas of investigation were used as parameters inside FED. The small areas of investigation ($5 \times 5, 7 \times 7$) were posed by the low resolution of the linear structures to be extracted (runways and taxiways of the airport). The edge map e , the non-maximum

suppression output filtered along the direction of 135 degrees according to the direction array's entries and the FED's final result were shown in figures 12(b), 12(c) and 12(d) respectively for 5×5 area of investigation. The results show that treating the data with such a small area of investigation produces too many structures, making the linear structures' extraction task harder.

The linear features reconstruction process was applied in 12(d) and the length & direction filtering was done in four different versions, namely the four combinations of edge length values of 5 and 10 pixels and an edge strength level set of 0.1 and 0.5. The "seed segments" resulting from these combinations are presented in figure 13. Once the "seed segments" have been extracted, the proposed linear structures' reconstruction process was applied. First, the NMS output then FED's final result and finally the edge map entries were used to resolve the structures. The process was applied sequentially along the four directions and iteratively until no more pixels could be reconstructed. A refining process similar to the one used inside FED (cf. 2.4) was applied in the output were it was necessary. The results are presented in figure 14 respectively. Figure 15 resumes the results with bigger area of investigation (7×7) and additionally introduces an overlaying between the two reconstructions in order to present a potential approach of overcoming the drawbacks of the two different resolutions of the edge detector, namely the sensitivity of the small area of investigation and the low feature resolving of the bigger area of investigation.

The results show that linear features' reconstruction can be achieved using the fuzzy information resulting from FED. The performance of this reconstruction is depending on the resolution of the SAR image, FED's resolution and the parameters used inside the reconstruction process. The different combinations of edge segments' length and edge segments' strength clearly outline the impact of these degrees of freedom in the final result. Higher edge segments' strength presents a bigger tension of revealing all the important features, producing though unwanted structures due to speckle and locally linear features. Bigger edge segments' length presents a higher reliability of revealing the strongly linear edge segments but the number of "seed segments" is small for the feature to be reconstructed. A good combination between the two parameters will result in an output, which will sufficiently fulfil the screening task.

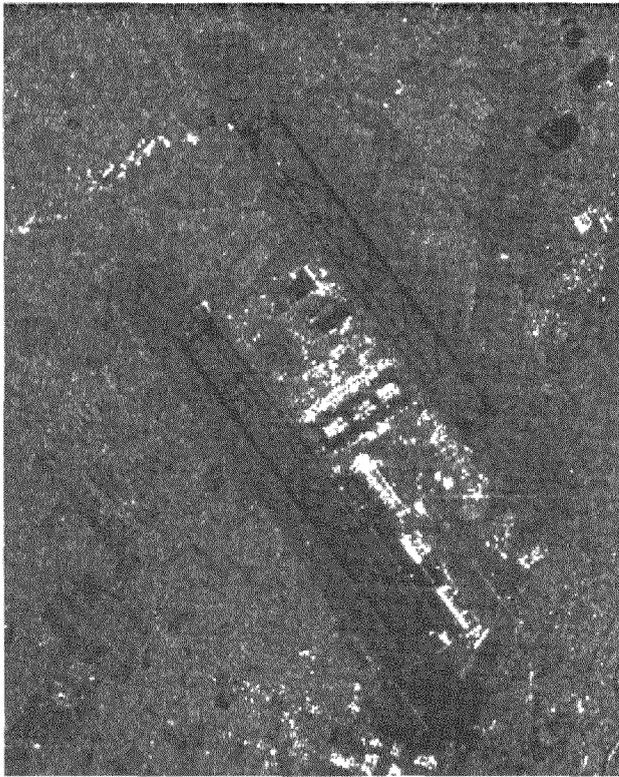
Nevertheless, the aforementioned procedure constitutes a first attempt to exploit FED's information for extracting figures of interest possessing certain properties (e.g. linearity). It was based in a contour tracing approach to investigate FED's capabilities towards features extraction out of SAR images.

