ANALYSIS OF UNCERTAIN FACTORS IN AUTOMATIC EXTRACTION OF ROADS FROM SAR IMAGERY

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ABSTRACT:

The uncertain factors of automatic extracting roads from the Synthetic Aperture Radar (SAR) imagery have been considered in details in the paper. We consider that the key point of the extraction is the accurate detection of the road points in the image. So, to get the good result, at first, through analyzing the roads features in the SAR image, we got the local model of roads structure. Then utilizing the statistic characteristic of the SAR image, we obtained the ratio probability density function (pdf) of the adjacent region to the road region. As follow, we analyzed the uncertainty of the parameters in the pdf. So we got the adaptable rules about setting the parameters. Subsequently, we used the K-S hypothesis testing to get the roads points in the image. Finally, we studied various objective quality measures to evaluate the extraction results. The practices have shown that the results are in agreement with the theoretical analysis, and so men can enhance the performance of the extraction through setting adaptable parameters.

1. INTRODUCTION

Various methods of extracting roads from remote sensing imagery automatically were investigated in numerous documents recent years. Because of the severe effect of speckle noise, the method used in the optical imagery to obtain the roads can not attain the satisfactory results in Synthetic Aperture Radar (SAR) imagery. It is shown that because of the multiplicative nature of the speckle, the operators just like the difference operators, Canny operators and zero-crossing operators et al. (the roads in the imagery are always considered as one kind of edges) detect lots of false edges in SAR imagery. So the approach about extracting roads effectively from the SAR imagery is few, and mainly adopted the statistical road model simulation. As the existence of the error in the road model, there are many defects in the results such as many fractures, false alarm and missing alarm and so on. The adaptability of the algorithm, the parameters of the model, and the fuzzy edge of the roads et al.—these uncertain factors must be expatiated in the extraction procedure.

The types of the uncertainty are classified as subjective and objective. That is including parameters uncertainty (measurement error, sampling error and system error), model uncertainty (the abstract of the real world, the error specification of the model structure, misuse of the model, and using inadaptable substitute parameter) and context uncertainty (description of the error, sets error, professional judgment error and the incomplete analysis). We must consider the uncertainty of the extraction in these three aspects.
The paper focused on the analysis of the uncertain factors in using roads model to extract road nets in SAR images with about 10m ground resolution, compared the extracting performance when using different parameters, and drew some useful conclusion in the end. The whole paper was organized as follows. Section 2 presented a structure mode of roads in the SAR imagery and gave some improvements. The next, some crucial parameters in the mode were analyzed, using variability index (VI) and probabilistic model, such as Gaussian model, we got various parameters alternatives and predicted the performance through theory analysis. Then optimization in adaptive parameters was also draw through analysis in section 3. Then in section 4 through experiments we testified the practice corresponded to the theories deduced in section 3. Further, some valuable metrics introduced for the performance gave the results some objective assessment. Finally, conclusions are drawn in the Section 5.

2. ROADS STRUCTURE MODE IN SAR IMAGERY

The key step of the extraction is the accurate detection of the road points in the image. Through reading the existing documents [1] and analyzing the images, we got the typical features of the roads in the middle or low resolution SAR imagery as follows.
The roads are stripped with low grey in the image, and some segments accompany with some bright edges.
The change of the road's direction is slow, that is to say the curvature of the road should not change dramatically.
There must be an obvious contrast between road and the background.

Most roads are not short, and furthermore it should very long and many roads construct a road net.

The roads in the images are linear structure which has a definite width and direction (Fig. 1).The local road model shown in figure 1 was composed with three sections: the road region, the left neighbour region and the right. The abuttal on both sides must remove one or two pixel width region adjacent to the main road because there may be strongly reflectors such as buildings along sides of the roads obvious different from the nearby. We get ride of this in the method, which nearly not considered in other document. Meanwhile, there are random directions of the roads; we must detect roads section in all direction. Considering the computation must be huge when calculates all directions in practice; we adopted finite directions to extract.

