DETECTION OF THE HETEROGENEITIES IN THE IMAGES USING MAXIMUM BIMAGNITUDE ESTIMATION

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Novel technique developed for detection and recognition the heterogeneities in the digital images is proposed and studied. Suggested approach is based on the evaluation of novel classification feature in the form of the maximum bimagnitude value computed for the image pixel intensities contained in the local image segment. In order to examine the performance of proposed technique test image contained the sharp contrast variations in the borders is designed. Mathematical model for computations by the Matlab software is developed for performance examination and the images contaminated by additive Gaussian noise with different variance values are studied. Receiver operating characteristic (ROC) parameter is used for evaluation the dependence of probability for true classified image areas on the false classified areas. Detection performance is assessed by the area under the curve (AUC) parameter. Proposed technique was compared with two common technique based on the estimation of the local root mean squared (rms) deviation values and quasi sweep values computed for the image pixel intensities contained within the slide window *limits. It was demonstrated that bispectrum-based and local rms deviation-based techniques provide very good detection of the image borders under assumption of noise absence. However, at the same time, better performance was obtained by proposed bispectrum-based technique in additive Gaussian noise environment and under increasing of noise variance value. It is also shown that common technique based on the estimation of local mean squared values provides better performance under small noise variance values. Proposed and common techniques provide AUC values equal to 0.678 and 0.8468, respectively. Proposed technique provides more efficiency index under large noise variance values. Computer simulations results indicate that under noise variance value equal to 0.6, proposed technique provides AUC value equal to 0.8748 i.e. proposed technique provides better performance as compared to common techniques.*

KEY WORDS: *image processing, image heterogeneities detection, bispectrum, bimagnitude, Gaussian noise, ROC curve, AUC parameter*

1. INTRODUCTION

Recently, intensive investigations and efforts are undertaken for development digital image processing systems in different applications as for: the radars, the aerospace remote sensing of the Earth, technical and medical diagnostics and other. Various problems like segmentation of spatially distributed objects, recognition of localized objects and classification of the Earth cover types, as well as measurements of the geometrical and radio-bright data are of heightened interest in the modern digital image processing area [1], [2]. Solving such problems is based on using both heuristic and statistical theory approaches. For description of spatially distributed objects in the images the latter strategy exploits mathematical models contained a number of stochastic fields represented in the form of several realizations. One of the most important problems is the recognition of local heterogeneous areas in the image and thereupon detection the borders of spatially distributed objects for their further segmentation and classification. Solving these problems has been considered by using both heuristic strategy [3] and theory of statistical decisions [4], [5]. It should be stressed that the algorithms based on the heuristic approach are practically cannot be able to obtain quantitative estimations for evaluation the efficiency index. In addition, heuristic algorithms have bad noise resistance and they are not always operable for recognition the image areas contained heterogeneous texture. Note that statistical-based algorithms also are not always operable for certain real-life applications because as follows. First, they have extremely complicated computation procedures necessary for calculation the maximum likelihood functionals under great number of the hypotheses and under uncertainty of spatial location of the object borders. Second, statistical image models developed for these algorithms do not always correctly approximate the images in real-life scenarios.

Recently, strategy of higher-order statistical analysis exploiting specifically third-order spectra that namely so-called bispectra have been successfully used in digital signal and image processing [6], [7]. Using third-order statistics for digital image processing provides extraction such important contributions in the images that allow obtaining novel class of information features. It should be noted that the latter data cannot be extracted from the images by evaluation the common second-order statistics, i.e. by strategy based on the estimate of power spectrum and correlation function.

In this paper, we propose a new bispectrum-based technique that permits effectively detect and recognize the heterogeneities in the images.

The rest of the paper is organized as follows. Section 2 presents description of the algorithm for bimagnitude evaluation. Next Section is dedicated to the estimation of efficiency performance for recognition of the heterogeneities in the images. Section 4 presents computer simulations results, and Section 5 concludes the paper.