5. ACKNOWLEDGEMENTS

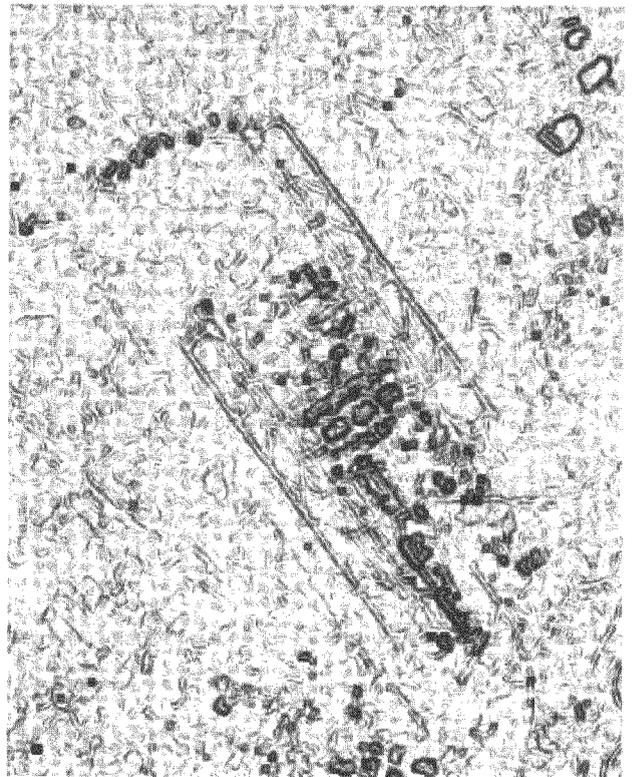
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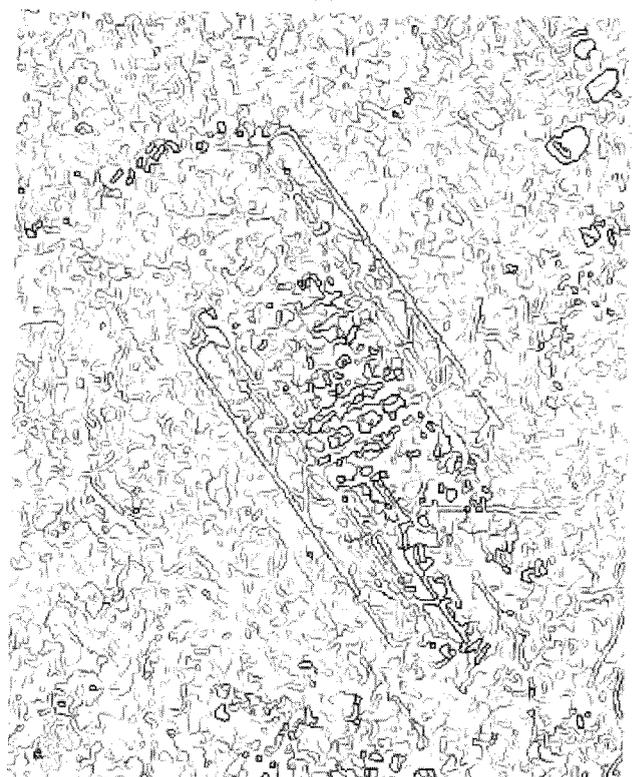
(a)



(b)



(c)



(d)

Figure 12: (a) 8-bit scaled version of the data set used. (b) Edge map of figure 12(a) using dissimilarity measure D_3 , 5×5 area of investigation and sorted pixels as feature. (c) Non maximum suppression result filtered along direction 3 (figure 2) using the direction array. (d) FED's final result after edge tracing (used iteratively three times) and refining (edge segments having length below 5 pixels were erased).

