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Objective Performance of Compressed Image Quality Assessments

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Abstract**—**Measurement of the quality of image compression is important for image processing application. In this paper, we propose an objective image quality assessment to measure the quality of gray scale compressed image, which is correlation well with subjective quality measurement (MOS) and least time taken. The new objective image quality measurement is developed from a few fundamental of objective measurements to evaluate the compressed image quality based on JPEG and JPEG2000. The reliability between each fundamental objective measurement and subjective measurement (MOS) is found. From the experimental results, we found that the Maximum Difference measurement (MD) and a new proposed measurement, Structural Content Laplacian Mean Square Error (SCLMSE), are the suitable measurements that can be used to evaluate the quality of JPEG200 and JPEG compressed image, respectively. In addition, MD and SCLMSE measurements are scaled to make them equivalent to MOS, given the rate of compressed image quality from 1 to 5 (unacceptable to excellent quality).

Keywords**—**JPEG, JPEG2000, Objective image quality measurement, Subjective image quality measurement, correlation coefficients.

I. Introduction

NOWADAYS, data compression is important for storage and transmission. The problem of information management is not new, especially that of managing of storage and bandwidth requirements, so data compression is an encoding process to reduce the storage and transmission. In general, measurement of image quality usually can be classified into two categories, which are subjective and objective quality measurements. Subjective quality measurement, Mean Opinion Score (MOS), is truly definitive but too inconvenient, the most time taken and expensive [1], [2]. Therefore, objective measurements are developed such as MSE, MAE, PSNR, SC, MD, LMSE, and NAE that are least time taken than MOS but they do not correlation well with MOS [3], [4].

In fact, MSE and PSNR are the most common measures of image quality in image compression systems, despite the fact that they are not adequate as perceptually meaningful measures, especially MSE variants do not correlation well with subjective quality measures [3]-[5]. A number of objective image quality measurements have been evaluated against subjective image quality measurement. Eskicioglu and Fisher have shown that some objective image quality measures correlate well with the observer's response although their experiments are based on only JPEG compressed images [3]. In addition, a set of fundamental objective image quality measures are investigated and show that some objective measurements correlate well with subjective image quality measures however their results are concluded from a few tested images [4]. In 1998, Picture Quality Scale (PQS) was proposed. It was reliable, resulting in good correlation with objective measurement [6]. However, for very high quality images, it is possible to obtain values of PQS larger than five. At the low end of the image quality scale, PQS can obtain negative values (meaning less result) [4]. Moreover, the most important problem of PQS, it spends long time to process [4]. Recently, the Universal Quality Index (UQI) and Structural Similarity (SSIM) were proposed. Their measurements are performed with greater accuracy and consistency than MSE and PSNR. Nevertheless, the UQI and SSIM measurement results were not rate the image quality from 1 to 5 (unacceptable to excellent quality) [7], [8].

In this paper, we propose the suitable measurements that can be used to evaluate the quality of JPEG and JPEG2000 compressed image. The results are given in scale from 1 to 5 (unacceptable to excellent quality) that comparable to subjective measurement (MOS). In our study, we evaluated the quality of the compressed gray-scale images from a variety of tested images, which have the range of spatial frequency measurement (SFM) values from 14 to 65. From the experimental results, we found the relationship between objective and subjective measurements from correlation coefficients, which show the reliability of each fundamental objective measurement. We demonstrated that Maximum Difference measurement (MD) and the new proposed measurement, Structural Content Laplacian Mean Square Error (SCLMSE), are provided highly reliability for JPEG2000 and JPEG compressed image quality evaluation, respectively.

The paper is organized as follows. In section 2 we describe the image characteristic measure (SFM). The image quality measurements and reliability of an objective measurement are shown in section 3 and 4, respectively. In section 5 gives the experimental results to show the performance of the proposed objective measurements. Finally, the conclusion and future work are described in section 6.

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II. Image Characteristic

The spatial frequency measurement (SFM) indicates the overall activity level in an image [3], [4]. SFM is defined as follow:

$$SFM = \sqrt{R^2 + C^2} \quad (1)$$

$$R = \sqrt{\frac{1}{MN}\sum_{m=1}^{M}\sum_{n=2}^{N}\left(x(m,n) - x(m,n-1)\right)^2} \quad (2)$$

$$C = \sqrt{\frac{1}{MN}\sum_{m=2}^{M}\sum_{n=1}^{N}\left(x(m,n) - x(m-1,n)\right)^2} \quad (3)$$

where R is row frequency, C is column frequency, $x(m,n)$ denotes the samples of image, M and N are number of pixels in row and column directions, respectively. The large value of SFM means that image contain component in high frequency area.