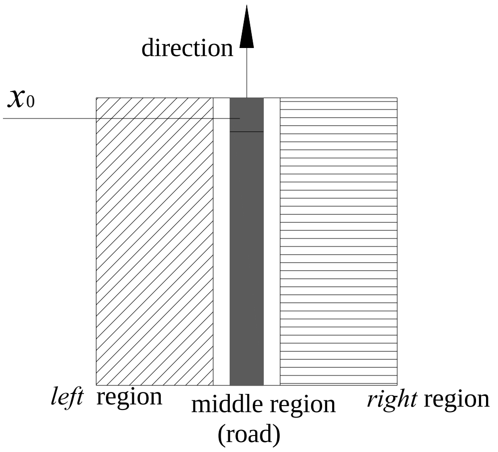


Figure 1: Road Structure Model

3. THE UNCERTAINTY ANALYSIS OF THE MODEL

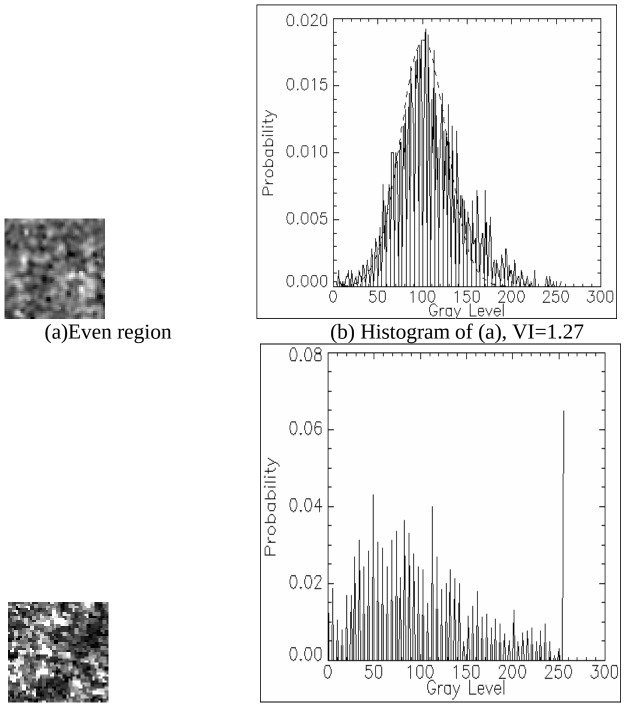
Since the statistical uncertainty of the SAR imagery, there are many statistical models to simulate. Gamma distribution, Log-Normal distribution, Weibell distribution, K distribution and Rayleigh distribution etc. can simulate the SAR signal under special condition. As we see the SAR image, we maybe have some feelings, some regions of the image are “smooth”, and some are “unevenly”. So we introduced the index called variability index (VI) to justify whether “smooth” region or not, which lead to the different processing method.

3.1 Variability Index (VI)

We have chosen the absolute value of the skewness of the distribution (the extent of the peak value deviate to the mean) as variability index (VI) reflected the extent of the distribution curve of a random away from the symmetry. VI is define as

$$VI = \left| \frac{E[X - E(X)]^3}{\{E[X - E(X)]^2\}^{3/2}} \right|$$

Where, X is a random variable about every pixel of the SAR imagery, E(X) is expectation. The farer the VI is from zero, the more deviation from the symmetric center. Through statistical analysis, the VI value of the “smooth” or “even” regions in the image is near to zero and the “uneven” or “rough” regions have larger VI values. Through selecting typical even local region, we can get the threshold of the VI .Then when the local VI is smaller than the threshold, we consider the local region of the image is smooth, or it is uneven.



(a)Even region (b) Histogram of (a), VI=1.27

(c) Uneven region (d) Histogram of (c), VI=2.87

Figure 2: The typical “even” and “uneven” local region in the image, the size of local region is 50×50

3.2 Model Analysis

In the even region of the image, R.Touzi and A.Lopes derived the analytical formula of ratio-of-average (ROA) [1] [3] which can extract edges in SAR image with constant false alarm rate (CFAR). But in the uneven region, ROA method can lead to a increased false alarm rate, we need to analyze it and make some improvement to guarantee the low false alarm rate.
Generally, SAR imaging procedure has the step of multi-look processing to reduce the effect of speckle noise, that is $I = \frac{1}{L}\sum_{k=1}^{L} I_k$. Where I represent the intensity of the image, L is look number. According to the Central Limit Theorem, when L is very large, Gaussian distribution can be used to model I. If SAR image has low look number, the hypothesis is untenable. Maybe we can use the approach in [4] to enhance the equivalent look number of SAR data to accord with the Gaussian hypothesis. So the probability distribution function (PDF) of pixel X is as

$$g(x) = \frac{1}{\sqrt{2\pi}\sigma} exp\left(-\frac{(x-\mu)^2}{\sigma^2} \right)$$

Where μ is mean of x, σ^2 is the variance of x.