2. BISPECTRUM-BASED STRATEGY

Recently, approach exploiting cumulant functions and higher-order spectra is used for solving various problems in digital signal and image processing [6]. Higher-order spectra give us unique opportunity to extract important information about phase relationships hidden in raw processed data. Higher-order statistics also provide to add novel prospective possibilities as compared to common non-coherent second-order analysis. The benefits of bispectrum-based approach can be listed below as follows:

- good suppression of additive Gaussian interference;
- third-order spectrum contains important information about phase coupling existing in spectral content and this information can be extracted;

- higher-order strategy allows to investigate non-linear properties and characteristics of a time or spatial series under study.

One of the most practically important benefits existing for bispectrum-based data processing techniques is the tendency to zero of bispectrum estimate computed for the interference having symmetrical shape of probability density function. This important feature provides robustness of signal and image restoration algorithms to Gaussian noise influence [6] – [8].

According to the definition accepted in polyspectral analysis [6], bispectrum is the Fourier transform computed for third-order or triple correlation function. Expressions commonly used for both bispectrum $\dot{B}_x(p,q)$ and third-order correlation function $R_x(k,l)$ computations [6] can be written as

$$\dot{B}_x(p,q) = \sum_{k=-I+1}^{I-1} \sum_{l=-I+1}^{I-1} R_x(k,l) \exp[-j2\pi(kp+lq)] = \left|\dot{B}_x(p,q)\right| e^{j\gamma_x(p,q)}, \quad (1)$$

$$R_x(k,l) = < \sum_{i=0}^{I-1} [x^{(m)}(i) - E][x^{(m)}(i+k) - E][x^{(m)}(i+l) - E] >_{M\to\infty}, \quad (2)$$

$$\begin{aligned} \dot{B}_x(p,q) &= < X^{(m)}(p) X^{(m)}(q) X^{*(m)}(p+q) >_{\infty} = \\ &= < X^{(m)}(p) X^{(m)}(q) X^{(m)}(-p-q) >_{\infty} \end{aligned}, \quad (3)$$

where p, q and i, k, l are the frequency and pixel spatial indexes, respectively; $|B_x(p, q)|$ and $\gamma_x(p, q)$ are the amplitude bispectrum (biamplitude) and phase bispectrum (biphase), respectively; $<\ldots>_M$ denotes ensemble averaging procedure performed by M observed realizations; E is the mean value of a process $x(i)$ under study; $X^{(m)}(\ldots)$ is the Fourier transform; * denotes complex conjugation procedure.

So, proposed algorithm contains the bimagnitude $\left|\dot{B}_x(p,q)\right|$ computations according to the formula (3). The computations are performed for the image pixels contained in the local image segment extracted by sliding window. Decision about existing of the heterogeneities is made by information feature evaluated in the form of bimagnitude values.

3. EFFICIENCY INDEX EVALUATED FOR THE HETEROGENEITIE RECOGNITION IN THE TEST IMAGE

One of the first stages intrinsic for the adaptive filtering, borders detection or for object recognition in the image is the detection of locally-active areas. In order to provide maximum efficiency of detection the optimization of the functional detector parameters must be performed. Moreover, the algorithms intended for recognition of heterogeneous areas have diverse robustness under different noise levels. Therefore, the problems of analysis the efficiency for proposed bispectral technique are arisen and efficiency index comparison with common detection techniques must be introduced. Each of detection type has its own number of parameters required to be optimized.

Enough great number of the approaches exists for quantitative efficiency estimation serving for heterogeneity detection. One of the most available strategy is the receiver operating characteristic analysis (ROC analysis) [9], [10]. This approach includes the computations of ROC data and construction of so-called ROC-curves. The latter graphs contain information about probability dependence of true classified values called sensitivity on the probability of false response called the specificity. It is evident; that this estimation must be examined by the test images contained real intensity distribution classes necessary for recognition.