III. Image Quality Measurements

A. Subjective Quality Measurement

In fact, in image compression system, the truly definitive measure of image quality is perceptual quality. The compressed image quality is specified by MOS, which is result of perception based on subjective evaluation [4], [9]. The meaning of the 5-level grading scales of MOS is 5-pleasant or excellent quality, 4-good, 3-acceptable, 2-poor quality and 1-unacceptable. MOS is defined as follow:

$$MOS = \frac{1}{S}\sum_{i=1}^{5} ip(i) \quad (4)$$

where i is image score $p(i)$ is image score probability and S is number of observer.

B. Objective Quality Measurement

The objective quality measurements are save time more than subjective quality measurement [3], [4]. The seven simple objective measurements are selected and used for this research study. Definition: $x(m,n)$ denotes the samples of original image, $\hat{x}(m,n)$ denotes the samples of compressed image. M and N are number of pixels in row and column directions, respectively.

1) Mean Square Error (MSE)

The simplest of image quality measurement is Mean Square Error (MSE). The large value of MSE means that image is poor quality. MSE is defined as follow:

$$MSE = \frac{1}{MN}\sum_{m=1}^{M}\sum_{n=1}^{N}\left(x(m,n) - \hat{x}(m,n)\right)^2 \quad (5)$$

2) Mean Average Error (MAE)

The large value of Mean Average Error (MAE) means that image is poor quality. MAE is defined as follow:

$$MAE = \frac{1}{MN}\sum_{m=1}^{M}\sum_{n=1}^{N}\left|x(m,n) - \hat{x}(m,n)\right| \quad (6)$$

3) Peak Signal to Noise Ratio (PSNR)

The small value of Peak Signal to Noise Ratio (PSNR) means that image is poor quality. PSNR is defined as follow:

$$PSNR = 10\log\frac{255^2}{MSE} \quad (7)$$

4) Structural Content (SC)

The large value of Structural Content (SC) means that image is poor quality. SC is defined as follow:

$$SC = \frac{\sum_{m=1}^{M}\sum_{n=1}^{N} x(m,n)^2}{\sum_{m=1}^{M}\sum_{n=1}^{N} \hat{x}(m,n)^2} \quad (8)$$

5) Maximum Difference (MD)

The large value of Maximum Difference (MD) means that image is poor quality. MD is defined as follow:

$$MD = Max\left(\left|x(m,n) - \hat{x}(m,n)\right|\right) \quad (9)$$

6) Laplacian Mean Square Error (LMSE)

This measure is based on the importance of edges measurement. The large value of Laplacian Mean Square Error (LMSE) means that image is poor quality. LMSE is defined as follow:

$$LMSE = \frac{\sum_{m=1}^{M}\sum_{n=1}^{N}\left[L(x(m,n)) - L(\hat{x}(m,n))\right]^2}{\sum_{m=1}^{M}\sum_{n=1}^{N}\left[L(x(m,n))\right]^2} \quad (10)$$

where $L(m,n)$ is laplacian operator:

$$L(x(m,n)) = x(m+1,n) + x(m-1,n) + x(m,n+1) + x(m,n-1) - 4x(m,n)$$

7) Normalized Absolute Error (NAE)

The large value of Normalized Absolute Error (NAE) means that image is poor quality. NAE is defined as follow:

$$NAE = \frac{\sum_{m=1}^{M}\sum_{n=1}^{N}\left|x(m,n) - \hat{x}(m,n)\right|}{\sum_{m=1}^{M}\sum_{n=1}^{N}\left|x(m,n)\right|} \quad (11)$$

IV. Reliability of Objective Image Measurement

The reliability of an objective measurement could be evaluated by finding the correlation between objective measurement and subjective measurement. The Correlation coefficient (r) is expressed as [4], [10].

$$r = \frac{\sum_i \left(s_i - \bar{s}\right)\left(o_i - \bar{o}\right)}{\sqrt{\sum_i \left(s_i - \bar{s}\right)^2 \left(o_i - \bar{o}\right)^2}} \tag{12}$$

where s_i and o_i are the series of subjective and objective measurements, respectively. The possible values of correlation coefficient are between -1 and 1, the better correlation make the correlation coefficient closer to -1 or 1.

V. Experimental Results

The ten original images, Fig. 1 (Image1 to Image10) are compressed and used to test their qualities using the fundamental objective measurements explained in section III. Image1 to 5 have 512x512 pixel sizes, 8-bpp resolution while image6 to 10 have 256x256 pixel sizes. The characteristic of ten original images are measured by using SFM. The results are shown in table I. From Table I, original images1 and 10 have the lowest SFM (3.74) and highest SFM (48.12) values, respectively. Next, ten original images (1 to 10) are compressed with JPEG and JPEG2000 algorithm, 10 rates for each. For JPEG, the Quantized Parameter (Q) = 0.25, 0.5, 0.75, 1, 1.25, 1.5, 1.75, 2, 2.25, and 2.5 are employed. In addition, the different threshold values that are 2%, 3%, 5%, 8%, 10%, 15%, 18%, 20%, 25%, and 30% remaining rate are used for JPEG2000. Then, there are 200 compressed images for used to test their qualities.