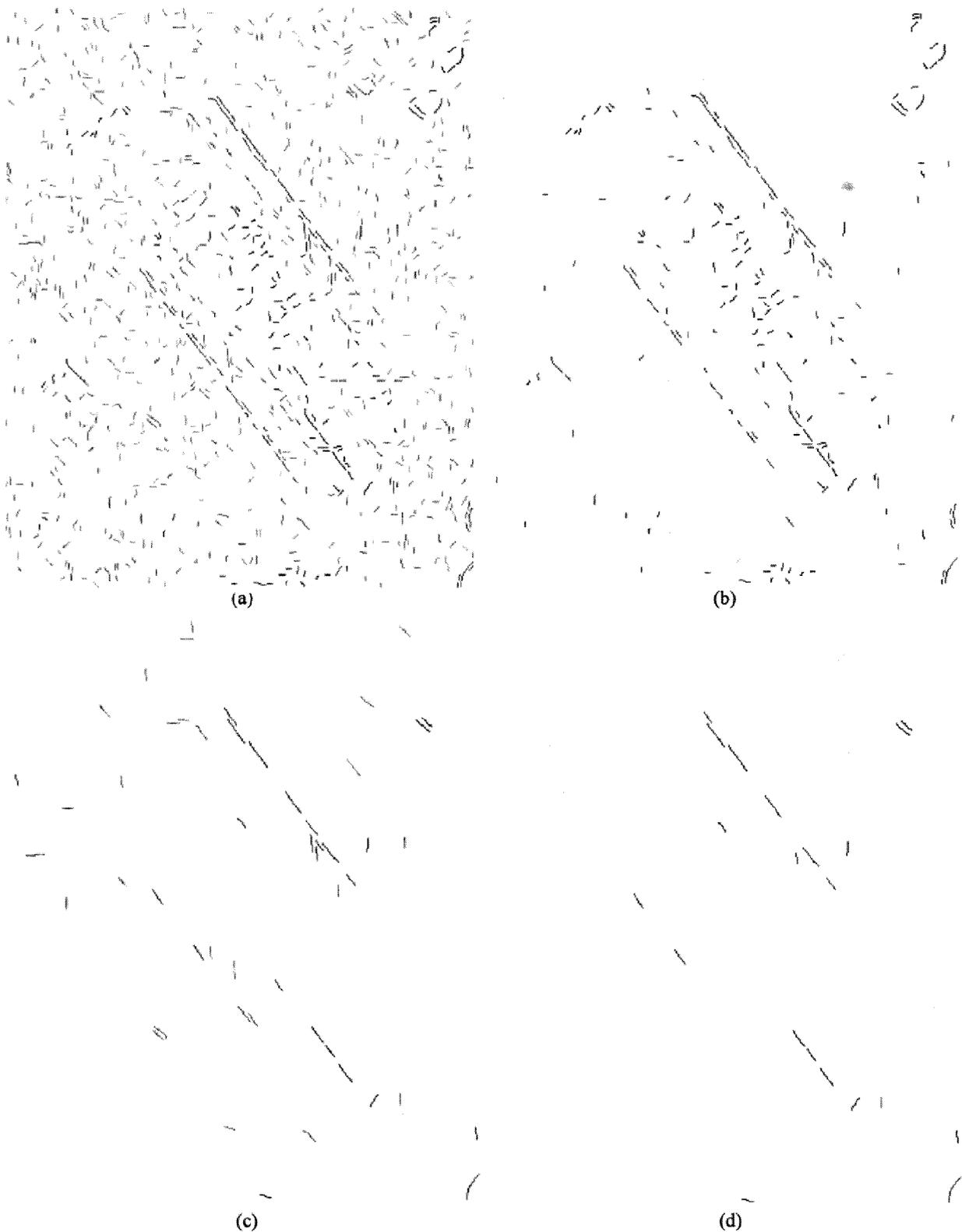


Figure 13: (a) "Seed segments" resulting from edge direction & length filtering with edge segments' length of 5 pixels and edge segments' strength above 0.1 applied on 12d, (b) "Seed segments" with edge segments' length of 5 pixels and edge segments' strength above 0.5, (c) "Seed segments" with edge segments' length of 10 pixels and edge segments' strength above 0.1, (d) "Seed segments" with edge segments' length of 5 pixels and edge segments' strength above 0.1

