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ASSESSMENT OF PERCEIVED IMAGE QUALITY FOR SMARTPHONES WITH EMBEDDED CAMERA

Specialty 232.02 – Information technologies, products and systems

Abstract of the PhD Thesis in Technical Sciences

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CONCEPTUAL HIGHLIGHTS OF THE THESIS

The actuality and significance of perceived image quality assessment problem. Smartphones are increasingly becoming primary photos acquiring and display devices for many consumers. Smartphone vendors are striving at improving embedded camera and display capabilities and delivered quality of captured photos and videos. Smartphones image quality is driving consumer preference in smartphones purchasing. This also affects popular consumer usage models like image and video sharing *(Instagram, Facebook etc.).* Figure 1 illustrates the use cases of mobile devices with embedded digital camera: smartphones, phablets and tablet computers etc. Smartphones acquire and display high-definition (HD) images and videos continues to increase very fast, stormy. It is estimated that more than half of digital photographs and videos being taken by smartphones and everyday photography by smartphones continue to increase exponentially [1].

Due to the use of increasingly intensive, large number of smartphones with embedded camera incorporated as digital photography and visual media, it appears the necessity to predict the perceived quality of these images. Today the most common and popular way of determining the image quality of an image or video is to perform visual experiments through human visual tests (HVTs) in order to solicit opinion from human observers. This is time consuming, expensive and requires special infrastructure (special labs), which makes the process in practice not acceptable. Moreover, evaluating the image quality via HVTs requires a standard reference/comparison, which in many instances simply does not exist.

Fig.1. Image processing use cases.

What is image quality testing in industry?

- Using full reference or reduced reference metrics;
- The process is time consuming and expensive;
- Need results immediately – "Time to market";

What is image quality testing in academia/research?

- Using full reference metric;
- Dealing with new algorithms compared to old versions;
- Dealing with known distortions (noise, Gaussian blur, JPEG artifacts etc.);
- Have availability of time, not marketing products;
- Tests done under controlled conditions (test targets, light, distance etc.).

If vendor A measures 5 and vendor B measures 2, who's to say which score is right? **An alternative process is needed in order to address:**

- Use standard image quality assessment metric across the industry;
- Correlate objective results with perceived image quality (IQ) by human;
- Meaningful consumer a simple rating scale (in 1-5 "stars").

To solve this problem, the thesis proposes a new model for forecasting the perceived image quality/PIQ of the image on smartphones, presents the principles and methods for evaluating quality of the image using a software (SW) tool VIQET, developed by video quality experts group/VQEG. This tool used by the group of video experts of institute of electrical and electronics engineers (IEEE), international for standardization organization (ISO) and open system interconnection (OSI) for image quality evaluation on large TV screens.

Relevance and importance of the subject of the thesis. Smartphones producers and vendors are striving at differentiating through smartphone capabilities of embedded cameras and delivered image quality of captured images. The problem is that the PIQ evaluation for smartphones, phablets and tablet PCs still uses outdated methods developed for large-screen televisions. There are several researches on non-reference (NR) subjective image quality assessment for PIQ based on using natural scene statistics [2], measure the impacts of appearance parameters on perceived image quality for mobile-phone displays [3] or measure the impact of three image quality attributes (colorfulness, contrast and brightness) [4]. But none of the proposed existing models addresses the requirement for reliable objective PIQ prediction process.

The thesis provides a new assessment PIQ procedure for mobile devices with small display with built-in camera *(e.g. smartphones, phablet, tablet PC and the like),* focused on new technologies. Also, this study provides an efficient, reliable and quick evaluation procedure that provides in real time clear answer to how the smartphone users perceive the image quality. Moreover, the new model supports the smartphone vendors to be able to improve the IQ and the photography experience of smartphones users through the immediate feedback on the preferred new developed algorithms to enhance the image quality attributes (IQAs). Although human beings judge image quality in a real-time without reference is a subjective image quality assessment. Developing a model to simulate this perception is still an industrial and academic challenge. The IQ circle in Figure 2 describes the actual situation in the image processing industry and place of new model.

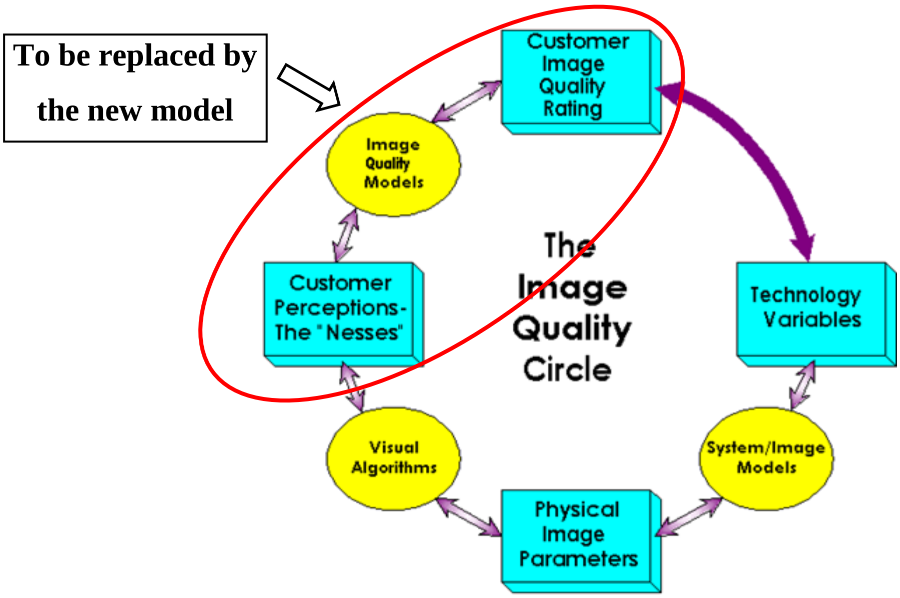


Fig.2. The image quality circle [2].

The main goal of this research is to develop a reliable new model and a new framework of non-reference (NR) image quality assessment for smartphones industry which aims to predict the image quality perception by smartphone consumers, based on software tool VIQET in order to shorten the IQ assessment time and reduce the resources cost.

In order to achieve this goal, the following objectives are formulated:

- Situation analysis of the NR IQ assessment methods;
- To address the requirement for a simple, reliable, complete and efficient solution for prediction of perceived image quality PIQ;
- Identify the most important IQAs that make the image more „pleasant" to smartphones users;
- Investigate the relationship between standard IQAs and VIQET IQ criteria;

- Develop new model to extract the standard IQAs to VIQET IQ criteria;
- Physical human visual experiments and statistical analysis of the results;
- New model performance evaluation according to VQEG recommendations, through improvement of the new model based on comparative analysis with HVT results;
- To provide free and comprehensive solution and evaluation model of PIQ both experts and non-experts.

Methodology of research. This research separates the objective research into two main categories: first, the methods that consider statistical or mathematical measurement (i.e. the image features extraction) and, second, methods that consider the HVTs characteristics. In this approach, considering the VIQET measures with incorporation of HVTs, that is, VIQET image feature extraction using HVTs characteristics.

The scientific novelty of the obtained results. With the latest digital image processing advances in digital cameras and smartphones display, and their widespread use to capture photos and videos, image quality has opened another level of investigation. In particular, PIQ of photos captured by such devices cannot be evaluated due to missing a reference image to compare with. A new reliable NR image quality assessment model provides an immediate IQ scoring.

