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Proyecto Fin de Carrera

Evaluación objetiva de la influencia del canal inalámbrico en la calidad de la imagen

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Summary

The main part of this project is the simulation of radio communication channel which includes: JPEG coder/decoder, BPSK modulator/demodulator, AWGN channel and additional matlab boxes. The purpose of this project was to see how the parameters and characteristics of radio communication channel make the influence on the image. An image assessment with objective and subjective metrics was made on random base of images. Validations of these results were shown on another base of images WIQ, where images had typical distortions for a radio communication channel. It was shown that objective metrics does not always correlate with subjective metrics. Human visual system is still an unexplored task. It is still not impossible to make the mathematical model of assessment that works and assess like human visual system. Objective methods cost less and it is easier to perform them while subjective methods take more time and results cannot be predicted. It is not possible to say which method has more effective results because both methods are very important for evaluation of image quality.

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1 Introduction

Service quality is important in Broadcasting, Internet and Telephony. Traditional mobile devices were used for voice services, and today, wireless image and video applications are on every modern mobile device. It is a challenge for network operator to deliver high quality image to customer. During image transmission through radio systems the image can get many kinds of distortions which are connected with characteristics and parameters of radio-communication channel. The most of objective image assessment is based on evaluating distortions caused with image compression while to distortion generated in a radio communication channel is not given much attention.

In this work it will be made a simulation of radio communication channel which will include JPEG coder, modulation, radio channel and receiver. Here will be chosen a base of images for transmission and analyzed how the parameters of the channel influence on type and degree of distortion that happens while transmission. After classification of objective image assessment and after processing the results, the results will be compared to the one from subjective metrics. Verification of the results will be made on a base of images WIQ[1] which contains typical distortions for radio communication channel and their subjective grades.

[1] The Wireless Imaging Quality

2 Radio-Communication Channel

To evaluate distorted images one has to have a radio-communication channel like the one shown in the Figure 1. The images are sent through the radio-communication channel and in the end they are saved on a computer. The source is the block *Image From File* and as the name says, any image from file can be chosen to go through that channel. Then, in the block *Embedded MATLAB Function* is written a code for JPEG[2] coder (because in MATLAB Simulink there is no block for JPEG coding) the images are limited on the size written in the code. JPEG coder is the first block in the channel that influence on quality of the image. The parameters of JPEG coder can be changed and that's how it can influence on quality of the image. The next two blocks are *Frame Conversion* and *Integer to Bit Converter*, they prepare a format of data to the next block *BPSK Modulator Baseband*. *BPSK Modulator Baseband* expects data to be in one vector (not matrix) and binary. This block does the BPSK modulation (Binary Phase Shift Keying Modulation) and it only has two conditions of relative phase of modulated signal (*1* or *0*). The BPSK modulation has small spectral efficiency but has high resistance to interference and that's why it is used here in this channel. The quality of the image can be changed by changing the Phase Offset in this block. Then there is the *AWGN Channel* which simulates radio channel with additive white Gaussian noise and this is the block were the noise influence on image. In this block the signal to noise ratio can be changed and that's how the quality of image can be regulated, also if the field *Initial seed* is changed the seed for the Gaussian noise generator changes. The next block is *BPSK Demodulator Baseband* because of the fact that in the end of the channel is wanted the real (almost original) image. The blocks *Bit to Integer Converter* and *Embedded MATLAB Function* are used for giving back the format of data that is needed for the image display. At the end of simulation the image is saved on the computer with the block *To Workplace* and it can be seen instantly because of the block *Video Viewer.*

[2] Joint Photographic Expert Group – in computing is a commonly used method of lossy compression for digital photography (image).

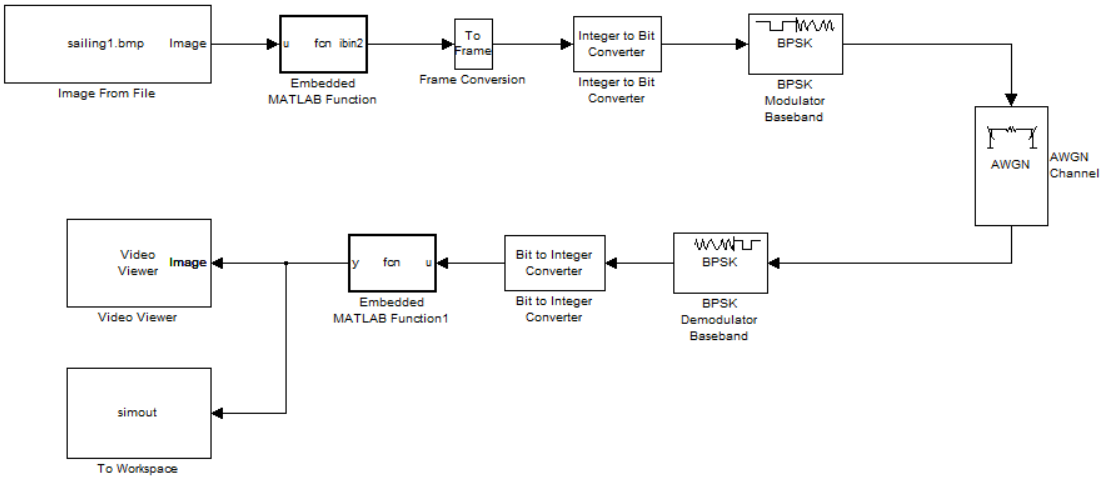

Figure 1. Radio-communication channel

2.1 Image artifacts made in the channel

Image artifacts can be made in the channel because of transmission errors or because of the image compression. In this channel is used JPEG coder and its characteristics are that a bit error location can have significant impact on image degradation. If the decoder fails to recognize the compressed image, the image can be completely lost.

Figure 2. Images with image artifacts as follows: blurring, blocking, ringing, masking and lost blocks

There can be five types of image artifacts:

Smoothness or blurring is when the received image is smoother than the original. Mathematical Blurring is described with PSF (Point Spread Function). PSF function does what the name of the function says-spread the pixel on the neighbor pixels. It can appear as edge smoothness or texture blur.

Blocking appears in the image because of the compression techniques and it appears in the image as visible edges at the block boundaries.

Ringing appears as periodical pseudo edges around the original edges.

Masking is reduction of the visibility of one image component because of the masker. It can be seen in two ways: as luminance masking or texture masking.

Lost block is when one or more pixels in the image alternate in their value from their neighbors pixels [8].

3 Objective metrics for Image Evaluation

Three types of knowledge can be used for the design of image quality measure:

- knowledge about the “original image”,
- knowledge about the distortion process,
- knowledge about the HVS.

Objective metrics are divided by the knowledge about reference image on:

- full reference (FR) – radio channel has all information about original image,
- reduced-reference (RR) – the radio channel has a low-bandwidth used for information from reference image,
- no-reference (NR) – the radio channel hasn’t any information about original image.