In order to evaluate the estimate for the probability of true heterogeneity recognition the number of responses contained within one separate image segment must be analyzed for one or several test images. After that, the number of responses attribute to total number of segments located in the studied area. Probability estimation computed for false responses is performed in the homogeneous image areas. Number of detector responses is evaluated and normalization procedure is performed by total segment number belonging to these areas. Certain optimization on the dependence value can be provided by variations of the threshold that specified for detector. The threshold means such value that is taken into account when it exceeds the detector responses or it equals to zero in the opposite case.

Note that the latter approach has the following essential drawback. Obtaining the dependences for several detectors requires installing for each detector some certain number of the thresholds. Besides, the threshold values corresponding to the same false detector response probabilities are of different values for each separate detector. This peculiarity provokes the following additional problems: before execution of described procedure, obligatory preliminary additional analysis is necessary for the detectors in order to evaluate approximate threshold value for each of them. As the addition to the standard ROC-analysis and in some real-life cases the alternative is the area under the curve (AUC) parameter. This parameter initially has been proposed for estimation of recognition quality for two classes and evaluated as the following value [10]

$$A = \frac{S_0 - n_0(n_0 - 1)/2}{n_0 n_1} \quad , \tag{4}$$

where n_0 and n_1 are the number of the elements contained in the first and second classes, respectively; $S_0 = \sum r_i$, r_i is the rank of *i*-th element that belongs to one of two noted classes.

AUC is the rank parameter, i.e. it is based not on the absolute values of the estimated local parameter but on their location in culled sample. This peculiarity is the characteristic property and the main benefit for exploiting AUC parameter. Therefore, AUC parameter has not the drawback intrinsic to the techniques described above as necessity to install some threshold for each detector. In addition, unique benefit for using AUC parameter is the following: it allows evaluating the classification efficiency by common parameter instead analysis performed for dependencies groups. This fact permits using the AUC parameter in automated data processing mode.

Let us consider an example for computation of AUC values for different border detectors and small objects in the image. First, ideal border maps in the test images are formed under assumption of noise absence. These ideal maps define two following classification classes: ”border” and “homogeneous area”, where n_0 and n_1 are the number of the values belonging to the noted classes, respectively. Studied border detector now is exploited for these test images. However, in this time, image is contaminated by given interference. After that, obtained data set is sorted for detector and, at the same time, permutation is performed for the elements in the data array contained ideal values. Positions of the elements in the “ideal” array vary at the same manner as in the sorted array contained the operating results of the border detector. After that, the sum of the elements indexes must be computed for the changed array of the ideal values that belong to one of the noted classes. For instance, S_0 belongs to the "border" class, and finally, output parameter value is computed. The values varied within the limits from 0 to 1 is the result of computation of the AUC parameter. The better recognition quality the AUC values larger. The values closed to 1 indicate high efficiency for studied detector. Above noted properties allow using this parameter as appropriate data for estimation and comparison the detection characteristics with other detector types.

4. DISCUSSION OF COMPUTER SIMULATIONS RESULTS

In order to examine and compare between each other the approaches dedicated to the heterogeneity detection we must have such test images where true border location and the brightness values in the separate image areas are known a priori.

Real-life images are only partially proper ones for examination of the operability and efficiency performance for border detectors since ideal border maps do not exist for such images. Because of this, in order to examine the efficiency of different types of detectors test noise free images and images contaminated by noise were used in our computer simulations.

Developed test image contains homogeneous areas with different intensities, variations of the borders and various texture areas. Test image contains array of 256x256 pixels. Eight vertical strips of different intensities are illustrated in Fig. 1. As a result, the border sequence with different contrast levels is formed in the test image. Both direction and border shape do not matter since all investigations were performed for parameters that computed within small sliding windows. Besides, only output parameter values are interesting and image elements are off the interest. In order to compare detection performance our study was carried out for proposed bispectrum-based technique and two common techniques. First known is based on the evaluation of root mean square (rms) deviation [10] and second one exploits quasi sweep parameter evaluation [10].