Theoretical importance and practical significance of the work. This work describes how to extract the standard IQAs to new IQAs which implemented in the VIQET in order to be able to estimate the expected mean opinion score MOS in HVTs. Also, the new diploid model explains the relationship between the standard IQAs values and the VIQET IQAs values, demonstrates how to transform one to other in order to get the most reliable MOS. In its turn, the calculated MOS predicts the perceived IQ by humans. The practical value of the new approach based on this model is improving the existing IQ assessment procedures in the smartphones industry through automation and replacement some of them.

It is out of question that the subjective testing, i.e. human viewers ranks the quality of images, is the most accurate method for perceived image quality assessment, because it reflects true human perception. However, as mentioned above, these assessments are time consuming and expensive. Furthermore, they cannot be done in real time while using smartphones. Therefore, the significance of the new method of objective assessment NR perceived image quality achieved with VIQET that can predict perceived image quality is unquestionable. Moreover, as it has been shown in the thesis, this prediction is correlating well with subjective evaluation that is required in the image processing industry.

This research proposes a NR objective quality assessment for smartphone images based on VIQET. The flow chart of the new proposed approach is shown in Figure 3.

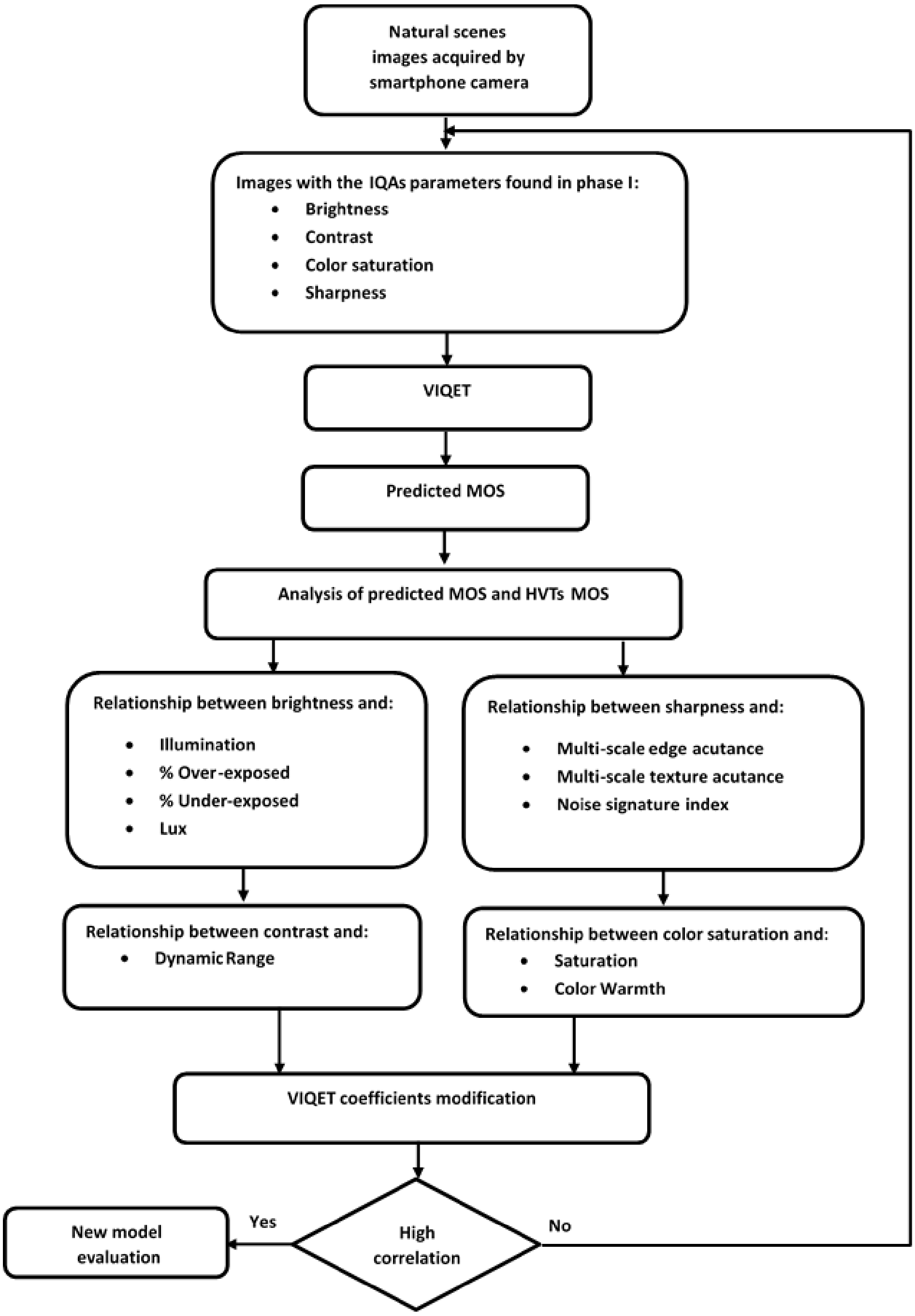


Fig.3. Image quality assessment flow chart.

The new assessment diploid model for IQ assessment can be used by smartphone producers and vendors in order to shorten „time to market", or by any image quality experts, including in the academia in order to reduce time and cost of PIQ assessment process of smartphones with small HD displays in comparison to the process that based on many human physical tests.

An important scientific problem solved consists in the new approach and framework for perceived image quality assessment, which summarize in extract the standard IQAs which used in large screens TVs for IQ assessment into new IQAs of VIQET in order to predict the perceived IQ of smartphones. This research is focused on small HD displays in various viewing conditions.

Main items to be defended:

- The new assessment process of PIQ approach based on diploid model;
- The extraction of standard IQAs *(brightness, contrast, color saturation* and *sharpness)* into VIQET IQ criteria;
- Calibration IQAs criteria, achieved by multiple human visual experiments, which provided a large database for analysis;
- Assessment PIQ with VIQET.

The results have been implemented in „ORT Braude College of Engineering" in Israel, and successfully used by Electronics engineering students in their IQ projects. The accuracy and reliability of the proposed model have been examined and evaluated according to international IQ standards organizations, international telecommunication union (ITU) and VQEG [3].

Approbation of the results. The results obtained in the thesis were presented at following international scientific conferences: „*Mathematics & Information Technologies: Research and Education (MITRE-2015)", Chisinau, Republic of Moldova, 2nd International Conference on Information Technologies, Systems and Networks (ITSN-2017), VQEG conference – Los Gatos (CA, USA, 2017*) and national *conference 11th Interdisciplinary Research Conference ORT Braude College of Engineering (2015).*

Publications: the results presented in the thesis, 7 scientific works were published, including 4 articles in research journals and 3 in proceedings of national and international conferences, including 5 without coauthors.

Structure and volume of the thesis: the thesis is written in English and consists of Introduction, 3 chapters and general conclusions and recommendations. The thesis contains 101 references, 107 pages of main text, including 66 figures, 30 tables, and 5 appendixes.

Keywords: image quality attributes (IQAs), human visual tests (HVT), image quality (IQ), objective IQ assessment, subjective IQ assessment, full reference model (FR), reduced reference model, non-reference model (NR), perceived image quality (PIQ), mean opinion score (MOS).

