Classification of Image Degradation Using Riesz Transform

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***Abstract* – This paper presents new method for classification of type of image degradation based on the Riesz transform and BRISQUE no-reference quality measure. Riesz transform has great properties and it can be used in many applications. Some of its benefits are: the ability to construct family of steerable wavelets with arbitrary order and any number of dimensions and it can bring the algorithm of filter banks with perfect reconstruction and also go to dimensions higher than two. Statistical properties of MSCN coefficients used by BRISQUE change in presence of distortion and by quantifying this changes with features calculated by using GGD and AGGD model the class of distortion can be determined. We calculated 18 statistical features out of spatial coefficients defined by BRISQUE measure and 19 parameters out of Riesz coefficients to get 37 features in total and then used features as input in SVM regressor in order to identify the type of image degradation. Then, we compared new method with BRISQUE method by using McNemar's statistical test to show statistical significance of our method.**

***Keywords* – image degradation; Riesz transform; BRISQUE; MSCN coefficients; statistical significance**

I. Introduction

Two key factors of image processing and enhancement are scale and directionality. Although signals are represented in time domain it is easier to analyze signals in transform domain.

Mallat [1] gave the foundation of multiresolution theory based on the wavelet transform. Wavelets are functions that are limited in time and can be translated to locate places of interest and scaled in order to analyze signal on different scales. With wavelet transform we can analyze signal in time and frequency domain and define all frequency components of signal and when they will appear [2].

Wavelet transform gives the representation of image that is consisted of summed wavelet functions with different scales and locations [3]. Decomposition of signal into a set of wavelets can be achieved with scaling function for low frequency components and with wavelet function for high frequency components (details). These two functions are translated and scaled on the time axis to give early mentioned set of functions. In the end wavelet transform will give a set of wavelet coefficients. In wavelet analysis image is divided into approximation and details and it is like the signal is passing through the bank of filters. Perfect reconstruction depends on the choice of filters and defines the shape of wavelet functions [3]. Discrete wavelet transform (DWT) connects multiresolution analysis and processing of discrete signals. It can be built by cascading analysis bank of filters in order to first decompose image into approximation (by using scaling function) and details (by using wavelet function) on first level and then each of them again into approximation and details on the second level of decomposition. Filtering results in four subbands with all combinations of highpass and lowpass filters in horizontal and vertical directions. These four subbands are consisted of three detail subbands and one approximation of the image. Reconstruction of decomposed signal can be done by synthesis with conjugate mirror filters used for analysis, but first signals have to be upsampled by 2.

In order to get directionality spatial rotation was added to concept of dilatation. First, Freeman and Adelson [4] steerable filters concept has to be mentioned. Next to mention is the Steerable Pyramid Wavelet Transform (SPWT) that was developed by Simoncelli in 1990s [5] in order to overcome constraints of orthogonality in wavelet decomposition. Steerability in this concept is referred to the property that by computing linear combinations of primary set of equiangular directional wavelet components, wavelets can be rotated to any orientation [6]. The term steerable filter defines class of filters where filter of arbitrary orientation can be obtained by combining set of basis filters. If the responses of basis filter are known, the response of steered filter can be found [4]. Subbands obtained by this transform are translation- and rotation-invariant [7] which is not the case in wavelet transform. SPWT is self-inverting transform which means in this case that the matrix of inverse transform is equal to the transpose of the forward transformation matrix what is known as the term *tight frame* and is also aliasing-free. With this transform any number of orientation bands, k, can be used and disadvantage in sense of computational efficiency is that the SPWT will be overcomplete by a factor of $4k/3$ [5]. The perfect reconstruction is only achievable in frequency domain of filtering.

Steerable wavelets are not ideal solution for the problem of directionality in transform and the connection with wavelet theory would be possible if the continuous-domain transform

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formulation exists [8]. Also, SPWT is not easy to generalize to higher dimensions, which is the reason why the Riesz transform is used. The higher order version of Riesz transform is able to map a primal isotropic wavelet frame of $L_2(\mathbb{R}^d)$ into a directional wavelet with steerable wavelet functions [9] but the cost of this transform is that the frame is not tight. Riesz transform connects properties of work with wavelets through invariance to translation and dilatation and properties of the work with steerable filters through rotation invariance.
It can define filter bank for a specific purpose and does not have restrictions in choice of coefficients for filters so it can be adapted for specific applications.