TABLE I
SFM values of Each Original Image

Image no.	SFM	Image no.	SFM
1	3.74	**2**	12.17
3	15.23	**4**	22
5	25	**6**	30.55
7	33.96	**8**	37.02
9	42.46	**10**	48.12

These compressed images are measured their image quality using both objective and subjective quality measurements. The fundamental objective assessments such as MSE, MAE, PSNR, SC, MD, LMSE, and NAE are used to measure the compressed image quality. For subjective assessment, 50 observers, who are senior in information engineers with some background in digital image processing, subjectively evaluate the compressed image quality using MOS. The reliability of each objective image quality measurement can be evaluated by finding the relationship between objective and subjective image quality measurement.

The relations between objective measurement and subjective measurement of JPEG and JPEG2000 compressed are considered and shown in Fig. 2 and 3, respectively. As can be seen, the scatter plots of JPEG compressed images in Fig. 2 are widely clustered. However, only SC and LMSE measurements are tightly clustered. In Fig. 3, the scatter plots of JPEG2000 compressed images, only MD measurement has closely distribution compared with other measurements. The reliability of JPEG and JPEG2000 compressed images are measured by correlation coefficient (r), shown in Table II.

TABLE II
Reliability Of Each Fundamental Objective Measurement

	Reliability of JPEG Compressed images	**Reliability of JPEG2000 Compressed images**
MSE	-0.505075	-0.793949
MAE	-0.524368	-0.894816
PNSR	0.494057	0.802721
SC	**-0.705405**	-0.871356
MD	-0.600811	**-0.937755**
LMSE	**-0.637481**	-0.873826
NAE	-0.487453	-0.929987

The highest reliability of objective quality measurement for JPEG compressed images are SC (-0.7054). While the highest reliability of objective quality measurement for JPEG2000 compressed images is MD (-0.9377). Then, MD is the best measurement and suitable for JPEG2000 compressed image quality evaluation. As the results, the reliabilities of objective image quality measurement for JPEG compressed images, SC and LMSE are still too low. Therefore, we adopt to use SC and LMSE measurements to define a new objective quality measurement for JPEG compressed image shown as:

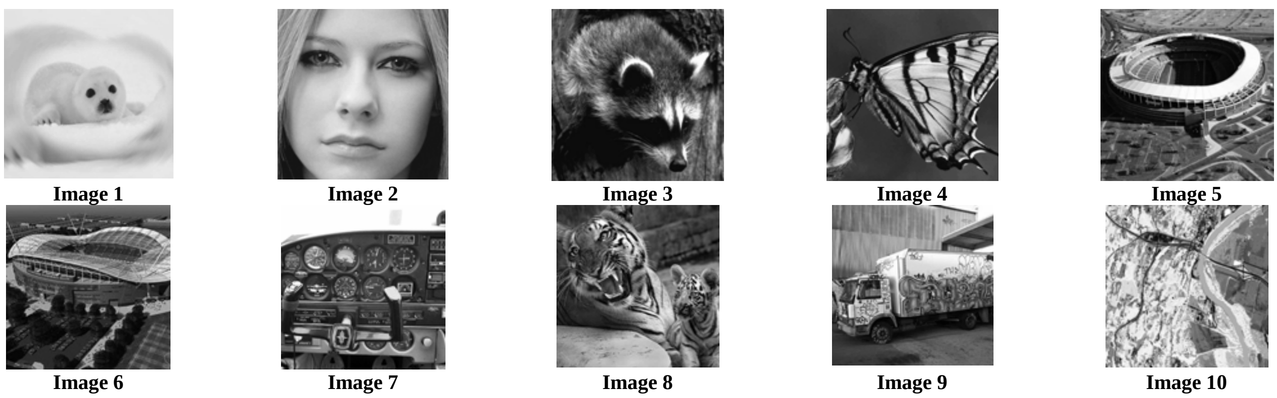
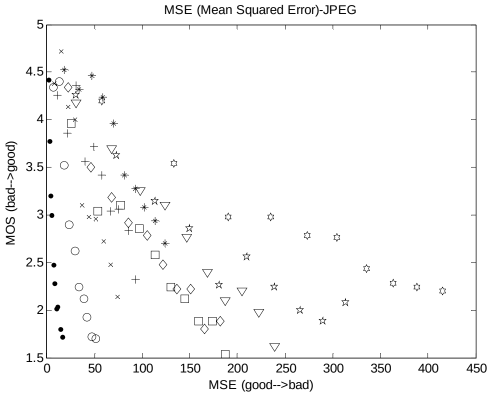
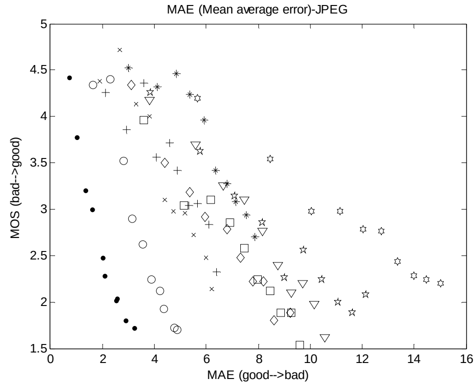