CONTENTS OF THE THESIS

In this work a new procedure was developed based on a new diploid model of subjective image quality assessment through HVTs and objective image quality assessment based on VIQET analysis. The received scores by subjective and objective IQ assessments analysis were conducted to find whether the increase of the image quality attributes would lead to improvement in user's perceived image quality.

One unique feature of this proposed framework was the capability of incorporating existing full reference image quality metrics which were adopted and have been implemented into the framework for smartphones displays.

The metrics evaluations were supported by the correlation of objective and subjective experimental results. This research also investigated the strategies to extend subjective experiments, which is expected to save quite a lot of time and resources for subjective experiments.

The thesis consists of introduction and three main chapters.

Introduction describes the objectives of the research and outlines the actual situation of PIQ assessment in the smartphone industry. It also presents the existing procedures in the field of objective and subjective IQ assessment in various methods which include: full-reference, reduced reference and non-reference IQ assessment.

Chapter I. **„Analysis of situation in the smartphones image quality"** provides a comprehensive introduction of the IQ assessment methods in the industry and academia. The flow chart in Figure 4 illustrates the metrics of perceptual image quality of smartphones. Evaluation of IQ is performed in the vendors IQ labs by image quality experts, then, they perform subjective IQ assessment through visual experiments while the observers are „non-experts" in image quality.

This process was described very well in the „Image quality circle" [6]. During the new IQAs development process, the IQ experts evaluate the IQ in labs through visual examinations in FR IQ assessment while comparing one image to other. Once the attributes had approved, the next phase will be subjective IQ assessment through many HVTs in order to measure the smartphone consumers "taste" of perceived IQ.

Objective image quality assessment is a computational method for predicting the perceived quality of images based on diploid model. This objective image quality model predicts the perceived image quality of an average human observer. The model provides a strong correlation between the subjective observations and the objective quality metrics is essential when developing an objective metric.

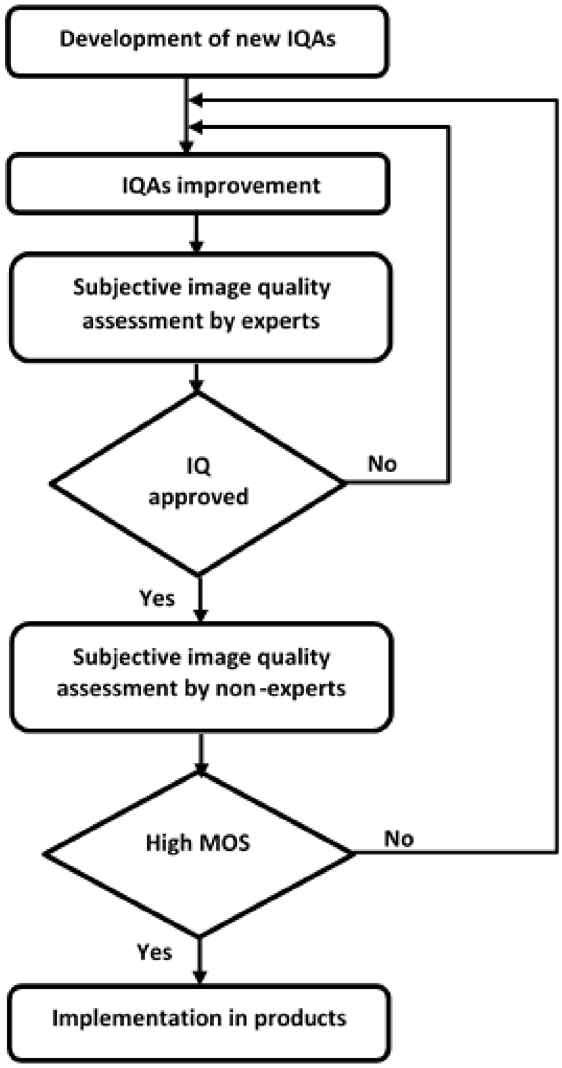


Fig.4. Actual IQ assessment process in the smartphones industry [7].

Subjective image quality assessment is the most reliable method for perceived image quality assessment. It done through HVTs of subjective testing, since human observers are the ultimate users in most of the multimedia applications. In HVTs a group of „non-expert" people are asked to give their opinion about the image quality of some image. In order to perform a subjective image quality testing, several international standards are proposed by the international transmitting union (ITU) and VQEG which provide reliable results. Some of these international standards were briefly described in this chapter.

There are three IQ assessment methods (full reference, reduced reference and non-reference model), that broadly used in the image processing industry which were originally designed for large screens and other displays *(e.g. TVs, projectors).* These methods are presented in Figure 5 and in Figure 6. The present research is focused on the ***no-reference model/NR,*** which is the most suitable for smartphones use cases.

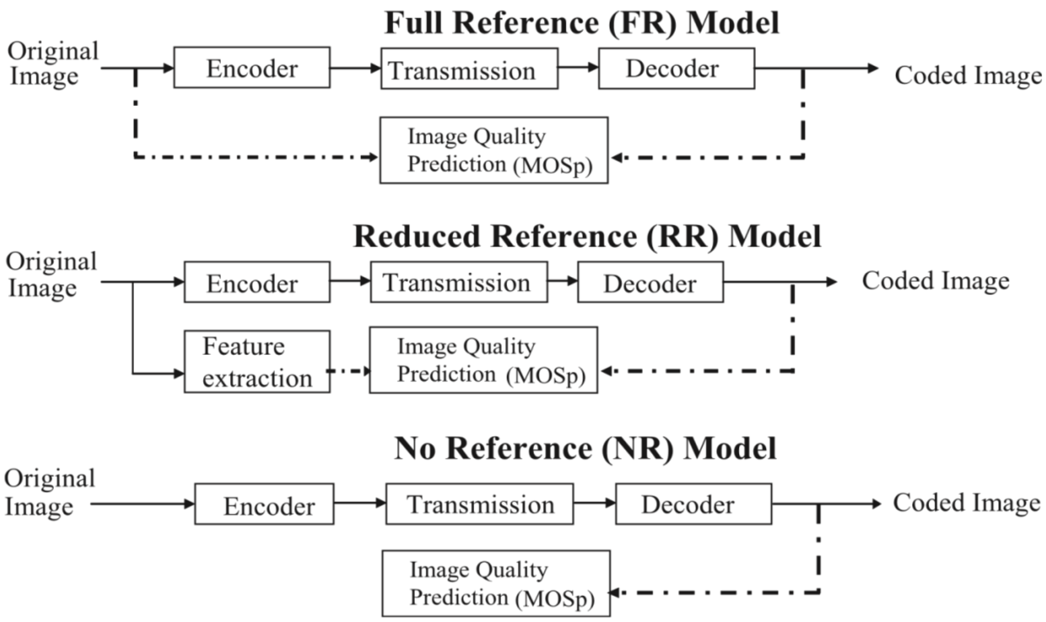


Fig.5. Image quality assessment models [7].