Mean Squared Error (MSE) measures the average of the squares of the "errors." In image evaluation it measure difference in pixel values between the original and the image transmitted through the channel. MSE for the two *m*×*n* monochrome images *I* and *K* (one of the images is a noisy approximation of the other) is defined as [8], [11]:

$$MSE = \frac{1}{m\,n}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}[I(i,j) - K(i,j)]^2 \qquad (1)$$

Standard measure (MSE) does not agree with human visual perception.

Peak Signal to Noise Ratio (PSNR) puts in a ratio the maximum possible power of a signal and the power of corrupting noise that effect on a signal. PSNR is usually expressed in logarithm decibel scale. The most commonly PSNR is used in image compression. The signal is then the original data, and the noise the error introduced by compression. This metric is valid only when is used to compare results from the same codec. Otherwise,

some results measured with human eye may appear better, even though they have lower PSNR. Image fidelity is an indication about the similarity between the reference and distorted images and measures pixel-by-pixel closeness between those pairs. The PSNR is the most commonly used fidelity metric. It is most easily defined via MSE.

The PSNR is defined as:

$$PSNR = 10 \cdot \log_{10}\left(\frac{MAX_I^2}{MSE}\right) = 20 \cdot \log_{10}\left(\frac{MAX_I}{\sqrt{MSE}}\right) \quad (2)$$

MAX is the maximum pixel value.

Typical values for the PSNR in lossy image and video compression are between 30 and 50 dB, where higher is better. Acceptable values for wireless transmission quality loss are considered to be about 20 dB to 25 dB [9], [11].

Because of the problems said before, PSNR does not correlate well with the visual quality as perceived by the human eye.

In general, there are two approaches for visual quality metrics; simple numerical and feature based metrics on the one hand and HVS based metrics on the other hand. The best examples for the numerical metrics would be mean squared error (MSE) and peak signal to noise ratio (PSNR). MSE and PSNR measure similarity between two images pixel by pixel, and these are also the RR methods. These measures can measure distortions but they cannot quantify visual quality done by a human observer. These metrics don't recognize different distortion types and also cannot recognize if only the part of image is distorted.

The Normalized Hybrid Image Quality Metric (NHIQM) is an objective quality metric that is developed based on structural feature differences between the reference and test image. Higher value indicates stronger distortions and worse quality. The metric Mean

Opinion Score (MOS)[3] is based on NHIQM and predicts subjective quality scores by taking into account the non-linear visual quality processing in the HVS. The metric ranges from 0 to 100 and higher values indicate superior quality. While PSNR is not able to quantify the distinct quality differences between the two test images, both NHIQM and MOS distinguish very well between the qualities of the test images. The NHIQM correlate good with characteristics of the HVS. The NHIQM compute structural features just like the HVS, on the other hand PSNR metric is not able to accurately quantify perceptually relevant structural degradations in an image [1].

The FR methods are: the structural similarity (SSIM) index, visual information fidelity (VIF) criterion, and the peak signal to noise ratio (PSNR).

The SSIM is a method for measuring similarity between two images. It is a full-reference metric, based on measuring structural distortions in images by comparing luminance, contrast, and structures of objects in a scene. The final outcome of the comparison, the SSIM index, quantifies the structural similarity between the reference and the distorted image. The measuring between two windows *x* and *y* of common size is:

$$\mathrm{SSIM}(x,y) = \frac{(2\mu_x\mu_y + c_1)(2\sigma_{xy} + c_2)}{(\mu_x^2 + \mu_y^2 + c_1)(\sigma_x^2 + \sigma_y^2 + c_2)} \tag{3}$$

with

- μ_x the average of *x*
- μ_y the average of *y*
- σ_x^2 the variance of *x*
- σ_y^2 the variance of *y*
- σ_{xy} the covariance of *x* and *y*
- $c_1=(k_1L)^2$, $c_2=(k_2L)^2$ two variables to stabilize the division with weak denominator;
- L the dynamic range of the pixel-values (typically this is $2^{\#\text{bits per pixel}}-1$);
- $k_1=0.01$ and $k_2=0.03$ by default.

[3] The Mean Opinion Score (MOS) is a subjective metric for image evaluation.

SSIM index have values between -1 and 1, if two images are identical then the value would be 1.

The Structural dissimilarity (DSSIM) is a distance metric derived from SSIM [10], [11].

$$\mathrm{DSSIM}(x,y) = \frac{1}{1 - \mathrm{SSIM}(x,y)} \tag{4}$$

The VIF criterion is centered around exploring information theoretical measures to quantify the loss of image information due to the distortion process. In this sense, the VIF criterion uses natural scene statistics to connect image information with visual quality [1].

Metrics based on feature measures correlate better with human perception and the metrics based on HVS mostly use the FR approach, which means that the reference image is available for quality assessment. If the application is made to correlate better with human visual system (HVS) than it has much higher complexity. The FR method in the real radio-communication channel doesn't exist. On the other hand, NR methods are very rare. The compromise is RR method. A set of image features are sent through an ancillary channel or they are embedded into the image using data hiding techniques, and receiver uses them to quantify the quality degradations. This is the engineering approach.

3.1 Full Reference and Reduce Reference

Image quality measure can be designed by knowledge about the “original image”. What does it really mean the “original image”? It is the image that is assumed to be sent via transmitter, through the radio channel to receiver. However, receiver gets the image with distortions. That image we compare to the one that was at the transmitter, the one without distortions with perfect quality. That’s why the “original image” is also called a reference. If all the information about the original (reference) image is known than the metric is called a full-reference (FR). So far, none of the algorithms for objective metrics are designed blindly, without a reference (NR). It is a very difficult task, although the human observer can very easily say which image is perfect and which is distorted without any reference at all. Human brain has a knowledge how an image should or should not look like. The reduce-reference (RR) is the third type of image quality assessment method. The features are extracted from the original image and sent through the auxiliary channel as side information to help evaluate the quality of distorted image.

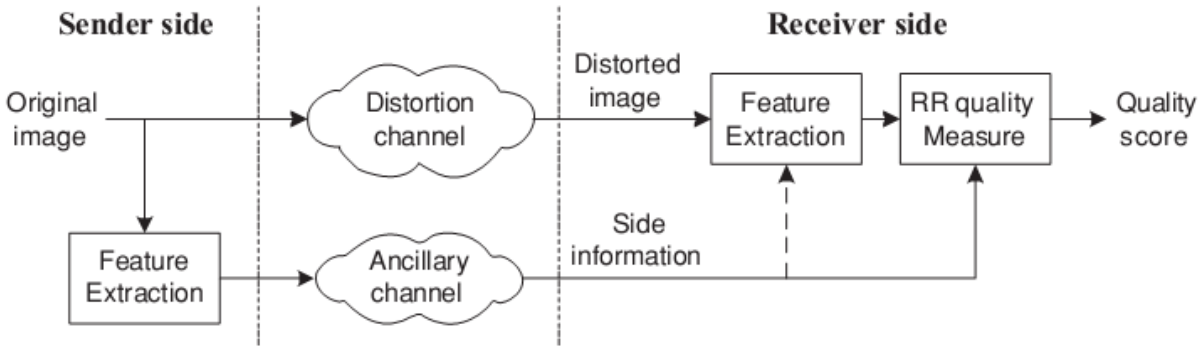

Figure 3. Diagram of reduce-reference image quality assessment system

The image quality assessment is also divided on General-Purpose and Application-Specific image quality measures. General-Purpose are used when the specific distortion type is not known and the Application-Specific when we are sure that exact distortion happened on the image.