The mean random variable is $\overline{X} = \frac{1}{N}\sum_{i=1}^{N} X_i$, (where Xi is the pixel of the region, i=1,…,N),the PDF of $\overline{X}$ is

$$f(\bar{x}) = \frac{\sqrt{N} e^{-N(x-\mu)^2/2\sigma^2}}{\sqrt{2\pi}\sigma}$$

According to local road model in the fig.1, we define variable l, m, r present the different region from left to right, and have the mean pixel random variable X_l, X_m, X_r respectively, at same time we consider they are independent. Then we get the ratio random variable that is left region to middle area (road region) is $R_{l,m} = X_l / X_m$ for example; then the PDF of the $R_{l,m}$ is as

$$\begin{aligned} f_{R_{l,m}}(y) &= \int_0^\infty f_l(yx_m) f_m(x_m) x_m dx_m \\ &= \int_0^\infty x_m \frac{\sqrt{N_l}\, exp\left(-\frac{N_l(yx_m-\mu)^2}{2\sigma^2}\right)\sqrt{N_m}\, exp\left(-\frac{N_m(x_m-\mu)^2}{2\sigma^2}\right)}{\sqrt{2\pi}\sigma\sqrt{2\pi}\sigma} dx_m \\ &= \int_0^\infty x_m \frac{\sqrt{N_l N_m}\, exp\left(-\frac{(N_l y^2 + N_m)x_m^{\ 2} - 2(N_l\mu y + N_m\mu)x_m + (N_m + N_l)\mu^2}{2\sigma^2}\right)}{2\pi\sigma^2} dx_m \\ &= \frac{\sqrt{N_l N_m}\,\mu(N_m + N_l y)}{\sqrt{2\pi}\sigma(N_m + N_l y^2)^{3/2}} exp\left(-\frac{N_l N_m \mu^2 (y-1)^2}{2(N_m + N_l y^2)\sigma^2}\right) \end{aligned}$$

As SAR image data has its own distribution characteristics, μ and σ^2 has correlation don't like ordinary Gaussian distribution. Let $k = \mu / \sigma$, then

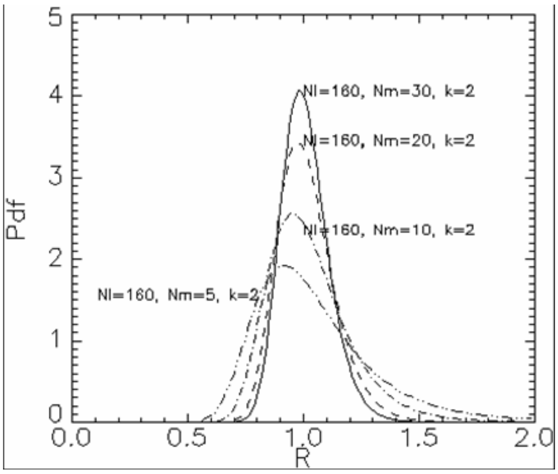
$$f_{R_{l,m}}(y) = \frac{\sqrt{N_l N_m}(N_m + N_l y)k}{\sqrt{2\pi}(N_m + N_l y^2)^{3/2}} exp\left(-\frac{N_l N_m (y-1)^2 k^2}{2(N_m + N_l y^2)}\right)$$

Where N_l present the pixel numbers of the left region in Figure 1; N_m is the pixel numbers of the middle region (road). We can get $f_{R_{r,m}}(y)$ at the same deduction. From above, we can get the conclusion that the model performance is relative to N_l, or N_r, N_m and k these parameters.