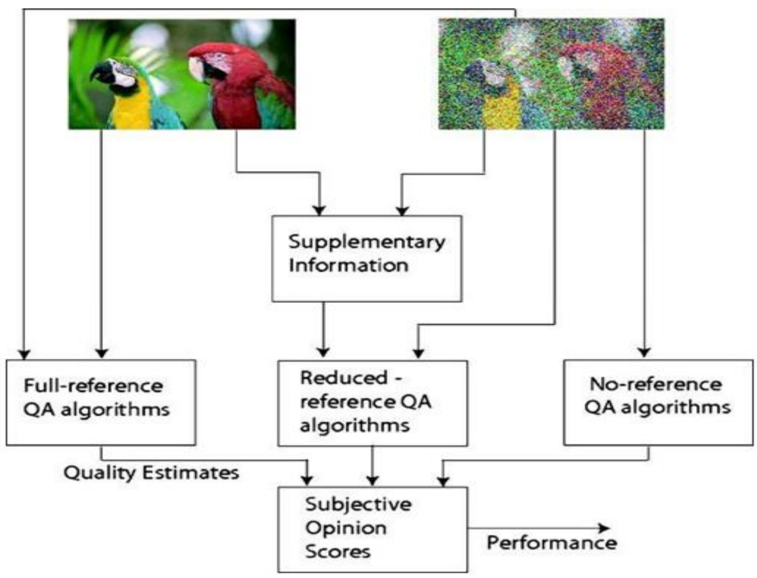


Fig.6. Flow chart of subjective image quality assessment [7].

In a **full-reference method**, reference images are required to assess the quality of distorted images and needs reference images. Most of the cases of quality assessment are using this method. However, in most of the real-time applications reference images are unavailable so, a FR metric is not useful for those applications.

In a **reduced-reference method** [8], partial information of the reference images is required to predict the visual quality of distorted images. This method is used as a substitute of FR method in case of missing an ideal reference image. For example, while developing new IQ feature, it is compared to the original image without the new IQ feature in order to see if there is an improvement in IQ or not.

No-reference method does not require any reference images to assess the quality of a distorted image is known as a NR method [8]. In many real-time applications, the reference image is not available. In these chases „blind" quality assessment approach in which a human observer can assess the quality of a distorted image without the use of any reference image is desirable. However, developing an objective NR quality measurement metric is difficult due to the human visual system (HVS) characteristics which are mostly subjective. This leads to the conclusion that a NR quality assessment is reliable only when the prior knowledge about the image distortion is available [9]. This research focuses on NR evaluation method.

New model for non-reference image quality assessment as the outcome of present research offers a new solution for NR IQ assessment. The research on NR metrics is in very preliminary stage in comparison to the research on FR and RR metrics. Nonetheless, research on NR metrics has recently received a lot of attention, because of their great practical potential in real-time applications while the reference image is missing. This NR assessment method addresses the smartphones use case in the everyday photography with extensive upload/download of images. Assessing image quality based on the comparison of ideal/original image with distorted image only seems an easy task for IQ experts and non-experts observers, yet the NR is the most difficult problem in objective image quality metric design [10, 11] due to the missing reference to compare with.

Chapter II **„Perceived image quality assessment"** provides a comprehensive overview on the perceived image quality measurements and VIQET parameters calibration process. The work was divided into two phases:

Phase I: Through HVTs with groups of observers in each experiment *(subjective image quality assessment),* the most contributing image quality attributes to the perceived IQ and the optimal parameters level of each attribute were identified.

Phase II: Creating a set of processed images based on the selected image quality attributes to be used as test content for HVT by performing HVTs with 98 observers (while ITU recommends 24 observers) is and analyzing the same images with the VIQET. The scores of HVTs and VIQET were analyzed. Then VIQET IQ criteria which presented in *Table 1* were calibrated due to the outcomes of the scores analysis. Once the VIQET has new image quality parameters a new HVTs conducted and the whole process done again in cycles with ten observers. The objective was to achieve the highest correlation between the HVTs scores and VIQET scores.

Table 1. VIQET image quality categories

IQ feature	Score	Range
Multi-scale Edge Acutance	12.14	Higher is better
Noise Signature Index	99.39	0 – 590
Saturation	123.41	0 represents B&W image
Illumination	92.00	0 – 255
Dynamic Range	106.72	Represents Gary levels

Subjective image quality assessment

A broad range of images with large set of IQ attributes, should be used in order to reveal different quality issues by the observers. To achieve this, the images were chosen based on the recommendations of VQEG with the criteria: pictures of natural image contents captured by smartphones camera in native resolution of 1920×1200 pixels. These images will be used as a reference. Each original image will be processed by adding the IQ attributes *(brightness, contrast, color and sharpness)* than the overall test content will include images in groups of 4 processed images and 1 for reference.

Test content was created according to the VQEG recommendations [5]. Contents were carefully selected to represent a wide range of different situations and demands for pictures. Also, recommendations of photo-space standards set by the international imaging industry association (I3A) were considered when choosing the image contents. Each original image was processed in order to enhance image quality attributes of: *brightness, contrast, sharpness and color saturation.* The overall test content for human visual tests and VIQET analysis includes 50 images (5 images of each scene) that represent various everyday scenes as demonstrated in Figures 7 – 10.

Fig.7. Outdoor day – landscape and people.

Fig.8. Indoor images.

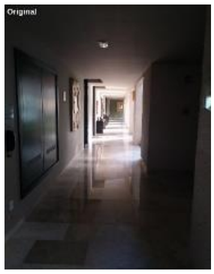


Fig.9. Indoor image with backlight.

Fig.10. Outdoor night.

Images in *Figures 7, 8, 9* and *10* were selected as test content for the subjective image quality assessment. Images in *Figure 7* „building”, „lake”, „man” and „taxi” are an example of outdoor day of some of the everyday city landscape. Images in *Figure 8* „king” and „room” are an example of indoor without backlight of some of the everyday scene when pictures are taken indoor with natural light. In this case the main objects are lighted. Image in *Figure 9* „hall” is an example of indoor with backlight of some of the everyday scene when pictures are taken indoor with window or door backlight. In this case the main objects are shaded. Finally, images in Figure 10 „sunset”, „bar” and „airplane”, are an example of outdoor night with considerable amount of black in the photo and the space was very bright and well-lit. A camera needs to properly meter off the light so that the people don’t get blown out, and so the shadows are precisely dark.

IQ assessment with different image quality attributes

In order to measure the contribution of the classic image quality attributes (*brightness, contrast, color saturation and sharpness*) to the perceived image quality, images of natural scenes that represent *outdoor day, outdoor night and indoor* lighting conditions were prepared as a basic test content. The total number of test content images was reasonable number of images kept the IQ assessment experimental time in about 10–15 minutes (10 seconds for each individual image with short break for voting), this encouraged the selected viewers to be cooperative with the IQ assessment tests. This process was implemented according to the ITU-R recommendation BT.500-

13 [9]. An example of an original test image with various levels of the classic IQAs added is demonstrated in *Figure 11*.