The third criterion to divide objective quality measures is based on simulating the quality evaluation behavior of HVS; Bottom-Up and Top-Down quality measures. Bottom-Up approach is simulating HVS, and Top-Down is much simpler because it treats HVS like a black box and only input-output relationship is of concern.

4 Subjective metrics for Image Evaluation: DSIS and DSCQS

The Double Stimulus Impairment Scale (DSIS) is a subjective method. Assessor is first presented original image, then the image which is transmitted through the channel. After observing, the assessor has to evaluate the image quality. Grades are 5 (imperceptible), 4 (perceptible but not annoying), 3 (slightly annoying), 2 (annoying) and 1 (very annoying).

The Double Stimulus Continuous Quality Scale (DSCQS) is a subjective method where assessor is presented images in pairs, first the original and then the one transmitted through the channel, or inverse. The difference is that the assessor doesn't know which one is original. The assessor puts marks on a vertical grading scale for each image. In the end there are grades (from 0 to 100) for original images and for distorted images and the difference between the original and distorted images.

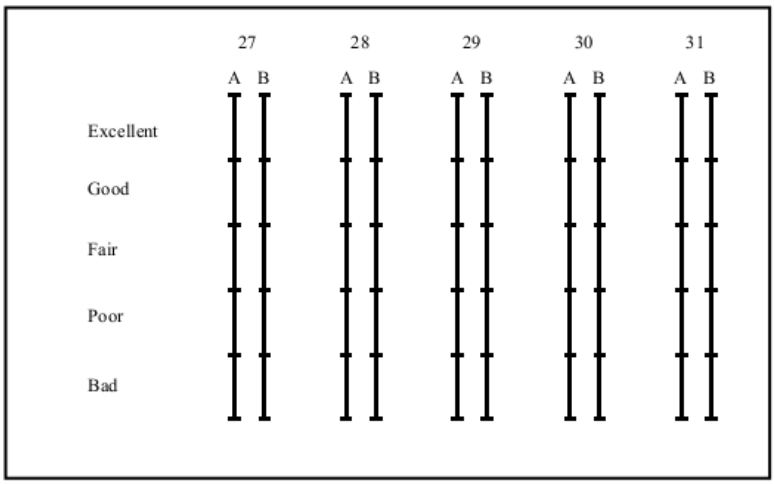

Figure 4. Quality scale in method DSCQS

5 Image Comparator

Program that will be used for image evaluation is *Image Comparator*. The program is simple, first two images have to be chosen then on click compare the program gives results for MSE, PSNR, SSIM and DSSIM. If images are the same the results would be: MSE=0, PSNR=Undefined, SSIM=1 and DSSIM=Undefined, in the opposite, if images are completely different MSE would have really big value, PSNR would depend on the similarity of pixels, SSIM would tend to be zero and DSSIM in the opposite would have value bigger than 1. After objective evaluation the results will be compared to the one with subjective evaluation.

Figure 5. *Image Comparator*,
the images that are compared: t01_img_001 and ref_img_004

The images that will be chosen here will be at first minimum and later much more distorted. For every image that will be compared there will be objective and subjective scores entered into the table.

6 Image assessment

Here will be chosen black and white and color images and sent through the radio channel with various characteristics: low or high PSNR, different phase offset and different quality of JPEG coder. According to characteristics of the channel the images will have different distortions. It will be seen how different image artifacts affect on image assessment. First few images will be evaluated with objective metrics only. Then, the other images will be evaluated with objective and subjective metrics both. In the end, it will be able to come to the conclusion which metrics are better and which correlate one with another.

6.1 Quality of image by MSE, PSNR, SSIM and DSSIM

Example 1.

Figure 6. Original image Alone, distorted images: Alone 1, Alone 2, Alone 3 and Alone 4

Table 1.

Metric	Alone 1	Alone 2	Alone 3	Alone 4
MSE	167,7602	4332,5669	7046,92395	2899,54515625
PSNR	25,8839142565404	11,7633508340544	9,65080776226548	13,5075048421841
SSIM	0,966218169712243	0,859624069180952	0,824741836198171	0,681479489960073
DSSIM	29,6017116740541	7,12372836401032	5,70586829342077	3,13951525405585

Image with highest MSE value and lowest PSNR value is image Alone 3, and image with lowest SSIM value is image Alone 4. In both images appear luminance masking, but in image Alone 3 is much less represented. These are the images with the lowest quality measured by objective metrics. Image Alone 1 is image with highest quality measured by objective metrics. This image has ringing.

Example 2.

Figure 7. Original image Las Fallas, distorted images: Las Fallas 1, Las Fallas 2, Las Fallas 3 and Las Fallas 4

Table 2.

Metric	Las Fallas 1	Las Fallas 2	Las Fallas 3	Las Fallas 4
MSE	1477,72862745829	7421,81955011064	1818,96728698938	6425,73020001989
PSNR	16,4348567404749	9,42569969915225	15,5325547225399	10,0515787418438
SSIM	0,769535462623814	0,277574728366565	0,785150510486946	0,183872891002817

DSSIM	4,3390623624133	1,38422621586722	4,65442111250276	1,22529933018492

Image with highest MSE value and lowest PSNR value is image Las Fallas 2, image with lowest SSIM index is image Las Fallas 4. These are the images with lowest quality measured by objective metrics. Image Las Fallas 1 has the lowest MSE value and highest PSNR value and image Las Fallas 3 has the highest SSIM index. The amount of image artifacts in these images is big and image artifacts that appear here are luminance masking and lost blocks.

Example 3.

Figure 8. Original image Playa, distorted images: Playa 1, Playa 2 and Playa 3

Table 3.

Metric	Playa 1	Playa 2	Playa 3
MSE	643,654026924894	2069,0249015903	7004,37832624783
PSNR	20,0442787017276	14,9731464325284	9,67710765351929
SSIM	0,836970640239942	0,944553076265813	0,469462344116335
DSSIM	6,13386448595378	18,0352656676502	1,88488034526861

Image with highest MSE value, lowest PSNR and lowest SSIM index value is image Playa 3. This is the image with lowest quality measured by objective metrics. Image Playa 1 has the lowest MSE value and highest PSNR value and image Playa 2 the highest SSIM index and these are the images with best quality measured by objective metrics.