Riesz transform is suitable for many applications and the one we will mention here is for classification of types of image degradation. This new method for classification will be based on statistical analysis of Riesz transform coefficients and no-reference perceptual quality measure called BRISQUE (Blind/Referenceless Image Spatial QUality Evaluator) [10]. BRISQUE uses statistics of locally normalized luminance coefficients in order to quantify specific loss of naturalness in the image when some sort of distortion is present.

This paper is organized as follows. In Section II. basic concepts of Riesz transform are analyzed. Third section brings some basic information about BRISQUE and how it is used to determine the type of distortion in images. Section IV. shows performance evaluation of the new method for determining the type of image degradation based on Riesz transform and perceptual quality measure BRISQUE.

II. RIESZ TRANSFORM AND ITS BASIC PROPERTIES

The Riesz transform is a multidimensional extension of Hilbert transform [8] and it transforms signal from scalar to vector $\mathcal{R}$ whose frequency domain is defined as follows:

$$\widehat{\mathcal{R}f}(\omega) = -j\frac{\omega}{\|\omega\|}\hat{f}(\omega) \tag{1}$$

where $\hat{f}(\omega)$ is a Fourier transform of d-dimensional input signal $f(x)$. Then we can define d-channel filterbank which can be described in space domain as:

$$\mathcal{R}f(x) = \begin{pmatrix} \mathcal{R}_1 f(x) \\ \vdots \\ \mathcal{R}_d f(x) \end{pmatrix} = \begin{pmatrix} (h_1 * f)(x) \\ \vdots \\ (h_d * f)(x) \end{pmatrix} \tag{2}$$

where the filters $(h_n)_{n=1}^d$ can be characterized with impulse responses $\hat{h}_n(\omega) = -j\,\omega_n / \|\omega\|$ which are antisymmetric $\mathcal{R}_n\{\delta\}(x) = h_n(x) = -h_n(-x)$ and decreasing with $1/\|x\|^d$, where d is the number of dimensions.

The higher order of Riesz operator of components with $\mathbf{n}=(n_1,\ldots,n_d)$ is defined as:

$$\mathcal{R}^n = \sqrt{\frac{|\mathbf{n}|!}{\mathbf{n}!}}\mathcal{R}_1^{n_1}\mathcal{R}_2^{n_2}\ldots\mathcal{R}_d^{n_d}, \tag{3}$$

and normalized so that global transform can keep energy [9].

A. Principles of Riesz operator

First property is invariance meaning that the Riesz transform is translation- and scale-invariant as described in [8]. Riesz transform is also rotation-invariant. Second property refers to steerability. Generalized Riesz transform is steerable in sense that impulse response can be simultaneously rotated into any spatial orientation by forming suitable linear combinations. Riesz transformation is changeable with rotations. Property of steerability can be connected with steerable version of Hilbert transform.

Third property of Riesz transform is inner-product preservation. Riesz transform complies Parseval identity [8].

B. Steerabiliy of higher –order Riesz transform

Steered wavelets are achieved by one-to many mapping of primal wavelets. The shape of steerable wavelet is defined by unitary matrix $\mathbf{U}$ of $M \times M$ size where $M = \binom{N+d-1}{d-1}$ is the number of wavelet channels which can be chosen arbitrarly. This brings higher specter of solutions than the traditional equiangular configuration of steered pyramid [9].

Generalized Riesz transformation of Nth order and coefficients matrix $\mathbf{U}$ is a transformation of scalar to M-vector signal given as follows:

$$\mathcal{R}_{\mathbf{U}} f(\boldsymbol{x}) = \mathbf{U}\mathcal{R}^{(N)} f(\boldsymbol{x}). \tag{4}$$

III. REFERENCELESS SPATIAL IMAGE QUALITY MEASURE

BRISQUE is a referenceless measure which uses natural scene statistics in the spatial domain and can be used for identification of distortion. For a given distorted image it first computes locally normalized luminances via local mean subtraction and normalization. A difference between luminance of an object and its close surroundings in relation to standard deviation is calculated. This applied to the image intensity $I(i,j)$ is defined as follows:

$$\hat{I}(i,j) = \frac{I(i,j) - \mu(i,j)}{\sigma(i,j) + C} \tag{5}$$

where $i = 1,2,\ldots,M$, $j = 1,2,\ldots,N$ are spatial indices, $C = 1$ is a constant, $\mu(i,j)$ local mean and $\sigma(i,j)$ is variance.