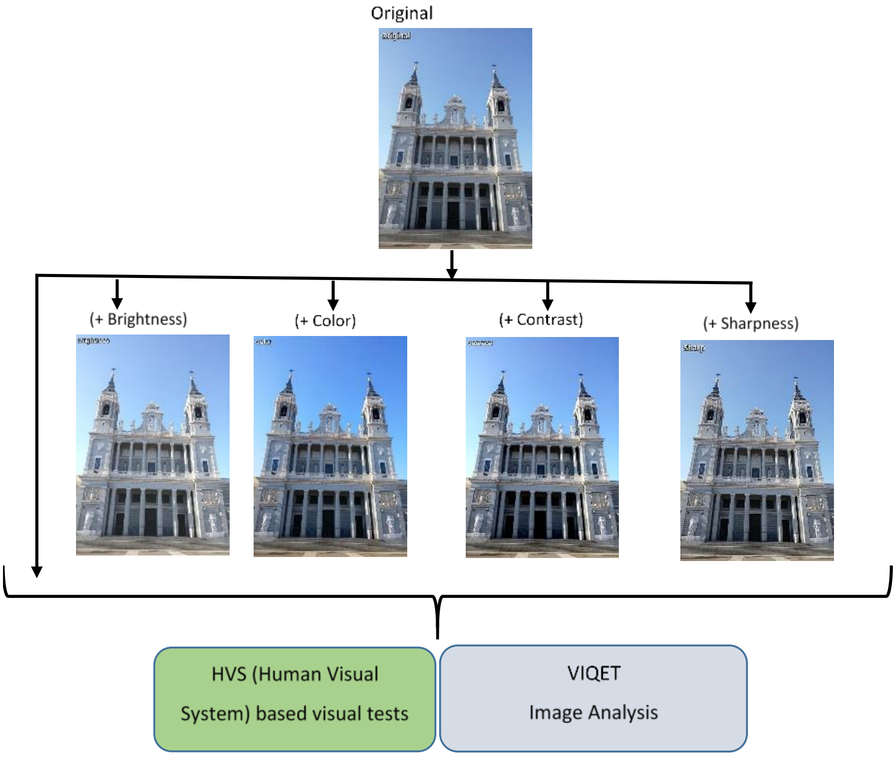


Fig.11. Examples of test material processing.

Perceived IQ comparison with VIQET image analysis

This part of study begins with an analysis of the images selected for test content for the HVTs by the image quality evaluation tool VIQET and design requirements followed by a detailed description of design and development procedures of an objective image quality assessment model. This new model consists of two parts: first, finding how image quality attributes effect observers' preferences through HVT, and, second image analysis with the VIQET.

Taking *brightness, contrast, color saturation* and *sharpness* as major image quality attributes, because these are the most visible everyday images. Variation of image quality attributes improve or degrade the perceived visual quality of an image. The relationship between the image quality and the level of increasing/decreasing IQ attributes depends on the texture contents of an image. The results indicate that visibility of image quality is strongly depended on the IQ attributes added to the image.

Measuring the perceived IQ in HVTs

A large number of non-expert *(in the sense that the viewers are not professional, experienced assessors)* subjects participated in this experiment, including male and females. All of them had normal or correct-to-normal sight. Each subject viewed the proposed images with a random order on the smartphones display and viewed ten sets of five images in each set (original, + brightness, + contrast, + saturation, + sharpness). Figure 12 illustrates the visual tests and VIQET image analysis process.

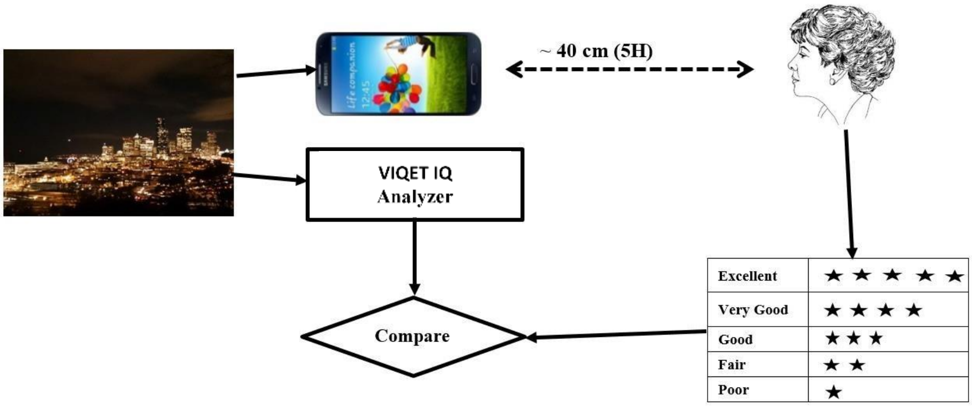


Fig.12. IQ visual tests and VIQET comparative analysis process.

When each viewer rated his/her perceived image quality in the absolute category rating (ACR) 5-point scale as shown in Figure 13 (corresponding to the perceived quality of *„excellent," „good," „fair," „poor,"* and *„bad")*.

Excellent	★ ★ ★ ★ ★
Very Good	★ ★ ★ ★
Good	★ ★ ★
Fair	★ ★
Poor	★

Fig.13. Staring points ranking.

The environment to the experiments was set following the suggestion of ITU-R recommendation BT.500-13 [9]. Before the formal test, the subjects were asked to rate a few example images to get familiar with the scoring scale and the image browsers.

Measuring IQ with VIQET

The VIQET is an open source tool designed to evaluate objective, no-reference photo quality of consumer photos:

- VIQET is available at www.GitHub.com/VIQET/;
- The desktop tool installer can be downloaded at https://github.com/VIQET/VIQET-desktop/releases/;
- The source code can be found at https://github.com/VIQET/VIQET-Desktop/.

In order to perform photo quality evaluation, VIQET requires a set of photos from the test device. Then estimates an overall Mean Opinion Score (MOS) of a device based on the individual image MOS scores in the set. The estimated MOS of each photo is based on a number of image quality features and statistics extracted from the test photo. The mapping from extracted features to MOS is based on psychophysics studies that were conducted to create a large dataset of photos and associated subjective MOS ratings.

The studies were used to learn a mapping from quantitative image features to MOS. The estimated MOS by VIQET falls in a range of 1 to 5, where 1 corresponds to a low quality rating and 5 corresponds to excellent quality. *Figure 14* demonstrates an example of VIQET RGB histogram, and *Figure 15* demonstrates VIQET sharpness map.

Fig.14. Example of VIQET RGB histogram.

Fig.15. Example of VIQET Sharpness map.

Table1 demonstrates an example of VIQET image quality attributes of quantitative image features.

Objective IQ assessment with VIQET

The estimated MOS for each photo is based on a number of image quality features and statistics extracted from the test photo. The same images used in phase I for rating IQ by HVTs were required for IQ rating by VIQET to analyze each individual image and get its IQ scores.

Chapter III **„New model performance evaluation"** describes the performance evaluation and validation of the proposed new model. Comparing the perceived image quality scores given by observers during the HVTs with predicted scores by VIQET as the outcomes of the new model, as demonstrated in *Figure 16* showing scatter plots of the perceived image quality versus the predicted image quality.

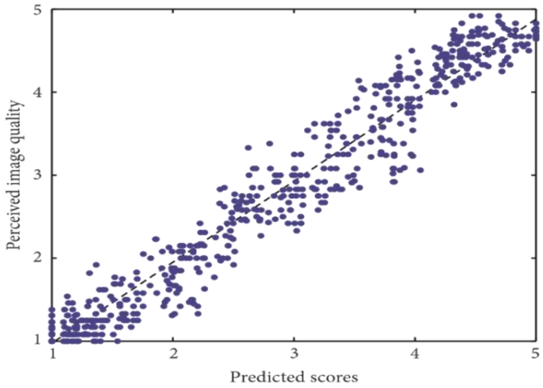


Fig.16. Perceived image quality and predicted scores [9].