Example 4.

Figure 9. Original image La Orotava, distorted images: La Orotava 1, La Orotava 2 and La Orotava 3

Table 4.

Metric	La Orotava 1	La Orotava 2	La Orotava 3
MSE	1644,12658515585	1711,76330892932	5442,20775211789
PSNR	15,9714510902745	15,7963664768355	10,7730524424809
SSIM	0,703818816663439	0,654385379370883	0,497031938156464
DSSIM	3,37631171816768	2,89339611321916	1,98819781187435

In the images La Orotava 1, La Orotava 2 and La Orotava 3 appears luminance masking. Depending on the amount of masking the objective image evaluation gives different

ratings. La Orotava 1 has the smallest amount of masking and has the smallest MSE value, highest PSNR value and highest SSIM and DSSIM index.

6.2 Image quality measured by objective and subjective metrics

The conclusion for objective metrics is that objective metrics doesn't always match one with the other. The one that give always proportional results are MSE and PSNR. SSIM is a different metric that measure structural similarity between two images and it is supposed that this metrics should correlate better with the subjective metrics. Subjective metrics that will be used here are DSIS and DSCQS.

Example 5.

Figure 10. Original image Port, distorted images Port 1, Port 2, Port 3 and Port 4

Table 5.

Metric	Port 1	Port 2	Port 3	Port 4
MSE	1077,84625547373	1645,15729459243	2994,47432219242	3787,74677724552
PSNR	17,8052354358049	15,9687293341004	13,3675976753449	12,3469942351474
SSIM	0,708737211841071	0,857122629692356	0,512775804851718	0,538695457813725
DSSIM	3,43332564493046	6,99900899524395	2,05244322830819	2,16776534490788
DSIS	3,375	2,625	1,9375	1,375
DSCQS	60,5	44,5	28,5	16,5
DSCQS differential	33,8125	49,8125	65,8125	77,8125

Images with highest MSE value, lowest PSNR value, lowest SSIM, DSIS and DSCQS are images Port 3 and Port 4. These are the images with lowest quality measured by objective and subjective metrics. Image Port 1 has the lowest MSE value, highest PSNR value and highest DSIS and DSCQS value, because of that, this is the image with best quality of all distorted images. Image Port 2 has the highest SSIM index. Here SSIM does not match with subjective or other objective metrics.

Example 6.

Figure 11. Original image Garden, distorted images Garden 1, Garden 2, Garden 3 and Garden 4

Table 6.

Metric	Garden 1	Garden 2	Garden 3	Garden 4
MSE	2288,37913710471	1285,98035191996	1463,90536784721	1066,29718992529
PSNR	14,5355238117019	17,0384602767468	16,4756735760872	17,8520209618058
SSIM	0,357545825251636	0,790271744952383	0,584724074839181	0,758630895689778

DSSIM	1,55653125048441	4,76807476309264	2,40803749847223	4,14303231914363
DSIS	3,75	2,875	3,0625	1,0625
DSCQS	52,8125	62,875	58,75	9,6875
DSCQS differential	38	27,9375	32,0625	81,125

Image with highest MSE value, lowest PSNR and lowest SSIM index is image Garden 1, in the same time this image has highest DSIS value. This is the image with lowest quality measured by objective metrics and high measured with subjective measures. This image has a lot of luminance masking what human eye doesn't bother so much, but for objective metrics this is a big distortion. Image Garden 4 has the lowest MSE value and highest PSNR value and image Garden 2 has the highest SSIM index and these are the images with best quality measured by objective metrics. Image Garden 4 has the lowest quality measured in subjective metrics because the luminance masking has a strong and irritating color for human eye.

Example 7.

Figure 12. Original image Calblanque, distorted images: Calblanque 1, Calblanque 2, Calblanque 3 and Calblanque 4

Metric	Calblanque 1	Calblanque 2	Calblanque 3	Calblanque 4
MSE	798,285295373926	2648,83164862575	32,9068110854018	293,289149636479
PSNR	19,1092223134229	13,9002600407927	32,9579456289794	23,4578436450914
SSIM	0,923096586205341	0,737225572972772	0,915494790326604	0,855369533544067
DSSIM	13,0033239183648	3,8055453542912	11,8335899510207	6,9141725426481
DSIS	2,375	2,125	1,9375	1,5625
DSCQS	27,0625	42,5625	42,75	24,25

DSCQS image quality differential	54,6875	39,1875	39	57,5

Table 7.

Images Calblanque 1, Calblanque 2, Calblanque 3 and Calblanque 4 have a lot of luminance masking, ringing and lost blocks. Calblanque 2 has the lowest SSIM index, highest MSE value and lowest PSNR value. Image with best quality measured with SSIM, DSSIM and DSIS is image Calblanque 1, although this image has lower PSNR than 20 dB.

Example 8.

Figure 13. Original image Pyramid, distorted images: Pyramid 1, Pyramid 2 and Pyramid 3

Table 8.

Metric	Pyramid 1	Pyramid 2	Pyramid 3
MSE	259,828411666667	4420,11897566667	9332,138942
PSNR	23,9839372238568	11,6764640152332	8,43099164683754
SSIM	0,861763465164199	0,485577567512089	0,399086575019184
DSSIM	7,23397762529139	1,94392766886872	1,66413323189097
DSIS	4	2,6875	1,4375
DSCQS	82,0625	52,0625	19,6875
DSCQS differential	11,5625	41,5625	73,9375

Image with highest MSE value, lowest PSNR value, lowest SSIM index and lowest DSIS and DSCQS value is image Pyramid 3. Image Pyramid 1 has highest quality measured by

objective and subjective metrics. Image artifacts represented in these images are luminance masking and lost blocks. By increasing amount of these artifacts in the image the image quality is reducing. Subjective metrics DSIS and DSCQS match with the results from objective metrics.

Example 9.

Figure 14. Original image FER, distorted images: FER 1, FER 2 and FER 3

Metric	FER 1	FER 2	FER 3
MSE	1161,81899447917	1906,56607262258	2397,9337712508
PSNR	17,479418884264	15,328285003911	14,3324317675792
SSIM	0,815282620615313	0,750284180237218	0,897323360441626
DSSIM	5,41367576419233	4,00455205821543	9,73931367739667
DSIS	3,75	2,9375	3,5625

DSCQS	60,8125	54,5	80,5625
DSCQS differential	35,5	41,8125	15,75

Table 9.

Although, almost the whole image FER 3 has luminance masking and has the lowest results in MSE and PSNR, the SSIM index and DSCQS value are the highest. This is because in other images beside luminance masking appears also the lost blocks.

Example 10.

Figure 15. Original image Burn, distorted images: Burn 1, Burn 2 and Burn 3

Table 10.