These spatial coefficients $\hat{I}(i,j)$ are defined as mean subtracted contrast normalized (MSCN) coefficients. MSCN coefficients have such a behavior that some characteristic statistical properties are changed by degradation of an image what can be seen on Fig. 1 where histograms of original images and images with different types of distortions are plotted. In order to predict the type of degradation these changes are quantified with generalized Gaussian distribution (GGD) model and asymmetric generalized Gaussian distribution

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(AGGD) model which can capture this changes effectively. GGD fits empirical distribution of MSCN coefficients and AGGD fits the empirical distributions of pairwise products of neighboring MSCN coefficients which are considered in horizontal (H), vertical (V) main-diagonal (D1) and secondary-diagonal (D2) orientations. AGGD and GGD parameters are estimated using moment-matching approach mentioned in [10].

First two parameters that are used to determine the type of distortion are two parameters estimated from GGD fit of MSCN coefficients: parameter that controls the shape of distribution and a parameter that controls the variance. Next 16 parameters are estimated from AGGD fit to pairwise products in H, V, D1 and D2 orientations. Four parameters per orientation are calculated: parameter that controls the shape of distribution, left and right variance meaning scale parameters that control the spread on each side of the mode and mean value described in [10]. 18 parameters on the original image scale and on a reduced resolution (the image is filtered with lowpass filter and downsampled by a factor of 2) are calculated for distorted image (total of 36 parameters).

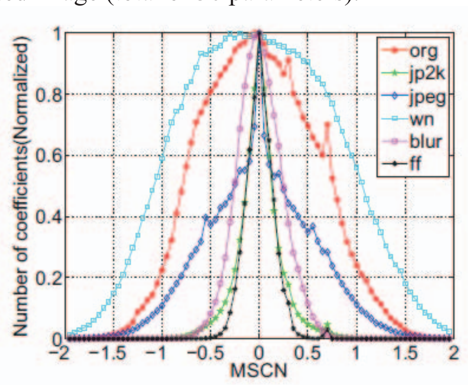

Figure 1. Histogram of MSCN coefficients for image without distortion and different types of distortions for LIVE database [11]; org-original image, jp2k-JPEG2000 compression, jpeg-JPEG compression, wn-additive white Gaussian noise, blur-Gaussian blur, ff-Rayleigh fast fading channel distortion [10]

For mapping from feature space to quality scores LIBSVM packet of support vector machine (SVM) regressor [12] is used.

IV. Performance Analysis of New Method for Determination of Type of Image Degradation

The new method for determination of type of image degradation is combining statistics of MSCN coefficients and Riesz transform coefficients. Early mentioned 18 statistical parameters from MSCN coefficients meaning two out of GGD and 16 out of AGGD fit calculated out of distorted image are used. Also, same 18 statistical parameters from Riesz transform coefficients are calculated. Another parameter of standard deviation for Riesz transform coefficients of high frequency band for primary wavelet pyramid (R band) is calculated for distorted image. For Riesz transform number of scales and channels (number of filters) can be defined. We will get Q structure and high frequency residual band R by using Riesz wavelet tool from [13]. Q structure is consisted out of cells of matrices and every element of the cell corresponds to one wavelet scale. Each element of the cell is 3D matrix whose third dimension is Riesz channel. Scale of two and Riesz order of two are chosen to calculate Riesz coefficients. Q structure is consisted of Q{1,1} cell which defines elements on scale two, Q{1,2} cell which defines elements on scale one and Q{1,3} cell which defines elements of original image and each one is consisted of number of elements filtered with each of three filters (channels). For example, if dimensions of an image are 512x512 elements, then Q{1,1} is composed of 512x512x3 elements (512x512 elements filtered with each filter), Q{1,2} is composed of 256x256x3 elements (256x256 elements filtered with each filter) and Q{1,3} is composed of 128x128x3 elements (128x128 elements filtered with each filter). For calculating 18 statistical parameters from Riesz coefficients structure Q{1,1} filtered with third filter is chosen because it improves the classification while statistics out of coefficients from Q{1,2} and Q{1,3} do not.