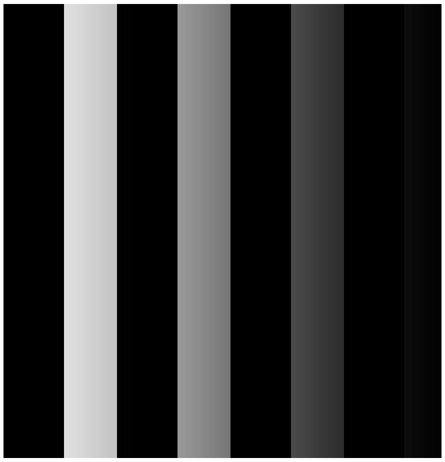


FIG. 1: Test image

Border contrast is defined as the ratio of the intensity contained relatively on the one side of the border side to the intensity value contained in the other side of the image border. As usual, contrast is always supposed to be equal to the ratio of the larger to smaller intensity values. The elements of different intensities are located not accordingly by the order of intensity variations but accordingly to create large contrast collection. Therefore, the following contrast values can be observed in the images as: 250; 223; 196; 153; 58.5; 37; 22; 15; 1.5. It should be stressed that there are the contrasts of very small values. Border detection for these small contrast values is rather complicated problem.

In this paper, three following approaches dedicated to image heterogeneities detection are considered and compared between each other: suggested bispectrum-based approach, known approach based on estimation of local root mean square (rms) deviations [10] and known approach based on quasi sweep estimation [10].

Relative value of mean rms deviation *S* is estimated for image pixel brightness within the limits of slide window of 8x8 pixels as [10]

$$S = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^2}\ , \qquad (5)$$

where x_i is the brightness of the *i*-th pixel, $\bar{x}$ is the mean value estimated within the limits of window size equal to 8x8 pixels, $n = 64$.

Operation principle of these heterogeneities detector is based on the assumption that the local rms deviation computed for the window appeared at the border is considerably larger as compared for the window appeared at the homogeneous area.

Quasi sweep parameter is the normalized difference of the order statistic values computed within the sliding window. Instead normalizing operation performed by local mean value the normalizing is performed by the value of $I_{ij}^{(q)} + I_{ij}^{(p)} \approx 2\bar{I}_{ij}$.

Quasi sweep parameter is defined in [10] as

$$QR_{ij} = \frac{I_{ij}^{(q)} - I_{ij}^{(p)}}{I_{ij}^{(q)} + I_{ij}^{(p)}}, \qquad (6)$$

where $I_{ij}^{(q)}, I_{ij}^{(p)}$ are the *q*-th and *p*-th elements of the ranked sample, respectively. According to the recommendations given in [10], q = 51 and p =13 for the sliding window size of 8x8 pixels.

Quasi sweep parameter is defined as the normalized difference of the order statistics values valuated in the window. Instead normalizing operation by the local mean value they use normalizing operation by $I_{ij}^{(q)} + I_{ij}^{(p)} \approx 2\bar{I}_{ij}$. Under impact of the window on the heterogeneity, the difference $I_{ij}^{(q)} - I_{ij}^{(p)}$ considerably increases as compared with the values observed on the homogeneous area.

Results of test image area detection contained the borders are demonstrate in Fig. 2 for the case of noise absence and in Fig 3 for the case of test image contaminated by additive Gaussian noise with rms deviation value equal to 0.2. The study was performed for three techniques: first one based on evaluation of bimagnitude maximum value, second one is based on the evaluation of local rms deviation values and third one is based on the quasi sweep evaluation [10]. Test image map constructed by bimagnitude maximum values has the logarithmic scale because intensity deviations are of the very large value equal to 10^{12}.

It can be seen from Fig. 2 that two of studied techniques namely bispectrum-based and local rms deviation-based techniques provide good recognition of the borders in the image under assumption of the noise absence. However, in additive

Gaussian noise environment, proposed bispectrum-based border detector visually seems to be loosed. However, it should be remembered and taken into account that the graph in Fig. 3a is plotted using logarithmic scale.