Metric	Burn 1	Burn 2	Burn 3
MSE	2123,72697482639	634,527594039352	6853,31052372685
PSNR	14,8598167752997	20,1062984763113	9,77179950707338
SSIM	0,581314965886711	0,709028865352506	0,426693791622837
DSSIM	2,38843024833177	3,43676702230783	1,74426856954971
DSIS	3,125	3,5	1,3125
DSCQS	41,3125	64,5	13
DSCQS differential	48,8125	25,625	77,125

The image with lowest quality measured with objective and subjective metrics is image Burn 3 and the image with highest quality measured by objective and subjective metrics is image Burn 2. This is because the image Burn 3 has the highest phase offset and lowest PSNR. This entails that this image has the most of luminance masking and block lost, there are more pixels than in other images with different values and because of that the results are the lowest.

Example 11.

Figure 16. Original image Los Gigantes, distorted images: Los Gigantes 1, Los Gigantes 2 and Los Gigantes 3

Table 11.

Metric	Los Gigantes 1	Los Gigantes 2	Los Gigantes 3
MSE	3195,35060320248	1282,11625446262	747,660023866246
PSNR	13,0856184369982	17,0515295473149	19,3937620060164
SSIM	0,448508952648928	0,870405541794233	0,874798884746318
DSSIM	1,81326606261917	7,71637934094547	7,98714929953944
DSIS	3,5	3	2,5625
DSCQS	50,8125	51,4375	47,25
DSCQS differential	44,5	43,875	48,0625

The image Los Gigantes 1 has the highest MSE index, and lowest PSNR, SSIM and DSSIM and because of that the lowest image quality measured in objective metrics. The image Los Gigantes 3 has the highest quality measured with objective metrics. Subjective metrics give a little bit different results. The image Los Gigantes 1 has the highest DSIS value, and image Los Gigantes 2 highest DSCQS value and image Los Gigantes 3 is image with lowest image quality measured with both subjective metrics. Conclusion would be that ringing in the image influence on objective metrics much more than luminance masking and in subjective metrics is exactly the opposite case.

Example 12.

Figure 17. Original image Bridge, distorted images: Bridge 1 and Bridge 2

Table 12.

Metric	Bridge 1	Bridge 2
MSE	287,349341	2375,37352766667
PSNR	23,5467015539747	14,3734844869685
SSIM	0,893026794538192	0,448308203008056
DSSIM	9,34813531746527	1,81260625126642
DSIS	4,6875	3,1875
DSCQS	87,6875	48
DSCQS differential	7,125	46,8125

In the image Bridge 1 there is intensity masking and on Bridge 2 beside intensity masking there is also a ringing. Image Bridge 2 because of that have lower image quality (higher MSE value, lower PSNR, lower SSIM and DSSIM index, lower DSIS and DSCQS). In these images subjective and objective metrics match.

Example 13.

Figure 18. Original image Palma de Mallorca, distorted images: Palma de Mallorca 1, Palma de Mallorca 2 and Palma de Mallorca 3

Table 13.

Metric	Palma de Mallorca 1	Palma de Mallorca 2	Palma de Mallorca 3
MSE	241,181871296296	1963,28903796296	2828,90408055556
PSNR	24,3073570040093	15,2009611916309	13,6146213875262
SSIM	0,96384707068511	0,65314991811927	0,798067318148391
DSSIM	27,6602759154055	2,88308999259186	4,95214539236821
DSIS	3,9375	3,25	1,9375
DSCQS	69,5	58,6875	28,6875
DSCQS differential	27,0625	37,875	67,875

Image with best and acceptable quality, measured with objective and subjective metrics, is image Palma de Mallorca 1. In image appears light luminance masking. Because of the ringing in image Palma de Mallorca 2, SSIM value doesn't match with subjective metrics. Lowest image quality measured with MSE, PSNR, DSIS and DSCQS has image Palma de Mallorca 3.

Example 14.

Figure 19. Original image Ship, distorted images: Ship 1, Ship 2 and Ship 3

Table 14.

Metric	Ship 1	Ship 2	Ship 3
MSE	49,7616122654132	3060,53316239343	2364,1732895313
PSNR	31,1618591791045	13,2728327121129	14,3940105450937
SSIM	0,927562980906184	0,403117729964951	0,682217658554082
DSSIM	13,8050959648803	1,67537226384908	3,14680795493536
DSIS	5	3,8125	1,875
DSCQS	93,0625	73,125	27,0625
DSCQS differential	0,75	20,6875	66,75

The image with best quality measured in MSE, PSNR, SSIM, DSSIM, DSIS and DSCQS is the image Ship 1. In the whole image appears only lost block to human eye barely visible. In images Ship 2 and Ship 3 objective and subjective metrics don’t match.

Example 15.

Figure 20. Original image Valencia, distorted images: Valencia 1, Valencia 2 and Valencia 3

Table 15.

Metric	Valencia 1	Valencia 2	Valencia 3
MSE	2134,53049415216	1319,08056143675	3033,76549017326
PSNR	14,8377799730189	16,9280904043981	13,3109835404804
SSIM	0,899545894388389	0,493123482620504	0,446428322670838
DSSIM	9,95479471855863	1,97286709033179	1,80645080114058
DSIS	3,25	3	1,8125
DSCQS	51,6875	52,0625	25,125
DSCQS differential	45,625	45,25	72,1875

Because of the luminance masking all the images have lower PSNR than 20 dB. But SSIM finds image Valencia 3 as the image with lowest quality. In this image appears ringing, lost blocks and luminance masking.

Example 16.

Figure 21. Original image Nature, distorted images: Nature 1, Nature 2 and Nature 3

Table 16.

Metric	Nature 1	Nature 2	Nature 3
MSE	1263,3240630789	1146,83768665146	1518,27047996172
PSNR	17,1156559245469	17,5357840484962	16,3173121283232
SSIM	0,537599500297217	0,527031248578342	0,521103088568738
DSSIM	2,16262742069433	2,11430458565007	2,08813207212245
DSIS	2,8125	1,8125	1,375
DSCQS	41,9375	24,125	15,3125
DSCQS differential	53,875	71,6875	80,5

These images have lower quality than it is acceptable. Image with best quality measured in SSIM, DSIS and DSCQS is image Nature 1.

6.3 Image Evaluation on a base of images WIQ

WIQ database consists of 7 undistorted reference images, 80 distorted test images, and quality scores rated by human observers that have been obtained from two subjective tests. The first test (T1) was conducted at the Western Australian Telecommunications Research Institute in Perth, Australia, and the second test (T2) at the Blekinge Institute of Technology in Ronneby, Sweden. In each test, 40 distorted images along with the 7 reference images were presented to 30 participants. The quality scoring was conducted using a Double Stimulus Continuous Quality Scale (DSCQS). The difference scores between reference and distorted image were then averaged over all 30 participants to obtain a Difference Mean Opinion Score (DMOS) for each image.