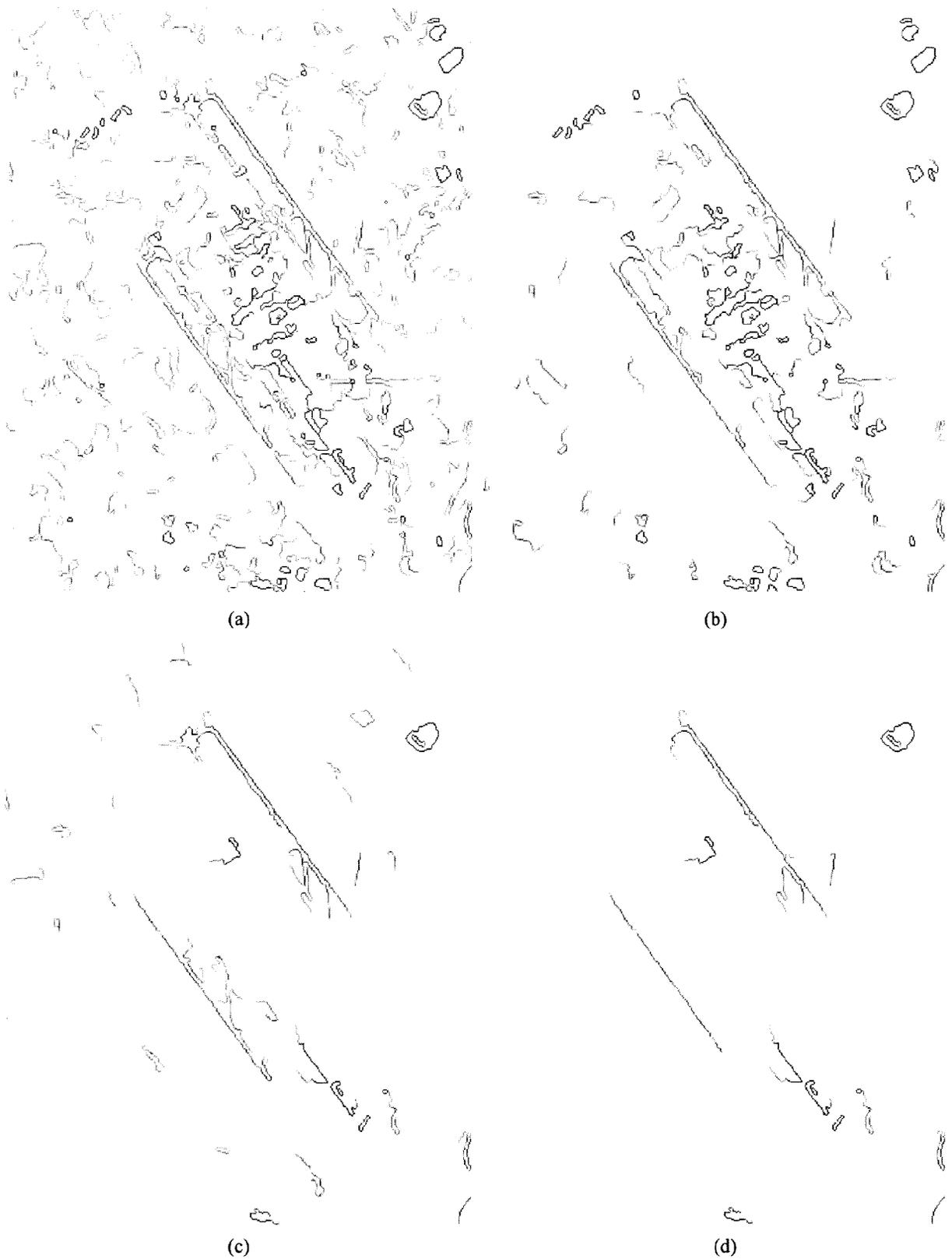


Figure 14: (a) Linear features' reconstruction based on the "seed segments" of 13(a), (b) Linear features' reconstruction based on the "seed segments" of 13(b), (c) Linear features' reconstruction based on the "seed segments" of 13(c), (d) Linear features' reconstruction based on the "seed segments" of 13(d),