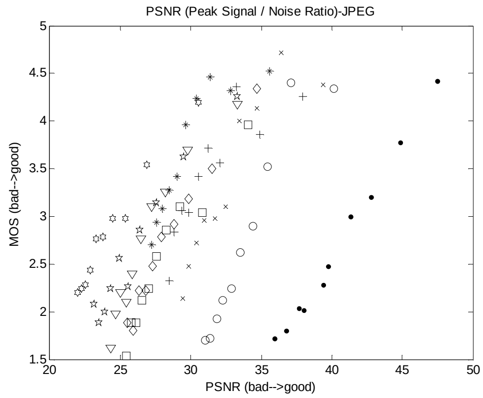
Fig. 1 Ten original tested images



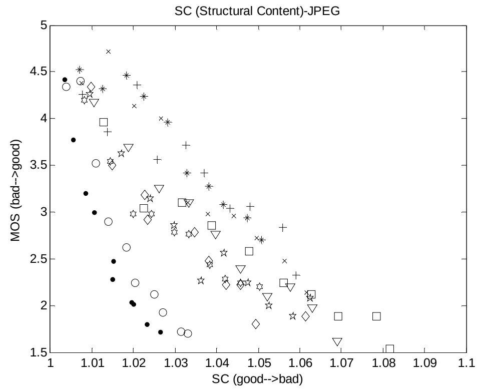
(a) MSE and MOS



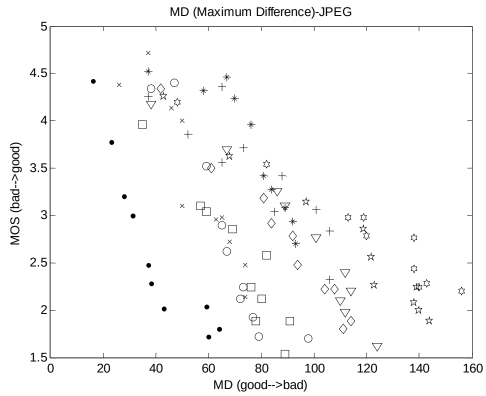
(b) MAE and MOS



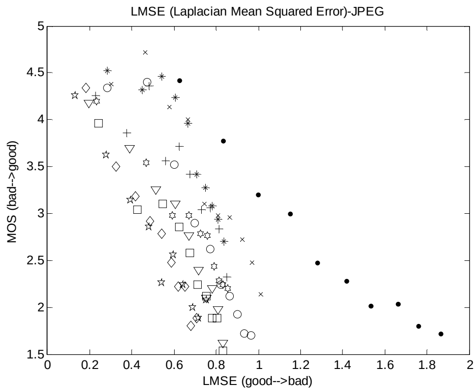
(c) PSNR and MOS



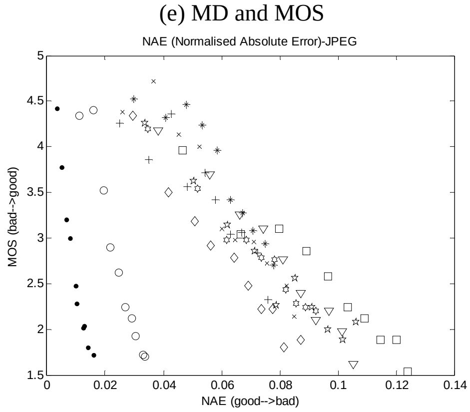
(d) SC and MOS



(e) MD and MOS

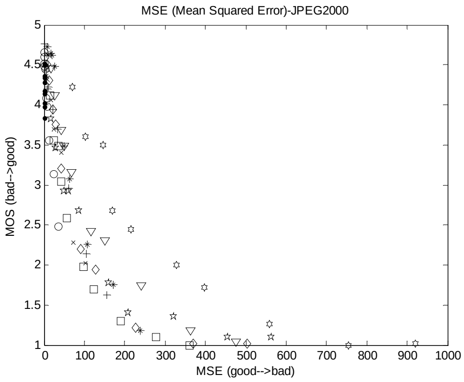


(f) LMSE and MOS

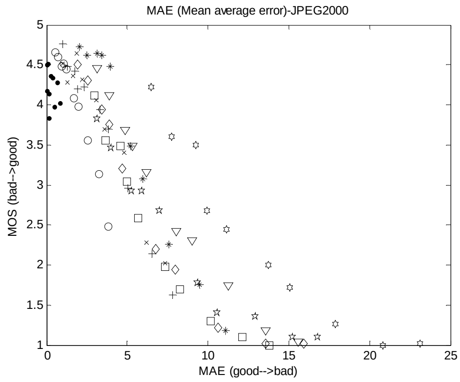


(g) NAE and MOS

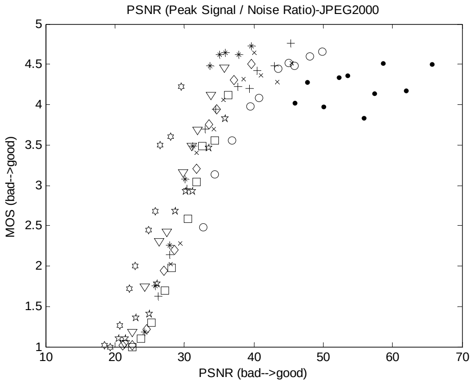
Fig. 2 Relations between Objective Measurements and Subjective Measurements of JPEG compressed images



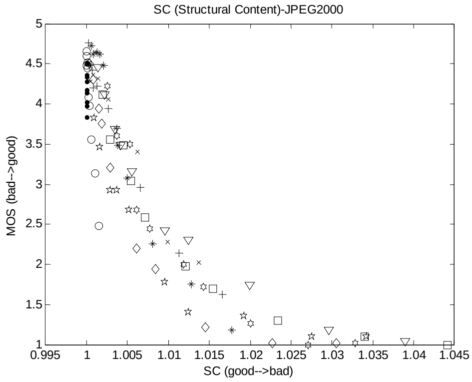
(a) MSE and MOS



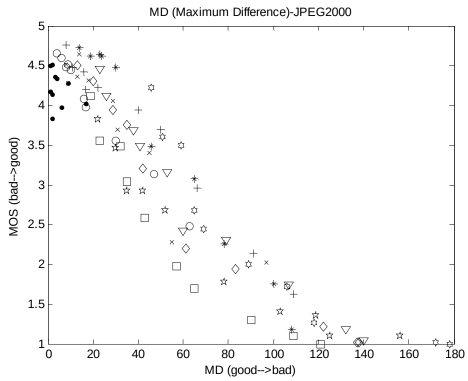
(b) MAE and MOS



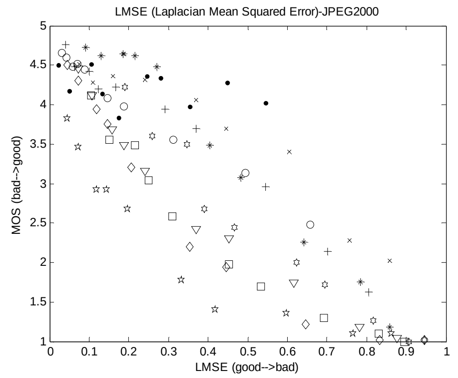