Here will be used only the T1 images and results which we'll be compared to the results of objective metrics.

GENERAL NOTATION FOR IMAGES AND OTHER DATA

The 7 reference images have unique names as follows:

- 'ref_img_XXX.bmp'

where XXX indicates the number of the reference image.

The distorted test images have unique names as follows:

- 'tYY_img_ZZZ.bmp'

where YY indicates the test in which the test image has been presented, ZZZ indicates the number of the distorted test image.

In general:

- ref - reference image
- dst - distorted (test) image
- t01 - test 1 (Perth, Australia)

- t02 - test 2 (Ronneby, Sweden)[4] [2], [3]

Figure 22. The referent images from WIQ base with unique names as follows:

ref_img_001, ref_img_002, ref_img_003, ref_img_004, ref_img_005,

ref_img_006 and ref_img_007

[4]WIQ_readme, Ulrich Engelke

Example 17.

Figure 23. Distorted images,

t01_img_001, t01_img_010, t01_img_020, t01_img_034, t01_img_036 and t01_img_040

Table 17.

Metric	t01_img_001	t01_img_010	t01_img_020
MSE	6,79782104492188	39,7086982727051	125,268135070801
PSNR	39,8071063342845	32,1419471057681	27,1523974895499
SSIM	0,976958199428365	0,985405843899253	0,993155005644881
DSSIM	43,3993861239738	68,5205772157555	146,092158462072
MOS	93,73333	59,83333	51

Table 18.

Metric	t01_img_034	t01_img_036	t01_img_040
MSE	6933,09178161621	1257,84296035767	246,65064239502
PSNR	9,72153411356342	17,1345393733207	24,2099810995988
SSIM	0,738361287436448	0,640281785253339	0,687147675670887
DSSIM	3,82206436578876	2,77995374992137	3,19639626186068
MOS	24,1	15,6	8,333333

Human eye can just by a quick look on these 6 images see that first image has the least degradations and the last one the most, and that's how the MOS results look like; first image has MOS value over 90 and the last one less than 10. The highest MSE value has image t01_img_034 because MSE measures image degradations pixel by pixel, and by a simple view on the images it can be seen that this image has about ¾ of all pixels lighter than the pixels in original image. Lowest PSNR has the same image because of the same reason. The lowest SSIM index has image t01_img_036 and the second one is image t01_img_040, because image t01_img_036 has the most different structures of object in the scene and image t01_img_040 has the highest luminance and the smallest contrast. Lowest DSSIM index have, logically, images t01_img_034, t01_img_036 and t01_img_040.

Example 18.

Figure 24. Distorted images,

t01_img_013, t01_img_030 and t01_img_039

Table 19.

Metric	t01_img_013	t01_img_030	t01_img_039
MSE	88,7287101745605	561,291343688965	329,997417449951
PSNR	28,6501619252537	20,6389201634484	22,9456981975252
SSIM	0,790642743827714	0,709208338021443	0,351231427329761
DSSIM	4,77652419736087	3,43888814829133	1,54138169160097
MOS	54,83333	35,46667	12,2

Images are again sorted by image distortions. Imaget01_img_013 has the highest MOS value, but the value is around 50 what means that image has some distortions (lighter pixels at the upper part of the image). Image t01_img_039 has the lowest MOS value. Image with the smallest PSNR value is image t01_img_030. This is an interesting result because image t01_img_039 has the smallest MOS value and it is expected that it should have the smallest PSNR value too. With PSNR one has to be careful because in some cases one image may appear to be closer to the original than another, even though it has a lower PSNR. It has the best results when it is used to compare results from the same codec or codec type and same content. SSIM values are as expected; the value of image t01_img_013 is the highest, although not even close to 1, also because of lighter pixels in the upper part of the image.

Example 19.

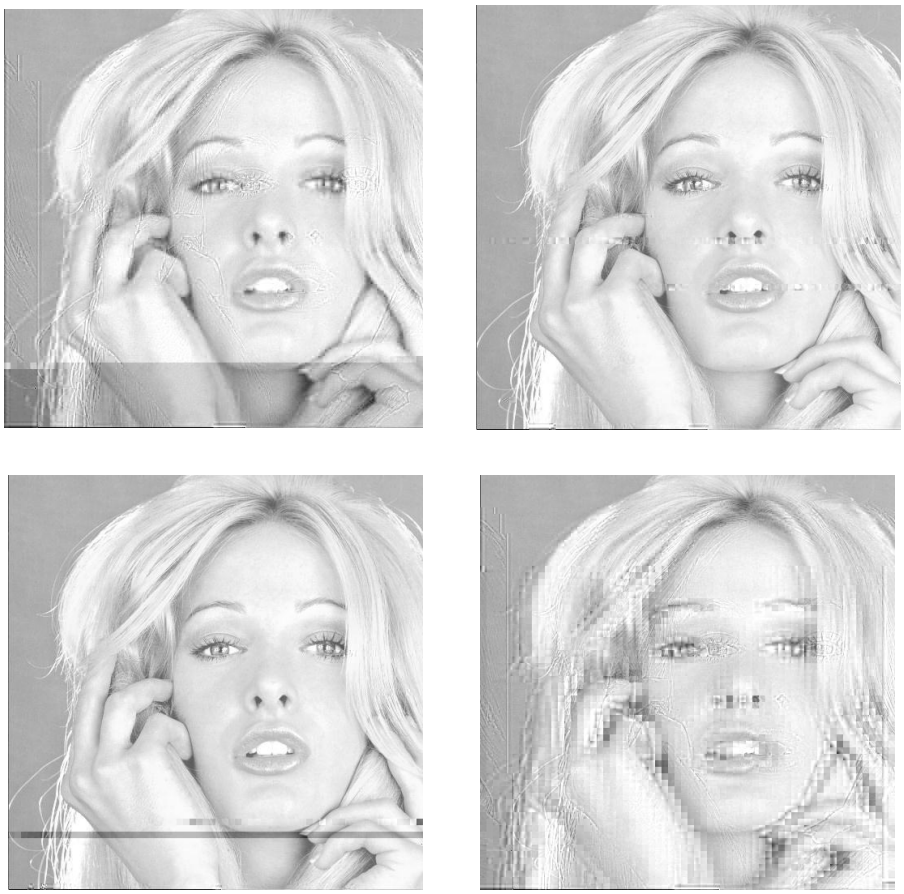

Figure 25. Distorted images,

t01_img_012, t01_img_022, t01_img_029 and t01_img_038

Table 20.