The new model evaluation performance

To evaluate the performance of the proposed quality assessment model, this study followed the standard performance evaluation procedures of VQEG [5]. The standard was developed for calculating the prediction error between a mathematical model and subjective scores (human viewers' opinion). According to the [5], the performance of an objective quality model is characterized by three prediction attributes: accuracy**,** monotonicity, consistency.

Accuracy is the ability to predict the distortions between MOS and MOSp. In an ideal case, the relationship between the *MOS* and MOS_p is expected to be linear. *Figure 17* illustrates the hypothetical relationships between the *MOS* and the MOS_p of two models. Model I is more accurate than the Model II because most of the images evaluations are reasonably closer to the straight line.

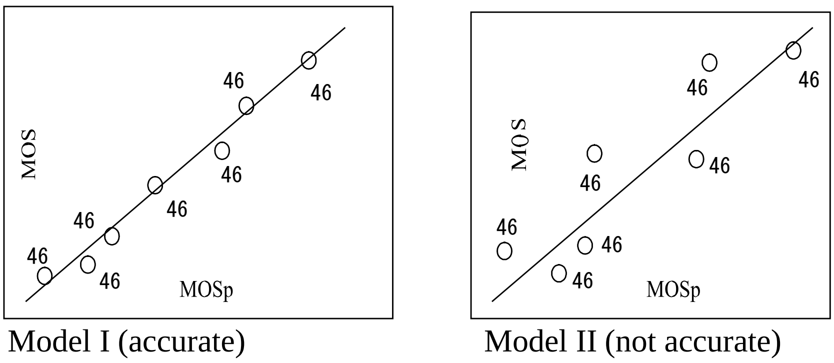
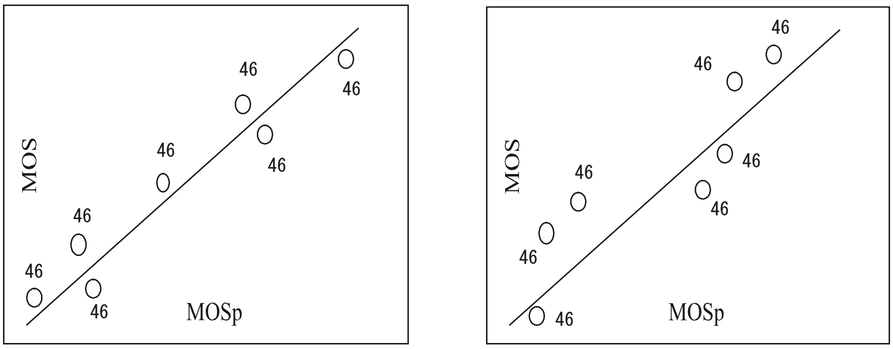


Fig. 17. Two hypothetical models with different prediction accuracy [9].

Monotonicity is the degree to which the model's predictions agree with the relative magnitudes of subjective quality ratings, i.e. between the subjective test and the objective model of variations in picture quality. As an example, viewers rank image A for many different levels of compressions where it implies the picture quality gets better when the level of compression is minimal.

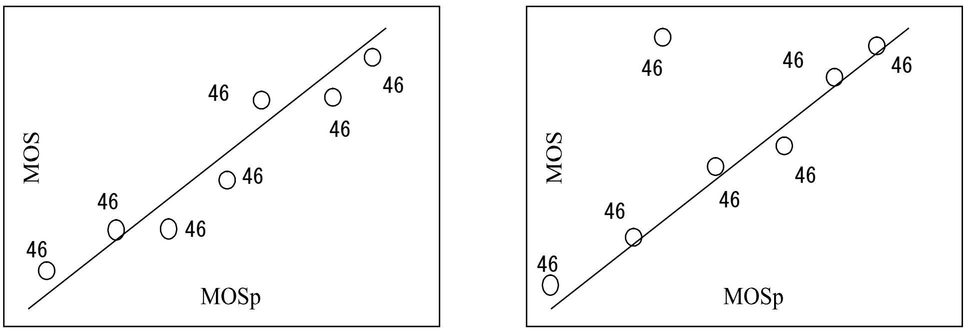
A monotonic objective model should give the same result, but it does not follow the trend even though they are mathematically equivalent. Figure 18 illustrates the hypothetical relationships between the *MOS* and the MOS_p of two models. Model I has a better Pearson correlation than Model II, but it falsely predicts degradation in picture quality in two events when the assessors actually see an improvement in picture quality. Therefore, in terms of monotonicity, Model II is better than Model I.



Model I (monotonic) Model II (non-monotonic)

Fig.18. Two hypothetical models with different prediction monotonicity [9].

Consistency is the degree to which the model maintains prediction accuracy over the range of all types of images or for a subset of images. An objective model should perform well over a wide range of test images with minimum prediction error. *Figure 19* shows two hypothetical models with *MOS* and the MOS_p, and in terms of consistency, Model I is more consistent than Model II.



Model I (consistent) Model II (inconsistent)

Fig.19. Two hypothetical models with different prediction consistency [9].

The followings are the performance evaluation metrics recommended by VQEG [5] for objective quality assessment model.

Metric 1 refers to the Pearson correlation coefficient (*CC*) between objective MOS_p and subjective *MOS* scores. MOS_p is the mean opinion score prediction that is the output of objective (i.e. mathematical) model and whereas *MOS* is the mean opinion score of human assessments. This metric provides an evaluation of *prediction accuracy*, which can be defined as:

$$CC = \frac{\sum_{i=1}^{N}(MOS(i)-\overline{MOS})\left(MOS_p(i)-\overline{MOS_p}\right)}{\sqrt{\sum_{i=1}^{N}(MOS(i)-\overline{MOS})^2}\sqrt{\sum_{i=1}^{N}\left(MOS_p(i)-\overline{MOS_p}\right)^2}},$$

where the index ***i*** denotes the image sample and ***N*** denotes the total number of samples.

The Pearson correlation coefficient is used to measure the strength of a linear association between two variables, where the value ***r = 1*** means a perfect positive correlation and the value ***r = –1*** means a perfect negative correlation.

Metric 2 refers to the Spearman rank order correlation coefficient (*SROCC*) between objective MOS_p and subjective *MOS* scores. It is considered as a measure of *prediction monotonicity*, and it is defined by

$$SROCC = 1 - \frac{6\sum_{i=1}^{N}\left(MOS(i)-MOS_p(i)\right)^2}{N(N^2-1)}.$$

The prediction monotonicity is the extent of agreement between the subject test and the objective model in terms of the sign of change in picture quality.

Metric 3 refers to the outlier ratio (*OR*), and represents number of „outlier-points" to the total points *N*. It is considered as a measure of *prediction consistency*, which can be defined by the following equation:

$$OR = \frac{Total\ number\ of\ outliers}{N},$$

where an outlier is a point for $|MOS(i)-MOS_p(i)|>2\times\sigma(MOS(i))$, where $\sigma(MOS(i))$ represents the standard deviation of the individual scores associated with the image sample *i*. The individual scores are approximately normally distributed and therefore twice the σ value represents the 95% confidence interval.

Metric 4, mean absolute error (*MAE*), is a quantity used to measure *how close forecasts are to the eventual outcomes*. *MAE* between objective MOS_p and subjective *MOS* scores is defined by

$$MAE = \frac{1}{N}\sum_{i=1}^{N}\left|MOS(i) - MOS_p(i)\right|.$$

The average (mean) absolute error is on same scale of data being measured. This is known as a scale-dependent accuracy measure and therefore cannot be used to make comparisons between series on different scales.