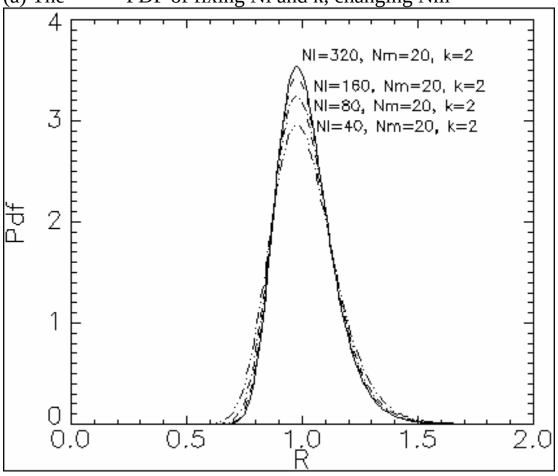
3.3 Uncertainty analysis of parameters selection

N_l, or N_r, N_m and k are the key parameters to the results. In the paper, we consider these parameters are all random variables. Through analyzing how to select value can get better roads extracted performance, we should commence on local roads model built on statistical theory. Due to statistical theory, every local region should include enough pixels to reduce the effect of random error. That is to say local region should be as larger as possible; this will mislead to the label of other ground objects other than roads. So the region should be proper.

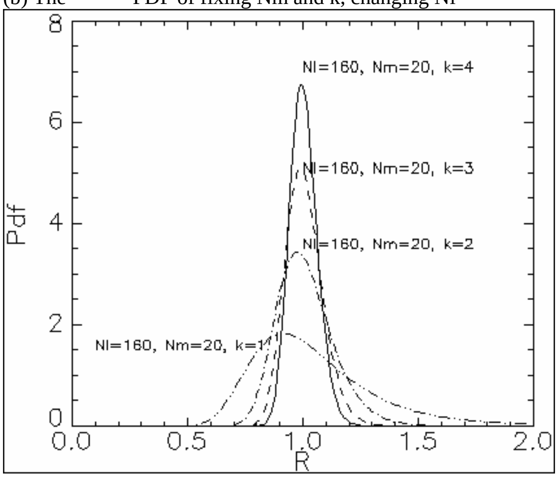
Through theory analysis, we drew the PDF of $R_{l,m}$ as N_l, N_m and k changed separately.



(a) The $R_{l,m}$ PDF of fixing Nl and k, changing Nm



(b) The $R_{l,m}$ PDF of fixing Nm and k, changing Nl



(c) The $R_{l,m}$ PDF of fixing Nm and Nl, changing k

Figure 3: The PDF curves of $f_{R_{l,m}}(y)$ with parameters changed

Three critical conclusions have been drawn through analyzing in Figure 3.

1) The curve is sensitive to the pixel numbers of the road region (Nm, middle region in Figure 1). As the decrease of the number; the increase of the curve kurtosis that is the curve is deviating from symmetry. For the Kolmogorov-Smimov (K-S) hypothesis testing theory, in order to get to an unchanged significance level α (correlated with constant false alarm rate), the threshold T should be increased otherwise it will lead to the increase of false alarm rate.

2) The pixel numbers of the abuttal (right or left) has little effect with the curve of the distribution curve (Figure 3(b)). The performance of the extraction is not effect with the change of the abuttal, when we determine the number of middle region (road) and k, the result would be foreseen.

3) From Figure 3(c), the value of $k = \mu / \sigma$ (where, μ is the mean value of the local image and σ is the standard deviation) has a great impact on the curve. Through analyzing, the decrease of k corresponds to the more uneven in the region, and the more deviate from the model assumption, which will destroy the ideal road model sooner or later. The roads can not be extracted under very low value of k.

3.4 The methods of reducing uncertainty

Used the rules above, we selected some sets of parameters to get the required results. The thresholds were determined by the K-S hypothesis testing: for the given significance level α, testing hypothesis H0: middle region and left region are the same landmark (homogeneous region); H1: middle region has lower grey than the left region. When H0 is true, the value of statistic $R = X_{l||r} / X_m$ is not very large; when H1 is true, R always very large, and middle region is road. So the formation of rejection field is $R_{l,m} = X_l / X_m \geq T \,\&\&\, R_{r,m} = X_r / X_m \geq T$.
Based on the curve of R probability distribution function, we used normal distribution to approximate the stochastic variable R. According to the normal distribution, as significance level $\alpha = 0.1$, $\Phi(1.28) = 0.1$.So we can initiate the threshold T=1.28. Based on P{reject H0｜H0 is true}<=α, we can get the critical Threshold T, and satisfy $P\{R_{l,m} > T_\alpha\} \leq \alpha$. If $R_{l,m} > T$, then middle region has lower grey than abuttal, the middle region must be road, otherwise they are homogeneous region. The probability of misjudging is α.
The critical points of the procedure are the judgement of whether region is homogeneous or not. We adopted VI (section 3.1) to testify. In practice, we need add a correction value(Δ)on R to compare with threshold the next for the correction judgement.