Totally 37 parameters are calculated and then LIBSVM is used for classification of type of image degradation. To calculate MSCN coefficients BRISQUE Matlab tool from [14] was used. To calculate Riesz wavelet coefficients the tool from [13] was used. In Fig. 2 channels for Riesz transform are shown.

a) Channel 1 b) Channel 2 c) Channel 3

Figure 2. Channels for Q{1,1} structure of Riesz transform

For the new method the database of distorted images was divided into two groups: the training (about 80% of all images) and the testing group (about 20% of all images). Then, 37 parameters were extracted from images described earlier and used for LIBSVM regressor (train-test procedure) and this was repeated for 1000 iterations and then mean value was calculated. LIBSVM classificator was used with radial basis function (RBF) kernel for classification of four types of degradation with $\gamma = 0.5$ and $C = 100$ to get a model for classification by mapping 37 parameters. Gamma defines the width of Gaussian RBF function and C defines factor of mistake. This was also repeated for BRISQUE method and then this two methods were compared using McNemar's statistical test [15] for LIVE database for four types of degradation. This is a test that calculates whether one of the method is statistically more significant that the other one.

Tables I. – V. show results of statistical significance between BRISQUE method and new method for classification of type of image degradation. '+' indicates that one of the methods is statistically more significant than the other one. '-' indicates that the method is not statistically more significant than the other one. Our method showed better results for JPEG distortion, Gaussian noise and also for all four types of distortion together.

This train-test procedure and then statistical test for comparing methods was done on same database. JPEG was

TABLE I.
MCNEMAR'S TEST FOR 1000 ITERATIONS FOR JPEG2000 DISTORTION FOR LIVE DATABASE

JPEG2000	Accuracy of determining class of distortion (%)	McNemar's exact test	McNemar's Hi-squared test
BRISQUE method	87,14	+	+
New method	87,11	-	-

TABLE II.
MCNEMAR TEST FOR 1000 ITERATIONS FOR JPEG DISTORTION FOR LIVE DATABASE

JPEG	Accuracy of determining class of distortion (%)	McNemar's exact test	McNemar's Hi-squared test
BRISQUE method	85,43	-	-
New method	85,91	+	+

TABLE III.
MCNEMAR'S TEST FOR 1000 ITERATIONS FOR GAUSSIAN NOISE DISTORTION FOR LIVE DATABASE

Gaussian noise	Accuracy of determining class of distortion (%)	McNemar's exact test	McNemar's Hi-squared test
BRISQUE method	97,87	-	-
New method	98,32	+	+

TABLE IV.
MCNEMAR'S TEST FOR 1000 ITERATIONS FOR GAUSSIAN BLUR DISTORTION FOR LIVE DATABASE

Gaussian blur	Accuracy of determining class of distortion (%)	McNemar's exact test	McNemar's Hi-squared test
BRISQUE method	94,27	+	+
New method	93,60	-	-

TABLE V.
MCNEMAR'S TEST FOR 1000 ITERATIONS FOR ALL DISTORTION FOR LIVE DATABASE

4 distortions together	Accuracy of determining class of distortion (%)	McNemar's exact test	McNemar's Hi-squared test
BRISQUE method	90,75	-	-
New method	90,83	+	+

most often mixed with JPEG distortion and vice versa, Gaussian noise with JPEG and Gaussian blur with JPEG2000 distortion.

V. CONCLUSION

In this paper the new method for classification of image degradation which combines BRISQUE no-reference quality measure and Riesz transform was presented.

BRISQUE shows statistically better results than the standard quality full-reference measures or most of no-reference quality measures and can be used for identification of image degradation.

Riesz transform can be used in many different cases. Basis functions do not have to be rotated versions of one another and this transform offers possibility for component subspaces to be rotation-invariant and is also translation- and scale-invariant.

We have shown statistical analysis of new method using McNemar's test for four types of degradation and all degradations together. We compared BRISQUE method and new method on LIVE database and got statistically more significant results for JPEG degradation, Gaussian noise and generally for four degradations together. Gaussian blur is a specific distortion (similar is JPEG2000) for which BRISQUE method has shown better results.

For further researching training will be done on groups of images for one database and testing on group of images for different database of images which will show that this new method can be applied on any image/images with distortion.

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