Metric	t01_img_012	t01_img_022	t01_img_029	t01_img_038
MSE	73,5470886230469	17,4748802185059	313,491371154785	249,610252380371
PSNR	29,465148751024	35,7066615330972	23,1685476948566	24,1581794147299
SSIM	0,992969113568198	0,972314445416663	0,731738575290857	0,464793432704378
DSSIM	142,229576554791	36,1199193965887	3,72770703459966	1,86843746154492
MOS	55,33333	47,26667	36,86667	14,66667

These images have lower MOS values, from around 50 to almost 15. Image t01_img_022 has the lowest MSE value, maximum PSNR value and high (but not the highest) SSIM value; it is because this image has the least surface area where the pixels are different by their values from the original.

Example 20.

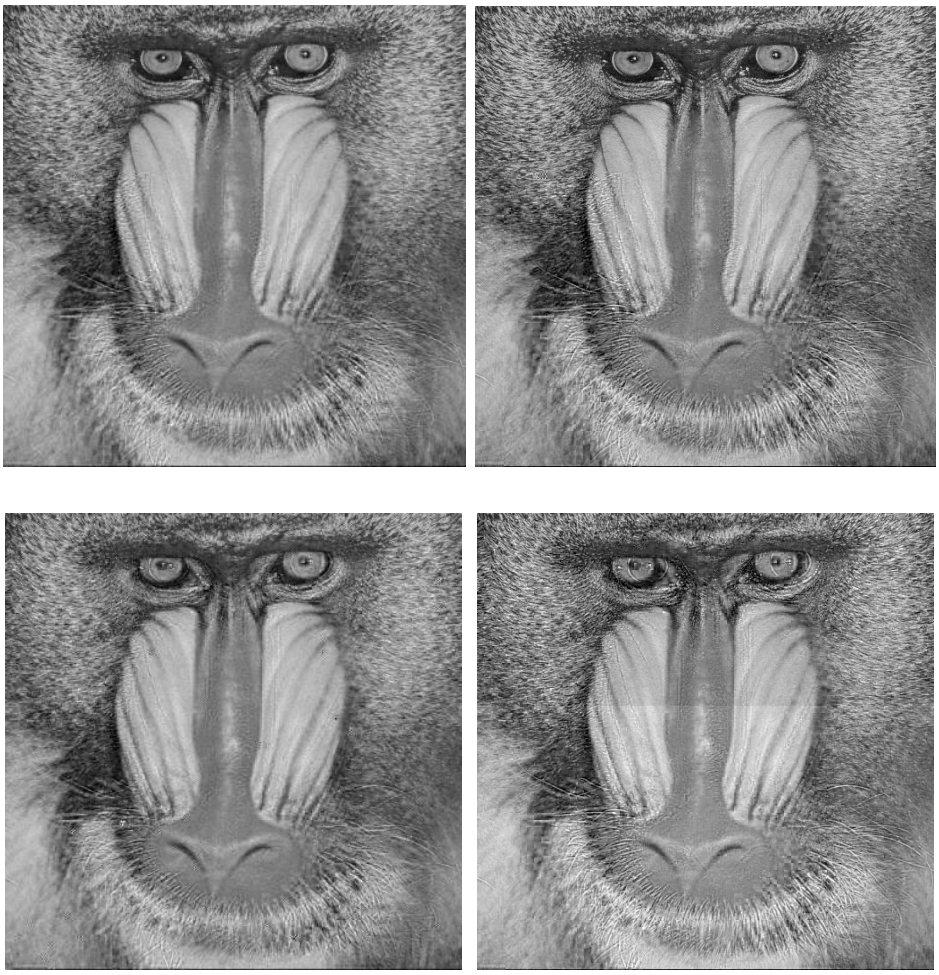

Figure 26. Distorted images,

t01_img_006,t01_img_009, t01_img_015 and t01_img_026

Table 21.

Metric	t01_img_006	t01_img_009	t01_img_015	t01_img_026
MSE	349,708820343018	376,170169830322	1061,46655654907	973,26904296875
PSNR	22,6937377466106	22,3769600769645	17,8717404539462	18,248474509947
SSIM	0,694311235524821	0,65777551057781	0,404827386224296	0,444950033405874
DSSIM	3,27130112785416	2,92205856362996	1,68018483521296	1,80163960036996
MOS	75,86667	63,9	52,66667	40,56667

The image with highest MSE value, lowest PSNR value and lowest SSIM is image t01_img_015, but image with lowest MOS value is image t01_img_026.

Example 21.

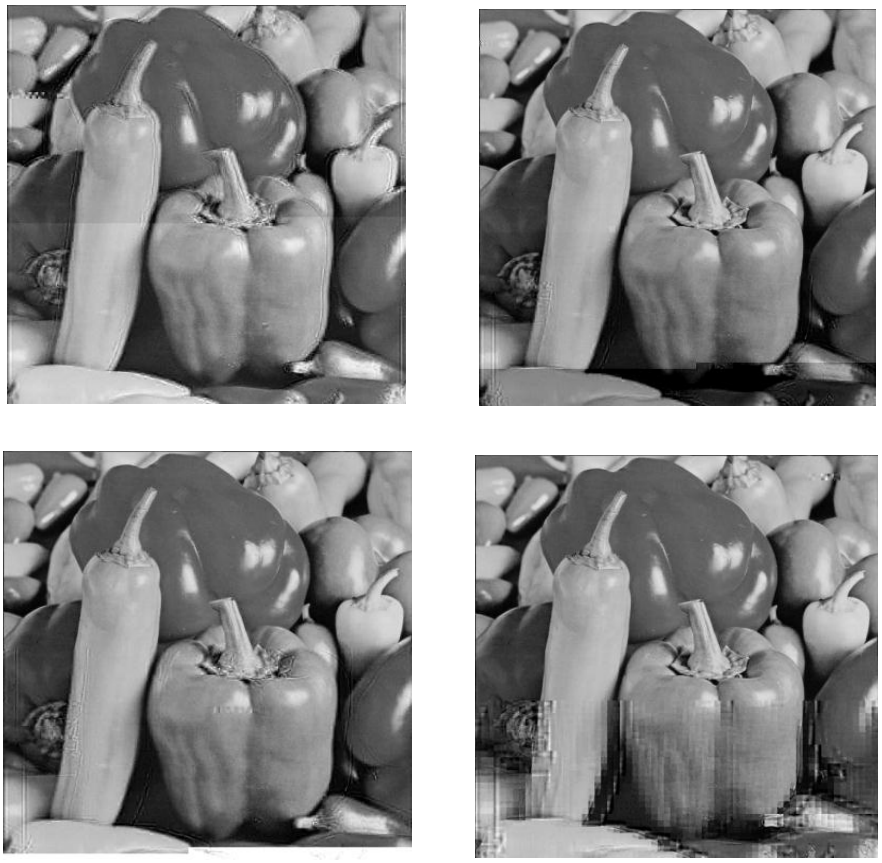

Figure 27. Distorted images,

t01_img_0014, t01_img_019, t01_img_028 and t01_img_032

Table 22.