Based on the analysis of section 3.3, we reduced the errors of extraction for three aspects. The pixel numbers of the middle region (road) can not be taken small value, for example one pixel width and fifteen pixel length (Nm=15) road region, the road in reality should be 13-40 meters width; too narrower the road can not be extracted exactly. Due to the curvature of the roads are small, the appearance of the roads in local should be linear. The length of the road model should accord with this characteristic, too short to extract other landmark and enhance the false alarm rate. Certainly, the length longer than gentle curve segment is not advisable. Because $k = \mu / \sigma$ has the drastic impact on the results, the more noise in the SAR image (correspond to the low value of k, the higher of misextract rate.

4. EXPERIMENTS AND ANALYZING

Since single-look amplitude SAR is Rayleigh distribution, only if look number greater than 4, the amplitude SAR image data is approximated Gaussian distribution [4]. So for the low look number SAR image, we utilized simulated annealing algorithm to handle 2 times of iteration. Simulated annealing algorithm is set on the statistical feature of the SAR data, and at the same time the resolution of the image can not be change, thus this approach can achieve a better equivalent look and meet the hypothesis in section 2.2.

There may be very large size of image, for the calculation amount and speed; we trim the large image down to small ones just like Figure 3 512×512 size. Furthermore, distributed computation on multi-computers is applied to the procedure. Because of the random directions of the roads, all directions extraction based on local road model should be applied. In practice, for the compute speed and efficiency, the local road model extractor rotates along the directions every 18° around the circle over the selected size. That is, we label the roads points in SAR image in 0°,18°,36°,⋯,144°,162° directions. Setting parameters ST=2, Nm, Nl, $\Delta = 0.522 / \sqrt{L}$ as rules in section 3.4, we can implement the extraction as the whole procedure flowchart shown in Figure 4. We used VC++ programming the algorithm; at the same time set extracting area and flattening calculated by formula $T_f = 4 \cdot \pi \cdot Area / (perimeter)^2$ threshold of extracting region, for eliminating the obvious not-roads landmark and noise. In several directions extraction some pixels have been labeled as roads points several times, we consider these points are mainly roads doubtlessly. After directions extraction, the main roads net are obtained and maybe need some auxiliary process such as filling the holes in the main road segments based on mathematical morphology. And the centre lines of the roads can be obtained by Hilditch thinning algorithm.

Maybe connecting the roads segments into the roads net is also a main problem in roads extraction [1].With the point of view of author, this problem can be eliminated by improving the roads algorithm detected the roads precisely.
The end of practice, some subjective and objective evaluation indexes were introduced for comparing the performance in various parameters and whether according with prediction by the theories above or not. In subjective, 2/3 part of a road extracted is considered the whole extraction of the road. Although subjective tests can sometimes be authentic if performed correctly, they are inevitable inconvenient, vary with each individual, subjective Therefore some useful objective indexes were introduced. These indexes are completeness (the ratio of points extracted correctly to reference roads points, the theoretical value is 1), correctness (the ratio of points extracted correctly to the whole number of extracted, the theoretical value is 1), quality (weighted value of the completeness and the correctness, the optimum value of this is 1), RMS (the mean

distance of the extracted roads position to the reference, and the optimum value is 0), false alarm rate and missing alarm rate(the complement sets of the completeness and the correctness respectively)[5].Used the indexes above, the performance of the selected various parameters were evaluated(table 1). From table 1 some conclusions in section 2 were verified. Low number of road region pixel can lead to bad results. The large of the road length pixel as row 4 in table 1 can lead the increase of the leak rate. One pixel width and 17 pixel length as middle road region, at the same time the pixels of number of left region and right region was set 119 can get desirable result and can not get to the theoretical 1% false rate alarm due to the change of the homogeneity. The result in figure 5 is quite satisfied.