(c) PSNR and MOS



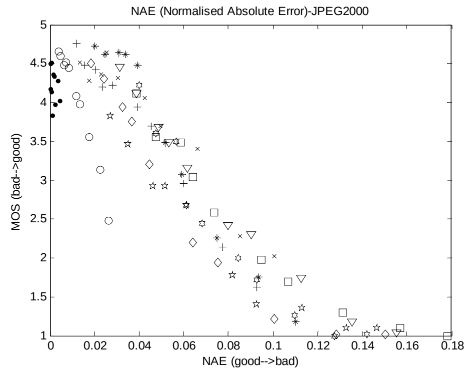
(d) SC and MOS



(e) MD and MOS



(f) LMSE and MOS



(g) NAE and MOS

Fig. 3 Relations between Objective Measurements and Subjective Measurements of JPEG2000 compressed images

$$SCLMSE = SC^{k_{SC}} + LMSE^{k_{LMSE}} \tag{13}$$

Suppose that the variable ranges of SC and LMSE from 200 compressed images are [SCmin, SCmax] and [LMSEmin, LMSEmax], respectively. From the experiments, SC and LMSE were determined as follows:

$SC \in [1,\ \ 1.0818]$, $LMSE \in [0.0221,\ \ 1.862]$, that must be normalized over the interval [0, 1] as follows:

$$SC' = \frac{SC - SC_{Min}}{SC_{Max} - SC_{Min}}$$
$$LMSE' = \frac{LMSE - LMSE_{Min}}{LMSE_{Max} - LMSE_{Min}} \tag{14}$$