Metric	t01_img_0014	t01_img_019	t01_img_028	t01_img_032
MSE	487,736782073975	303,644199371338	268,038028717041	155,648471832275
PSNR	21,2489485225316	23,3071537181994	23,8488394560664	26,2093549976244
SSIM	0,819325711470029	0,846117438009566	0,710474055771737	0,789888039351568
DSSIM	5,53482185061497	6,49846211984802	3,45392190211319	4,75936732451534
MOS	53,7	51,2	38,06667	33,96667

Image t01_img_0014 has the highest MSE value and the smallest PSNR value, what means that comparing values pixel-by-pixel these images have the most degradations. The highest SSIM value has the image t01_img_0019. The highest MOS value has image t01_img_0014 but it is around 50, what means that this image has still a lot of degradations.

Example 22.

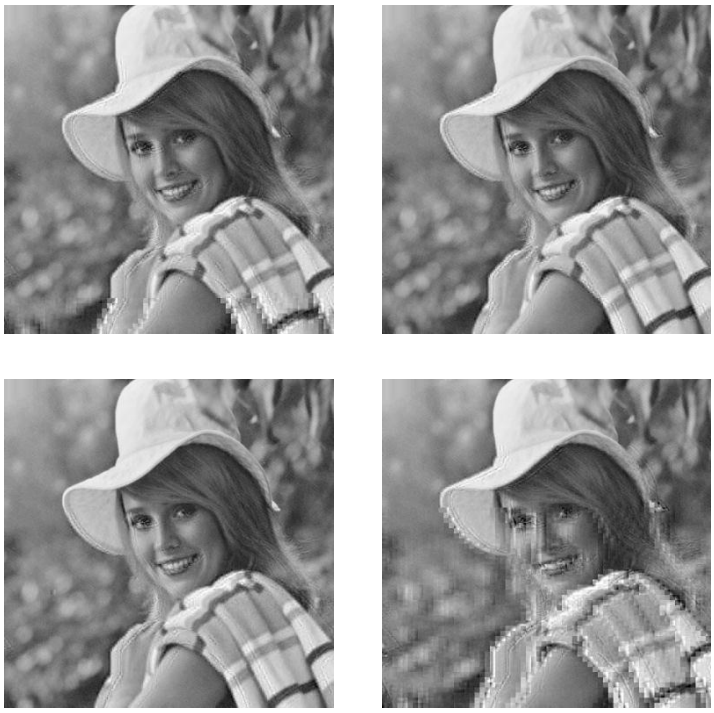

Figure 28. Distorted images,

t01_img_0016, t01_img_018, t01_img_024 and t01_img_035

Table 23.

Metric	t01_img_0016	t01_img_0018	t01_img_024	t01_img_035
MSE	73,8140296936035	92,1663818359375	148,388324737549	285,936897277832
PSNR	29,4494144566501	28,4850782208724	26,4168062907266	23,5681016056334
SSIM	0,761226930987873	0,709443440849246	0,629032712449802	0,485303126103689
DSSIM	4,18807700607647	3,44167071265858	2,69565547572623	1,94289114761839
MOS	52,33333	51,36667	42,56667	20

Using the results from WIQ base for distorted images tested in Perth, Australia and the simple program *Image Comparator* it is proved that objective metrics for image evaluation are not that good yet. Computer logic is still not adjusted to the HVS. Comparing the results from the tables in Examples 1 to 6 it can be concluded that if one image human eye sees well, the objective metrics as MSE and PSNR could “see” as totally distorted because the most of pixels in the image are brighter or darker (luminance masking). SSIM index is the method that correlate better with HVS and the results are always the same or similar as results for the MOS values.

7 Comparison with Subjective metrics

Objective metrics are made to save time, money and reduce complexity of subjective metrics for image evaluation. Because of the fact that HVS is still not explored till the end and big part of it is still a mystery, objective metrics cannot match with subjective metrics as good as they should have.

Also, the human eye can easily notice, without any reference, that one image has degradation and for objective metrics it is quite a difficult task. Objective metrics differ one from another and because of that sometimes give different final results. Comparing results from examples above, it is easy to conclude that objective metrics that compare original image with the one at the receiver pixel by pixel give poorer results than the one that is based on measuring structural distortions in images by comparing luminance, contrast, and structures of objects in a scene. The most similarity with the subjective metrics showed SSIM.

After assessment of two bases of images the conclusion is simple. SSIM method finds ringing like a big error in the image, because ringing make structural distortions. MSE and PSNR have much lower results if there is a luminance masking in the image, because luminance masking usually ruins much more pixels. This is why the results of SSIM, MSE and PSNR didn't always correlate well. In the end, this is also explanation why subjective metrics didn't correlate with objective metrics. HVS sees images and errors on the images on the different way.

The image artifacts that were made in this channel are mainly blocks, ringing, luminance masking and lost blocks.

8 Conclusion

Radio-communication channel can make all kind of negative effects which are reducing image quality. Those effects are generated in all parts of the radio-communication channel but they can be removed in a certain level. Today there are many techniques for image evaluating and they are divided into two groups: subjective and objective. Subjective techniques are complicated and require a lot of time and money. For example, in these studies one of those methods could take around 40 minutes which includes testing and results processing. Objective techniques are easier to perform and take a less time than the objective methods.

Image comparator is a program that provides the results for all objective measures that were processed (MSE, PSNR, SSIM and DSSIM). While comparing the results from objective and subjective methods, SSIM method proved like the technique with most similar results. The results from MSE and PSNR methods were not always correlating with the results of subjective methods. The reason is because MSE and PSNR methods compare images pixel by pixel. Luminance masking is a good example because human eye will not perceive this distortion as a big problem, while PSNR and MSE will give very bad results.

Image assessment is very important process for overall quality of wireless communication today. If the distorted image can be defined as sum of reference image and error signal, then image quality depends on error visibility in distorted image. Each objective method assesses images on different way: MSE and PSNR give better results if the most of pixels in the distorted image have the same values as in the reference image; SSIM gives better results if there is a less ringing in the image; subjective metrics depend only on HVS and there is no simple way to explain them.

9 Summary

The main part of this project is the simulation of radio communication channel which includes: JPEG coder/decoder, BPSK modulator/demodulator, AWGN channel and additional matlab boxes. The purpose of this project was to see how the parameters and characteristics of radio communication channel make the influence on the image. An image assessment with objective and subjective metrics was made on random base of images. Validations of these results were shown on another base of images WIQ, where images had typical distortions for a radio communication channel. It was shown that objective metrics does not always correlate with subjective metrics. HVS is still an unexplored task. It is still not impossible to make the mathematical model of assessment that works and assess like HVS. Objective methods cost less and it is easier to perform them while subjective methods take more time and results cannot be predicted. It is not possible to say which method has more effective results because both methods are very important for evaluation of image quality.

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