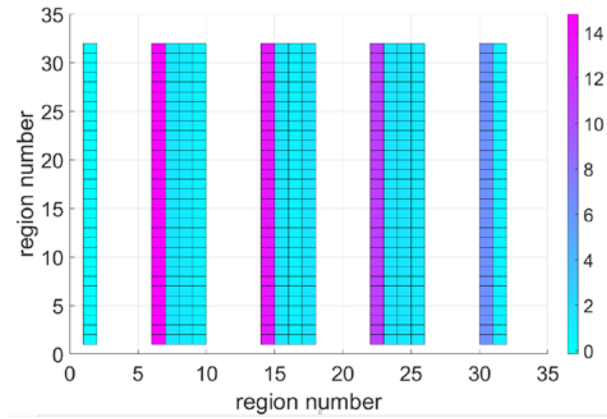
The curves demonstrated dependence of true probability of classified image areas on false responses are shown in Figures 4 - 6 for three studied detectors.

As can be seen from Fig. 5, the curves plotted for additive Gaussian noise of variations equal to 0.6 and 0.8 are visually absent. However, in fact, these data are present but they coincided in the graph to the value equal to (1, 1).

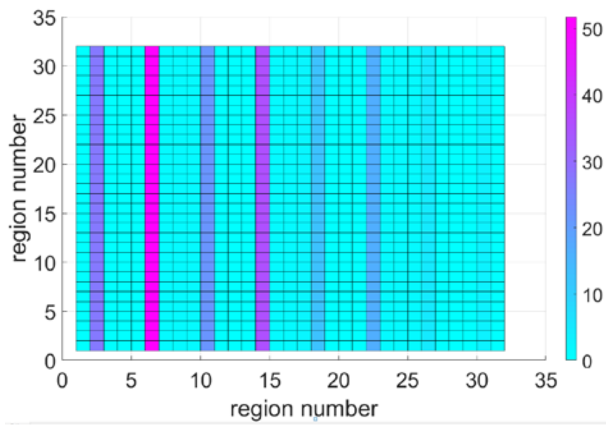
It also can be seen from Fig. 6 that for the quasi sweep evaluation strategy, the curves are visually absent for the case of additive Gaussian noise with variance values equal to 0.12…0.8.

The latter dependences reflect the detector sensitivity to the noise and detector ability to recognize the border under fixed probability of false alarm. The higher curve location the detection efficiency better, i.e. detector is of smaller sensitivity to the noise and, at the same time, it is more effective for border recognition.

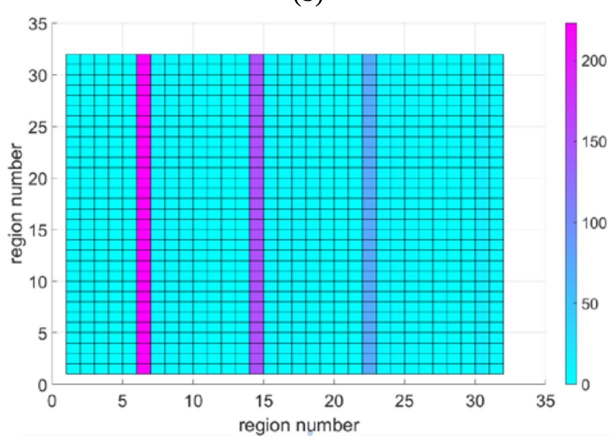
For the small noise variancies, analysis of the graphs plotted in Figures 4 and 5 demonstrates better efficiency for detector based on the evaluation of local rms deviation value. At the same time, for growth of noise variance, more effective becomes proposed detector based on the evaluation of bimagnitude maximum value.