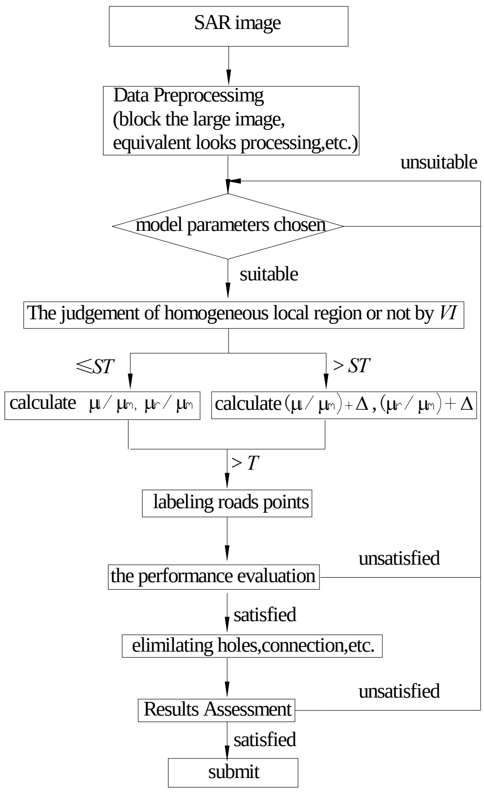


Figure 4: the flowchart of roads extraction from SAR imagery

5. CONCLUSIONS

In the article, we amplified the uncertain factors in the automatic roads obtained from SAR Imagery. We put forward the hypothesis of the SAR imagery and then built up the local road model. From the probability distribution theory, we got the mathematic function of the model base on the assumption. The next we analyzed the parameters of the function. From the uncertain property, we concluded three criteria for the extraction. Through tests, with the objective performance evaluation system, use these metrics to continually adjust uncertain parameters in a real time manner to get a satisfactory result automatically ,we got one reasonable procedure for the roads net extraction from the SAR imagery in practice. The achievements can be applied in image registration, mapping and GIS applications etc.

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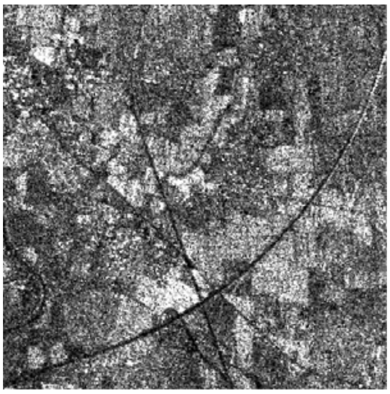
Parameter selection	completeness	correctness	quality	RMS	missing alarm rate	false alarm rate
Nm=5, Nl= Nr=50	69.25%	64.9%	64%	7	30.75%	35.10%
Nm=10, Nl= Nr=70	92.59%	88.61%	88%	1	7.41%	11.39%
Nm=17, Nl= Nr=119	93.13%	97.34%	93%	0.4	6.87%	2.66%
Nm=50, Nl= Nr=350	31.16%	83.86%	31%	5	68.84%	16.34%

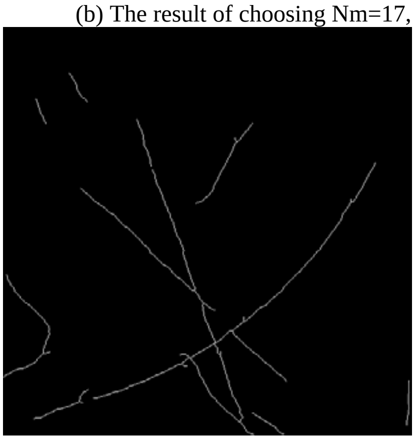
Table 1 the performance of roads extraction



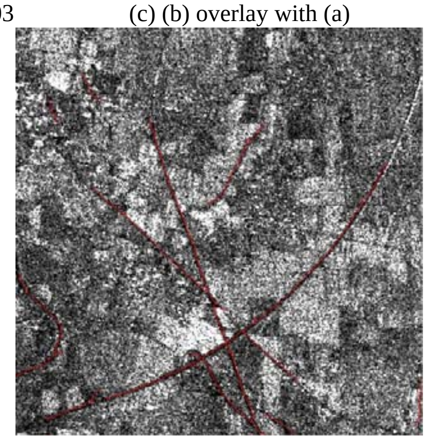
(a) SAR original image

(b) The result of choosing Nm=17, Nl= Nr=119, k=2.03

(c) (b) overlay with (a)



(d) (b) thinned by the Hilditch algorithm



(e) (d) overlay with (a)

Figure 5: the results of automatic extraction and the images overlaid by original image