Metric 5 refers to the root mean square error (*RMSE*) between objective MOS_p and subjective *MOS* scores is defined by

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(MOS(i) - MOS_p(i)\right)^2}.$$

Metrics 4 and 5 are considered as a measure of *prediction accuracy*.

Calculation of expected score of perceived IQ

The new IQ assessment model realized in the work is presented in detail in chapter 2, and the evaluation of model is presented in chapter 3 of the thesis. The main deliverables of research include equations for image quality attributes calculation, framework and calibrated tool *VIQET*.

The evaluation framework describes how to extract the IQ parameters measures and provided by VIQET to MOS_p (predicted MOS).

IQ attributes of VIQET and their value range:

- multi-scale edge acutance (M) – range: 0–255;
- noise signature index (N) – range: 0–590;
- color saturation (C) – range: 0–255;
- illumination (I) – range: 0–255;
- dynamic range (D) – range: 0–255.

The image quality evaluation model is represented in the equation below. The weighted coefficients (A_m, A_n, A_c, A_i and A_d) are obtained by applying linear regression of the image quality assessment resulted of HVTs and VIQET [12, 13]. The weighted coefficients are proposed to formulate a better perceived image quality. In order to obtain an image quality evaluation model for a single (individual) given image, this equation should be applied.

This formula represents five IQ criteria measured by VIQET. Each IQ criteria multiplied by the respectively coefficient, which was obtained by linear regression of the obtained results in HVTs and by VIQET:

$$MOS_p = \frac{M_i}{M_{max}} A_m + \frac{N_i}{N_{max}} A_n + \frac{C_i}{C_{max}} A_c + \frac{I_i}{I_{max}} A_i + \frac{D_i}{D_{max}} A_d,$$

where M_{max}, $N_{max,}$, $C_{max,}$, I_{max}, and D_{max} are the maximum values of the IQ criteria measured by VIQET; A_m, $A_{n,}$, $A_{c,}$, A_i, and A_d represent the IQ coefficients for each IQ criteria. Coefficients indexes and their values are:

- multi-scale edge acutance (A_m), value = 3.04;
- noise signature index (A_n), value = 1.01;
- color saturation (A_c), value = 1.22;
- illumination (A_i), value = 1.12;
- dynamic range (A_d), value = 1.84.

GENERAL CONCLUSIONS AND RECOMMENDATIONS

This research proposes a new ***framework for smartphones perceived image quality prediction.*** The new framework is composed of a HVTs procedure and an evaluation by the ***computer based application VIQET***. Another application for the research outcomes can be used in social networks [14], e.g. *Facebook, Instagram, Snapchat etc.*

The VIQET is an open source evaluation tool, designed to objective, no-reference photo quality evaluation of consumer photos. In order to perform photo quality evaluation, VIQET requires a set of photos from the test device. It estimates an overall MOS for a device based on the individual image MOS scores in the set. This thesis provides a detailed description and analysis of subjective image quality assessment through HVT and objective image quality assessment based on VIQET analysis:

- The correlations between the metrical and perceptual results indicated that *MOS*, MSE, PSNR metrics give excellent prediction performance in most cases in terms of both correlation and its variance. According to the group comparison had comparatively better prediction performance than no reference metrics.
- The statistical analyses were conducted to check whether the increase of the image quality attributes would lead to improvement in user's perceived image quality.
- The results are useful for the mobile phone industry to have a better and efficient process for understanding of the concrete benefit of enhancing the image quality attributes. The proposed quality assessment model can be used by technology magazines while comparing and rating new smartphones models.
- One unique feature of this proposed framework was the capability of incorporating existing full reference image quality metrics without modifying them. This research implemented the framework for smartphones displays, and used the framework to evaluate the prediction performance of state-of-the-art image quality metrics regarding the most important image quality attributes for projection displays.
- The evaluated image quality attributes were brightness, contrast, color saturation and sharpness, however the proposed framework was not bound by the possibilities. All the metric evaluations were supported by the correlation of objective and subjective experimental results.
- In addition, this study also investigated the strategies to extend subjective experiments with baseline adjustment method, which is expected to save quite a lot of time and resources for

subjective experiments. In a broader point of view, the originally defined research scope have been fully covered by the research presented in this thesis, all research goals have been successfully achieved, and the corresponding research questions have been answered. The proposed image quality assessment framework was originally designed for smartphones displays, but could be easily adapted to other types of displays with limited modifications.

- The framework and new approach provided by this research can be a good process for perceived image quality prediction.

Future work

The research was focused on still images quality assessment based on four IQ attributes. The continuation of this research will deal with video material in HD content. The perceived image quality of live video is a new challenge in the image quality assessment field. The recommended IQ attributes for future research might be:

- frame rate conversion quality;
- band width limitations;
- video compression/decompression artifacts;
- motion artifacts.

Also, since the VIQET tool for image analysis is an open source application, it is highly recommended to use the current version as starting point in order to improve and make it up to date for future IQ attributes and objective image quality assessment.

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SUMMARY

of PhD thesis "*Assessment of perceived image quality for smartphones with embedded camera*"
Specialty 232.02 – *Information Technologies, Products and Systems,*
presented by Pinchas ZOREA, Moldova State University, Chisinau, 2018
to obtain the title of doctor in the Technical Sciences

Thesis structure: The thesis contains Introduction, 3 chapters, general conclusions and recommendations, bibliography of 101 titles. The main text amounts to 107 pages, includes 66 figures, 30 tables, 37 formulas, and 5 appendixes. The obtained results of the thesis were published in 7 scientific papers.

Keywords: human visual test (HVT), perceived image quality (PIQ), image quality attributes (IQAs), mean opinion score (MOS), objective/subjective image quality assessment, video quality experts group (VQEG), VQEG image quality evaluation tool (VIQET).

Aim of research is to develop a new no or zero (NR) reference subjective quality assessment model and framework that would enable the smartphones industry prediction of the PIQ.

The objectives of thesis include the design of NR subjective and objective image quality metrics based on extensive visual tests experiments and evaluation by SW tool VIQET that measure the perceived image quality of smartphones users.

Scientific novelty and originality of the obtained results is reflected in a new approach which predicts the PIQ by extraction of the classic, objective IQAs *(brightness, contrast, color saturation and sharpness)* to new subjective IQ criteria that evaluated by VIQET. This is a new assessment process based on a new diploid model, which aims to predict how the smartphones users perceived image quality.

Important scientific solved problem consists in elaborating a new diploid model for PIQ assessment that describes how to extract the standard IQAs which used in large screens TVs into new IQAs of SW tool VIQET. This can be used by smartphone producers and vendors in order to shorten „time to market", or by any image quality experts, including in the academia in order to reduce time and cost of PIQ assessment process of smartphones with small HD displays in comparison to the process that based on many human physical tests.

Theoretical significance is supported by analyzing, specifying and defining the theoretical principles and new PIQ criteria which implemented in the SW tool VIQET in order to predict the expected *MOS* in HVTs. The new model determines the relationship between the standard IQAs values and the VIQET PIQ criteria.

Applicative value of the work is determined by the developed model, which has huge potential for smartphone industry and users in reducing significantly the time and cost of PIQ assessment.