(a)



(b)



(c)

FIG. 2: Examples of detection the areas in the test image without noise influence:
(a) by bispectrum-based technique,
(b) by evaluation of local rms deviation value
(c) by quasi sweep evaluation

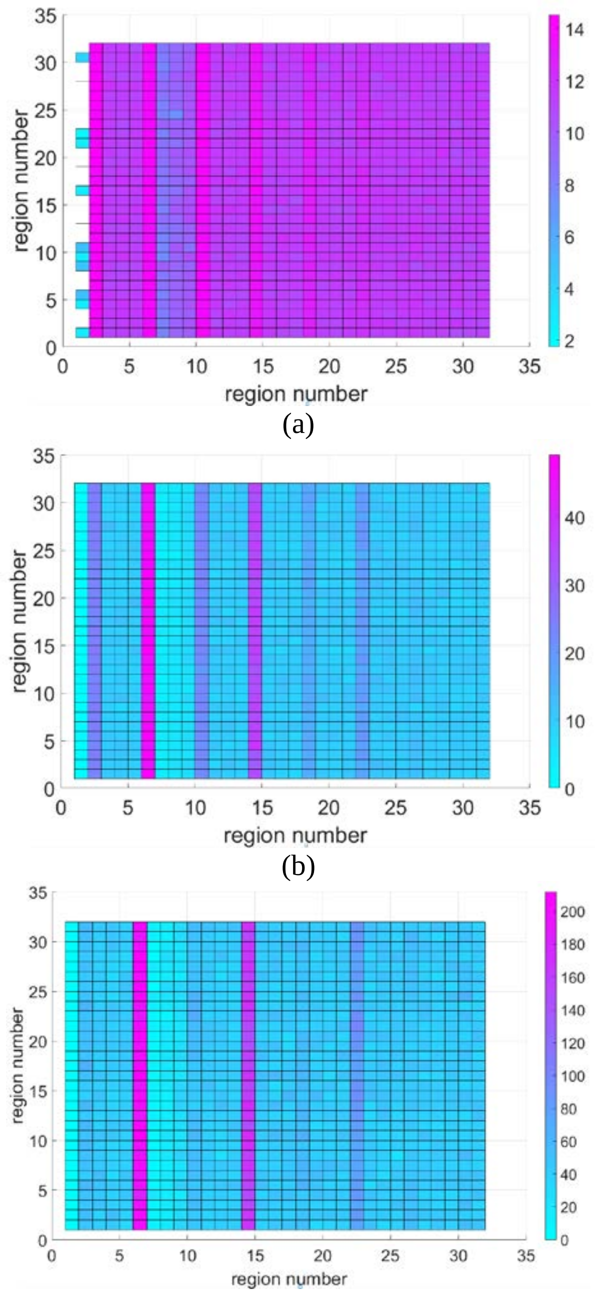


FIG. 3: Examples of detection the areas in the test image contaminated by Gaussian noise with rms deviation value equal to 0.2:
(a) by bispectrum-based technique,
(b) by evaluation of local rms deviation value,
(c) by evaluation of quasi sweep

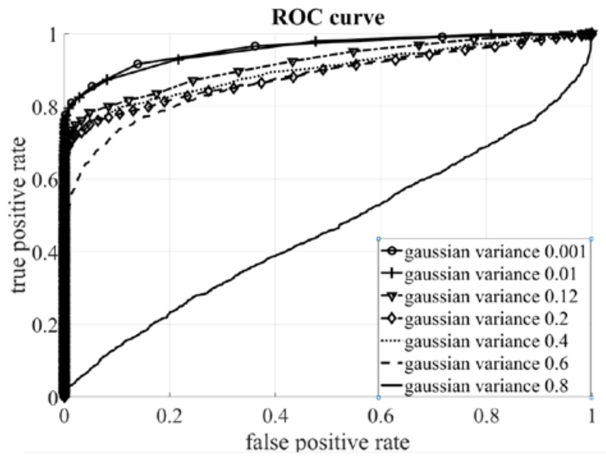


FIG. 4: Sensitivity curves for border detection based on proposed maximum bimagnitude evaluation