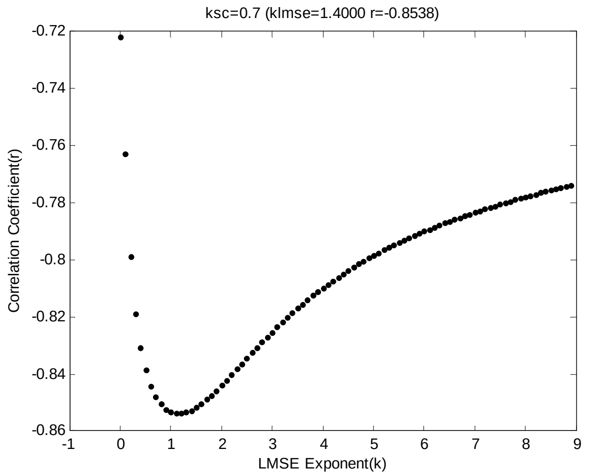


Fig. 4 Relations between LMSE exponents k_{LMSE} and correlation coefficient

Next, to find the optimal exponents (k_{SC} and k_{LMSE}), equation 13, bringing out the possible highest reliabilities, the k_{SC} was varied from 0.1 to 1 and the k_{LMSE} was automatically varied. We demonstrate the relations between k_{SC}, k_{LMSE} and correlation coefficients shown in Fig. 4

In Fig. 4, when k_{SC} is equal to 0.7, the LMSE exponents k_{LMSE} is varied to 1.4. It could make the correlation coefficient between SCLMSE and MOS in JPEG compressed images led to -0.8538. The equation 13 can be replaced as,

$$SCLMSE = SC^{0.7} + LMSE^{1.4} \tag{15}$$

From the experiments, the variable ranges of MD and SCLMSE were determined as follows:

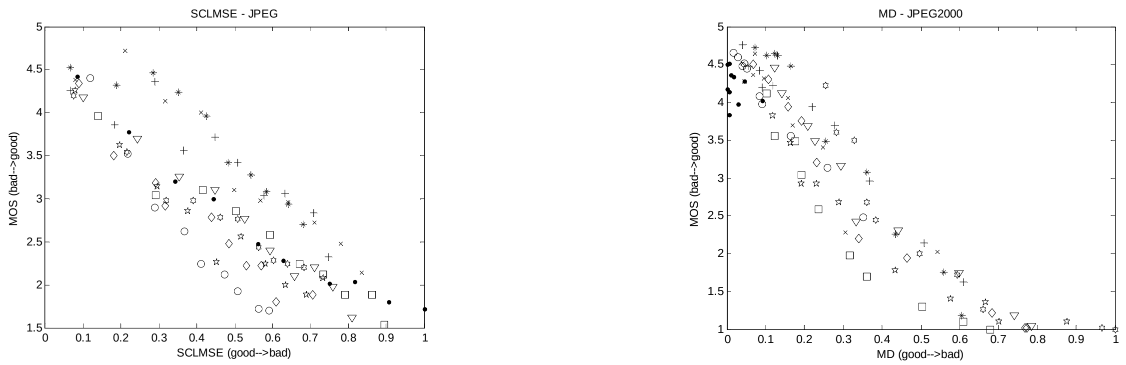
$MD \in [-178,\ \ -1]$, $SCLMSE \in [-1.923,\ \ 0]$, that must be normalized over the interval [0, 1] as follows:

$$MD' = \frac{MD - MD_{Min}}{MD_{Max} - MD_{Min}}$$
$$SCLMSE' = \frac{SCLMSE - SCLMSE_{Min}}{SCLMSE_{Max} - SCLMSE_{Min}} \tag{16}$$

In Fig. 5, scatter plots of SCLMSE and MD measurements, poor quality image has the rate value higher than good quality image. So we make the change in measurement of SCLMSE and MD that good quality of image has the rate more than poor quality of image, shown in equation (17) and (18).

$$MD = -MD \tag{17}$$
$$SCLMSE = -\left(SC^{0.7} + LMSE^{1.4}\right) \tag{18}$$

To make MD and SCLMSE measurements comparable to MOS, given the rate of compressed image quality from 1 to 5 (unacceptable to excellent quality), the result in equation 17 and 18 need to multiply with 5. From the results, we found that when SCLMSE and MD has rate less than 1, the image quality is bad. Then we set the rate which less than 1 to 1. Next, PQS, MD and SCLMSE are used to evaluate the quality of 200 compressed images. Their reliabilities are tabulated in table III. We can see that SCLMSE measurement provides the higher reliability than other measurements for JPEG compressed image compared with Table II. The scatter plots in figure 5 (a) are tightly clustered in contrast to figure 2.