Implementation of results: the obtained results are used in „Ort Braude College of Engineering" in Israel, and can further be used by students and researchers in image processing. Also, an Israeli company (ASI – Applied Spectral Imaging Ltd.) evaluated the PIQ framework and found the benefits of PIQ framework for IQ improvement of images taken by medical spectral imaging system.

ADNOTAREA

tezei de doctorat

„Evaluarea calității percepute a imaginii pentru smartfonuri cu camera foto încorporată”

Specialitatea 232.02 – *Tehnologii informaționale, produse și sisteme,*

prezentată de Pinchas ZOREA, Universitatea de Stat din Moldova, Chișinău, 2018

pentru obținerea titlului de doctor în științe tehnice

Structura tezei: Teza constă din introducere, 3 capitole, concluzii generale și recomandări, bibliografie (101 titluri). Textul de bază este expus pe 107 pagini, incluzând 66 figuri, 30 tabele, 37 formule și 5 anexe. Rezultatele obținute au fost publicate în 7 lucrări științifice.

Cuvinte-cheie: test vizual uman (HVT), calitate percepută a imaginii (PIQ), atribute de calitate a imaginii (IQAs), media scorurilor de opinie (MOS), evaluare obiectivă/subiectivă a calității imaginii, grup de experți în domeniul calității imaginii (VQEG), instrumentar VQEG de evaluare a calității imaginii (VIQET).

Scopul cercetării constă în dezvoltarea unui nou cadru și model de evaluare subiectivă a calității imaginii fără referință la original (NR), care ar permite industriei de smartfonuri predicția PIQ.

Obiectivele tezei includ proiectarea metricilor subiective și obiective de calitate a imaginii fără referință la original NR, în baza unor multiple teste vizuale experimentale și evaluării cu instrumentarul VIQET, care permite măsurarea PIQ de către utilizatorii de smartfonuri.

Noutatea științifică și originalitatea rezultatelor se reflectă în noua abordare a predicției PIQ prin extragerea noilor criterii subiective de calitate evaluate cu instrumentarul VIQET din atributele clasice de calitate IQAs *(luminozitate, contrast, saturație de culoare* și *claritate)*. Acesta reprezintă un nou proces de evaluare bazat pe un nou model diploid, care urmărește să prezică modul în care utilizatorii de smartfonuri percep calitatea imaginilor.

Problema științifică importantă soluționată constă în elaborarea unui nou model diploid de evaluare a PIQ, care descrie cum pot fi extrase noile IQAs, folosite de instrumentarul VIQET din IQAs standarde, folosite pentru televizoare cu ecrane mari. Acest lucru poate fi utilizat de către producătorii și furnizorii de smartfonuri pentru a scurta „timpul ieșirii pe piață” sau de către orice alți experți și cercetători, inclusiv din mediul academic, pentru a reduce timpul și costul procesului de evaluare a calității percepute pentru smartfonuri cu ecrane mici de înaltă rezoluție (HD) comparativ cu multiplele teste fizice.

Semnificația teoretică este susținută de analiza, specificarea, definirea principiilor teoretice și a noilor criterii PIQ, implementate în VIQET pentru previziunea valorii medii așteptate MOS în HVT. Noul model stabilește relația dintre valorile IQAs standarde și criteriile utilizate în VIQET.

Valoarea aplicativă este determinată de noul model elaborat, ce are un potențial solid pentru industria și utilizatorii de smartfonuri în ce privește reducerea semnificativă a timpului și a costurilor de evaluare a PIQ.

Implementarea rezultatelor: rezultatele obținute sunt utilizate în Ort Braude College of Engineering (Israel) și pot fi utilizate cu succes de către studenți și cercetători în domeniul procesării imaginilor. Compania israeliană (ASI-Applied Spectral Imaging Ltd.), de asemenea a evaluat noua metodă PIQ și a constatat avantajele acesteia în îmbunătățirea imaginii calității în sistemele medicale spectrale.

АННОТАЦИЯ

Диссертационной работы *«Оценка воспринимаемого качества изображения для мобильных устройств со встроенной камерой»,*
Специальность 232.02 – *Информационные технологии, системы и продукты*
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Государственный Университет Молдавии, Кишинев, 2018
на соискание учёной степени кандидата технических наук.

Структура работы: Диссертация состоит из введения, трех глав, общих выводов и рекомендаций, библиографии, включающей 101 название. Основной текст представлен на 107 страниц, включая 66 рисунков, 30 таблиц, 37 формул и 5 приложений. Полученные результаты были опубликованы в 7 научных статьях.

Ключевые слова: визуальный тест, осуществлённый человеком (HVT), воспринимаемое качество изображения (PIQ), атрибуты качества изображения (IQAs), среднее значение оценок (MOS), объективная/субъективная оценка качества изображения, экспертная группа по качеству видео (VQEG), инструмент VQEG для оценки качества изображения (VIQET).

Цель исследования заключается в разработке новой модели субъективной оценки качества, без ссылки на оригинал NR, которая позволит производителям смартфонов прогнозировать PIQ.

Задачи исследования включают разработку субъективных и объективных NR показателей качества на основе множества визуальных экспериментальных тестов и оценки при помощи программного приложения VIQET, позволяющий измерять воспринимаемое пользователями смартфонов качество изображения.

Научная новизна и оригинальность результатов состоит в разработке нового подхода к прогнозированию PIQ, который позволяет извлечь классические объективные IQAs (*яркость, контраст, насыщенность цвета* и *резкость)*, в новых IQAs критериях, используемых в VIQET. Это новый процесс оценки, основанный на новой диплоидной модели, целью которой является предсказание того как пользователи смартфонов воспринимают качество изображения.

Важной научной задачей решенной в исследовании является разработка новой диплоидной модели оценки PIQ, описывающей как извлечь новые IQAs инструмента VIQET из стандартных IQAs, используемые для больших телевизионных экранов. Это может использоваться производителями и поставщиками смартфонов для сокращения времени выхода на рынок, или любыми экспертами PIQ, в том числе в академических кругах, для сокращения времени и снижения стоимости оценки PIQ для смартфонов с малыми экранами высокой четкости (HD) в сравнение с ручным процессом на основе множества визуальных тестов, осуществляемых людьми.

Теоретическая значимость работы подтверждается анализом и определением теоретических принципов и новых критериев PIQ, внедрённых в программном приложении VIQET для прогнозирования ожидаемой MOS в HVT. Новая модель определяет взаимосвязь между стандартными значениями IQAs и критериями IQ VIQET.

Практическая применяемость работы определена разработанной моделью, которая имеет огромный потенциал для индустрии и пользователей смартфонов, заключающийся в сокращении времени и снижении стоимости оценки PIQ.

Внедрение результатов: полученные результаты используются в «Ort Braude College of Engineering» (Израиль) и может быть успешно использована студентами и исследователями в области обработки изображений. Израильская компания (ASI - Applied Spectral Imaging Ltd.) также оценила новый метод PIQ и нашла преимущества для улучшения IQ визуализации изображений в медицинских спектральных системах.

ZOREA PINCHAS

ASSESSMENT OF PERCEIVED IMAGE QUALITY FOR SMARTPHONES WITH EMBEDDED CAMERA

Specialty 232.02 – Information technologies, products and systems

Abstract of the PhD Thesis in Technical Sciences

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