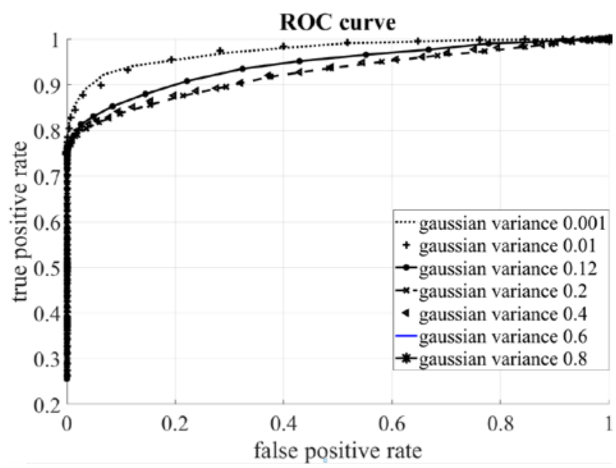


FIG. 5: Sensitivity curves for image border detection based on evaluation of the local rms deviation

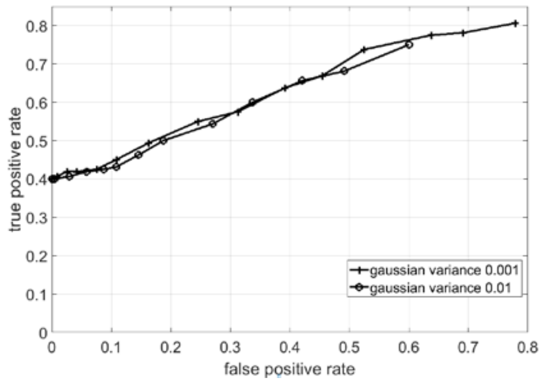


FIG. 6: Sensitivity curves for image border detection based on evaluation of the quasi sweep value

Computation results of AUC parameter are demonstrated in Table 1. The mean AUC values computed for the technique based on the evaluation of local rms deviation and technique based on the evaluation of bimagnitude maximum equal to 0.678 and 0.8468, respectively.

Table 1. AUC parameter values

AUC (bimagnitude maximum)	AUC (local rms deviation)	AUC (quasi sweep)	Noise variance
0.9382	0.9744	0.4877	0.001
0.9491	0.9745	0.3407	0.01
0.9187	0.9437	0	0.12
0.8876	0.9241	0	0.2
0.8987	0.9276	0	0.4
0.8748	0.0015	0	0.6
0.4608	0	0	0.8

In spite of proposed technique loses by efficiency index (see Table 1) under small noise variance values, proposed technique is certainly more effective as compared to the common techniques in the important case of large noise level. Thus, results of comparative analysis executed for three different techniques and demonstrated in Table1 show both the benefits and drawbacks intrinsic to proposed technique.

5. CONCLUSIONS

Novel technique serving for homogeneities detection in digital images and using information feature evaluated in the form of local estimate of bimagnitude maximum is proposed and studied.

Test image having sharp contrast borders was formed for examination of efficiency index. Proposed technique was compared with two common techniques designed for image homogeneities detection namely the techniques based on the estimation of local rms deviation and evaluation of quasi sweep value. Image borders map was constructed by using proposed and common technique in noise free and additive Gaussian noise environments.

In order to examine the performance of proposed strategy and to compare it with common approchesa, the graphs demonstrated dependence of true probability of classified image areas on false responses (ROC curves) are plotted. It can be seen from the ROC curves that common technique using evaluation of the local rms deviation is more effective for small noise variance. However, for practical important case of increasing noise variance, the benefits take proposed bispectrum-based technique.

Despite proposed technique is worsening as compared with common technique for small noise variances it is more effective for large noise variances. For significant instance, for noise variance equal to 0.6, AUC = 0.8748 for proposed technique.

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