(a) SCLMSE for JPEG compression (b) MD for JPEG2000 compression

Fig. 5 Relations between (a) SCLMSE, (b) MD and Subjective Measurements of JPEG and JPEG2000 compressed images

Fig. 6 Original tested images (11 to 35)

TABLE III
RELIABILITY OF COMPRESSED IMAGES (1 TO 10)

	Reliability of JPEG Compressed images	Reliability of JPEG2000 Compressed images
PQS	0.774884	0.945053
MD	0.602155	**0.948807**
SCLMSE	**0.853731**	0.925071

TABLE IV
SFM VALUES OF ORIGINAL IMAGES (11 TO 35)

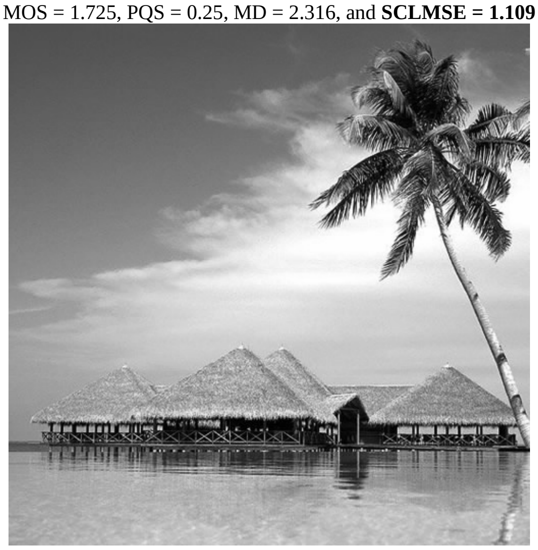
Image no.	SFM	Image no.	SFM
11	14.01	**12**	27.82
13	18.81	**14**	59.68
15	17.27	**16**	21.04
17	31.63	**18**	40.69
19	16.78	**20**	22.43
21	24.16	**22**	60.08
23	28.84	**24**	20.28
25	34.92	**26**	29.42
27	37.2	**28**	29.51
29	13.30	**30**	14.03
31	6.29	**32**	8.42
33	11.5	**34**	65.46
35	6		

In Table III, SCLMSE and MD give the highest reliability in JPEG and JPEG2000 compressed image, respectively. To test the performance of our new proposed measurement, a new set of tested images, Image11 to Image35, are used (Fig. 6). The SFM values, characteristic of each image, are ranged from 6 to 65. From table IV, original images 35 and 34 have the lowest SFM value (6) and highest SFM value (65.46).

In this experiment, the compression rates of the each compressed image are randomly selected based on JPEG (2 rates) and JPEG2000 (2 rates) for each original image11 to 35. Therefore, we have almost 100 compressed images for testing. Twenty observers are subjectively evaluated the quality of compressed images. In addition, PQS, MD and SCLMSE are used to objectively evaluate the compressed image quality. The reliability of each measurement is tabulated in Table V. As can be seen, PQS gives the highest reliability in JPEG and JPEG2000 but incur greater computation cost, which lead to computational complexity (Table VI). However, the reliability of SCLMSE and MD are a bit less than PQS, they are least time taken as shown in Table VI.

Example 1
MOS = 1.725, PQS = 0.25, MD = 2.316, and **SCLMSE = 1.109**

Example 2
MOS = 3.05, PQS = 2.521, MD = 2.514, and **SCLMSE = 2.926**



Example 3
MOS = 4.475, PQS = 4.885, MD = 4.011, and **SCLMSE = 4.49**

Example 4
MOS = 2.3, PQS = 1.452, MD = 2.57, and **SCLMSE = 2.491**

Example 5
MOS = 1.65, PQS = -1.751, MD = 1, and **SCLMSE = 1**

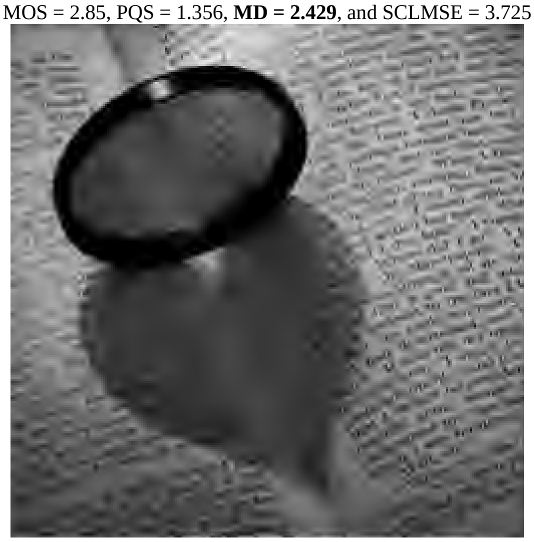
Example 6
MOS = 1.25, PQS = -2.755, MD =3.47, and **SCLMSE = 1**