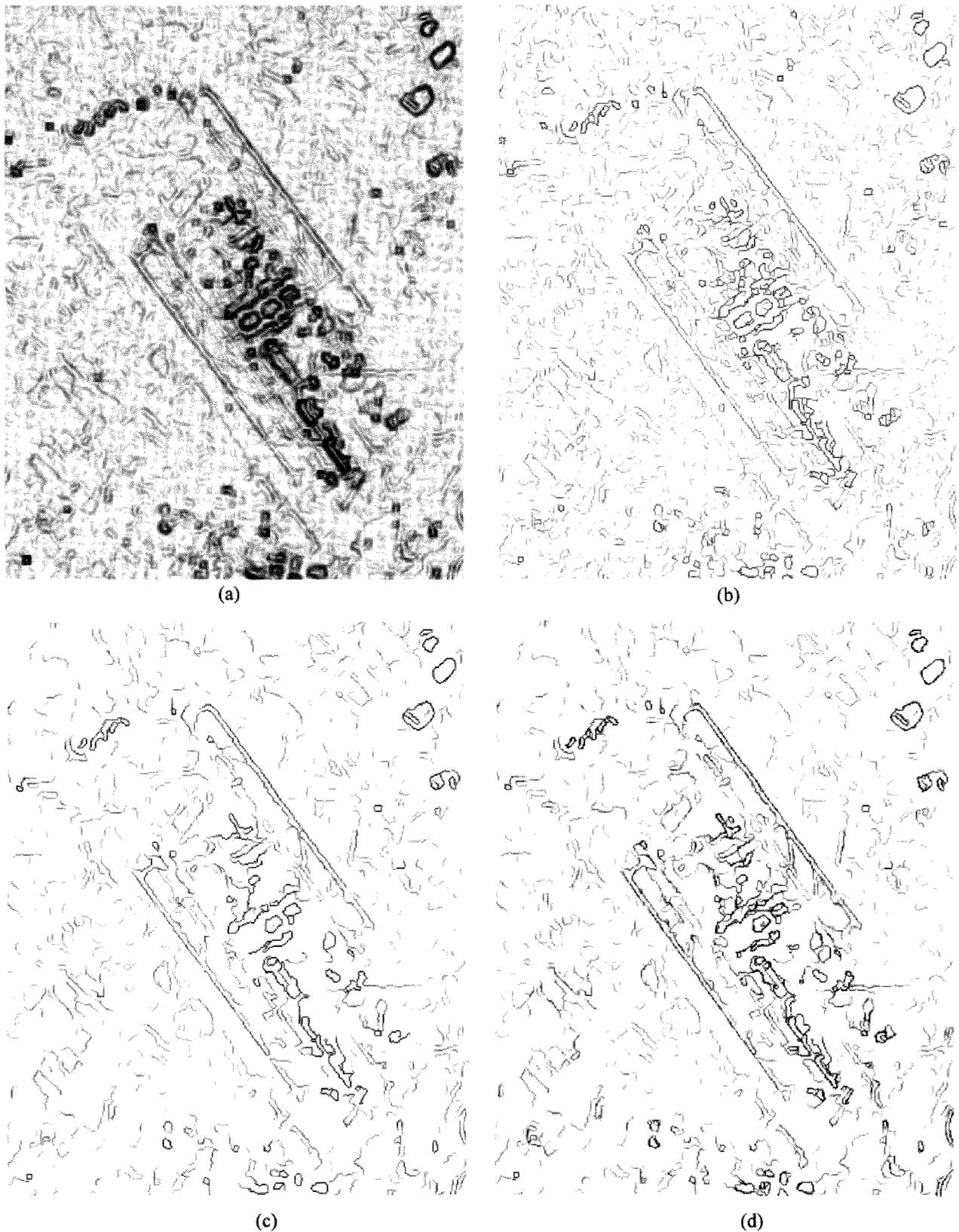


Figure 15: (a) Edge map of figure 12(a) using dissimilarity measure D_3 , 7×7 area of investigation and sorted pixels as feature, (b) FED's final result after edge tracing (used iteratively three times) and refining (edge segments having length below 5 pixels were erased), (c) Linear features' reconstruction based on the "seed segments" resulting from edge direction & length filtering with edge segments' length of 5 pixels and edge segments' strength above 0.1 applied on 15b, (d) Overlaying figures 14(b) and 15(c) results in an improved extraction of the airport.