Fig. 7 Compared score with each measurement in JPEG compressed images

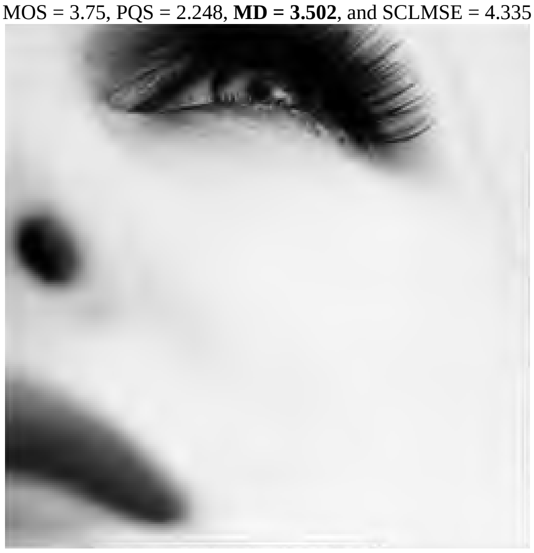
Example 7
MOS = 1.075, PQS = -4.067, **MD = 1**, and SCLMSE = 1.525

Example 8
MOS = 2.85, PQS = 1.356, **MD = 2.429**, and SCLMSE = 3.725

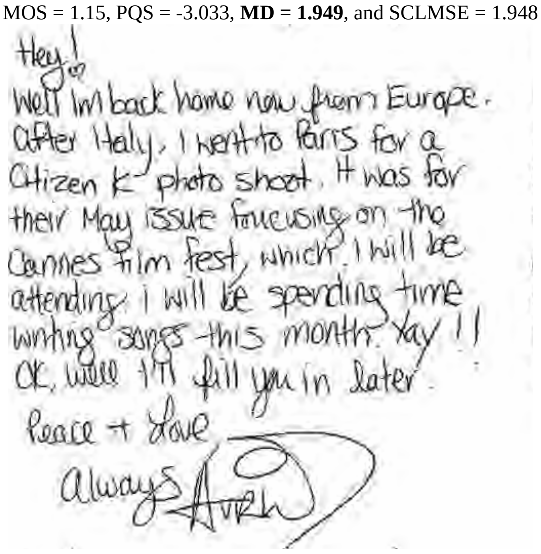
Example 9
MOS = 3.75, PQS = 2.248, **MD = 3.502**, and SCLMSE = 4.335



Example 10
MOS = 1.15, PQS = -3.033, **MD = 1.949**, and SCLMSE = 1.948



Example 11
MOS = 2.925, PQS = 0.742, **MD = 3.587**, and SCLMSE = 3.887



Example 12
MOS = 1.525, PQS = -1.528, **MD = 1**, and SCLMSE = 3.036

Fig. 8 Compared score with each measurement in JPEG2000 compressed images

TABLE V
RELIABILITY OF COMPRESSED IMAGES (11 TO 35)

	Reliability of JPEG Compressed images	Reliability of JPEG2000 Compressed images
PQS	**0.867227**	**0.916046**
MD	0.458354	0.870127
SCLMSE	0.785563	0.849517

Fig. 7 and Fig. 8 show the compressed image quality evaluation rating results of some selected compressed images. By comparing the scores from example 1 to 6, we can see that our proposed measurement (SCLMSE) provides the closest score with MOS. While example 7 to 12, MD measurements give the closely scores with MOS. Importantly, if we consider the poor quality images in example 5,6,7,10 and 12, PQS show the negative score, which lead to meaning less result.

TABLE VI
COMPUTATION TIME (SECONDS)

	512x512	256x256
PQS	8.6179	2.0209
MD	0.0222	0.0102
SCLMSE	1.1134	0.2484

To test the running speed time of 3 measurements (PQS, MD, and SCLMSE), our experiments were tests on MATLAB R2006a, implementation running on a PC (AMD Athlon XP 1.8 GHz, 256 MB RAM). From table VI, we can see that PQS has the most time taken in measuring the quality of the image, while MD has the least time taken.

VI. CONCLUSION AND FUTURE WORK

In this paper, we have proposed a new objective image quality measurement, Structural Content Laplacian Mean Square Error (SCLMSE), which was developed from a few fundamental objective quality measurements. From the experimental results, we found that the Maximum Difference measurement (MD) and a new proposed measurement (SCLMSE) are the suitable measurements that can be used to evaluate the quality of JPEG200 and JPEG compressed image, respectively. In addition, MD and SCLMSE measurements are scaled to make them comparable to MOS, given the rate of compressed image quality from 1 to 5 (unacceptable to excellent quality). Importantly, MD and SCLMSE provide closely reliability and less time computation compared with PQS. In future work, we will extend our study to assess others kinds of distortion such as blurring, Gaussian noise, sharpening, etc.

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