Comparison of Parametric Models for Video Quality Estimation: Towards a General Model

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***Abstract*— This paper presents a review of parametric models for video quality estimation published by ten different authors in the last years. Each model is briefly described, and the relevant parametric formulas are presented. The performance of each model is evaluated and contrasted to the other models, using a common video clips set, in different coding and transmission scenarios, including different bit rates, frame rates and percentage of packet losses. The strengths and weaknesses of each model are remarked. Finally, some suggestions towards the development of a "general" parametric model for video quality estimation are presented.**

***Index Terms*—Video perceptual quality, Video quality parametric models codecs, Video signal processing**

I. INTRODUCTION

In recent years different evaluations and standardized efforts have been made, and are currently ongoing, in order to obtain objective models and algorithms to predict the perceived video quality in different scenarios.

The video quality models can be classified into FR (Full Reference), RR (Reduced Reference) and NR (No Reference) models. In the first one, FR models, the original and the degraded video sequences are directly compared. In the RR models, some reduced information about the original video is needed, and is used along with the degraded video in order to estimate the perceived video quality. NR models are based only in the degraded video in order to make an estimation of the perceived video quality.

Based on the work of VQEG (Video Quality Experts Group) and other contributions, ITU-T has standardized some FR and RR models. Among them the Recommendation ITU-T J.144 [1] in 2004, the Recommendations ITU-T J.247 [2] and ITU-T J.246 [3] in 2008 and the Recommendation ITU-T J.249 in 2010 [4].

Parametric models predicts the perceived video quality based on a reduced set of parameters, related to the encoding process, video content and/or network information. These models typically present a mathematical formula, representing the estimation of the perceived video quality as a function of different parameters. Parametric models are easy to implement since there is no need to full access to the original video source. They may be applied to network design, network assessments and/or to real time monitoring. The quality estimation is obtained very fast as the result of a direct mathematical formula.

Many different parametric models have been proposed, with different scopes and applicable to different scenarios, and a parametric model was standardized in the Recommendation ITU-T G.1070 in 2007 [5]. Each of the proposed parametric models has been evaluated by their authors. However, they typically study them in a particular use case. Nevertheless, a *general* parametric model that would apply for a wide range of applications, encoding parameters and transmission scenarios has not been developed yet.

In this paper we present a review of parametric models published in the last years by ten different authors. The model's parameters and performance are evaluated and compared. The strengths and weaknesses of each model are remarked and are used towards the development of a *general* parametric model for video quality estimation.

The paper is organized as follows: Section 2 describes the published parametric models. In Section 3 the performance of each model is presented. Section 4 describes the characteristics of a general parametric model, taking into account the results of the previous section. Section 5 summarizes the results and main contributions.

II. PARAMETRIC MODELS

In this section different parametric models are presented. These models have been proposed in last years. Each model is briefly described, and the parametric formula is detailed.

A. *Kazuhisa Yamagishi et al.: ITU-T G.1070 Model*

ITU-T has published a model for predicting the video quality in video telephony applications, based on measurable parameters of an IP network. The Recommendation ITU-T G.1070 [5] describes a computational model for point-to-point interactive videophone applications over IP networks. The model is similar in form to the E-Model (Recommendation ITU-T G.107 [6]) and is based on the work performed by K. Yamagishi et al. [7][8]. The model consists in three functions, one for video quality estimation (V_q), other for audio quality estimation (S_q) and the last for the overall multimedia quality estimation (MM_q). Audio quality estimation is based on a simplification from ITU-T G.107 model. Video quality estimation is performed according to Equation (1).

$$V_q = 1 + I_c I_t \tag{1}$$

where V_q is the estimation for MOS (MOS_p), I_c is the video quality estimation determined by the encoding process and I_t is the video quality determined by the transmission process. I_c depends on bit rate b and frame rate f, according to equations (2) to (5).

$$I_c = I_o e^{-\frac{(\ln(f)-\ln(f_o))^2}{2D_{Fr}^2}} \tag{2}$$

$$f_o = v_1 + v_2 b \tag{3}$$

$$D_{Fr} = v_6 + v_7 b \tag{4}$$

$$I_o = v_3\left(1 - \frac{1}{1+\left(\frac{b}{v_4}\right)^{v_5}}\right) \tag{5}$$

I_t depends on bit rate and frame rate and the percentage of packet loss, according to equations (6) and (7).

$$I_t = e^{-\frac{p}{D_{Pplv}}} \tag{6}$$

$$D_{Pplv} = v_{10} + v_{11} e^{-\frac{f}{v_8}} + v_{12} e^{-\frac{b}{v_9}} \tag{7}$$

In these equations, b is the bit rate, f is the frame rate, p is the percentage of packet loss, and v_1 to v_{12} are coefficients that must be calculated for each codec and display size. In this model, video content is not taken into account. The Recommendation states that the model handles video whose size is between VGA (Video Graphics Array, 640×480 pixels) and QQVGA (Quarter Quarter VGA, 160×120 pixels), but provisional values for the coefficients are provided only for MPEG-4 in QVGA (Quarter VGA, 320×240 pixels) and QQVGA video formats. In [9] a new set of values for the coefficients are proposed for the MPEG-2 codec.

A similar model, for HDTV, was proposed by K. Yamagishi and T Hayashi in [10].

B. Fenghua You et al: T-Model

The ITU-T G.1070 model takes into account the packet loss, assuming a random loss distribution, but does not take into account the packet loss pattern. Fenghua You et al. [11] have proposed an extension to the ITU-T G1070 model, according to equations (8) and (9).

$$I_t = e^{-\frac{p}{B_{Pplv} D_{Pplv}}} \tag{8}$$

$$B_{Pplv} = 1 + \alpha \frac{Den_{burst}}{N_{BP}} + \beta \frac{Den_{burst} D_{burst}}{Loss} \tag{9}$$

where Den_{burst} is the density of burst, D_{burst} is burst duration, and $Loss$ is the total loss including both burst and gap loss. N_{BP} is the number of burst periods. Coefficients α and β are dependent on codec, distortion concealment, and other factors related to media content.

The authors made subjective tests using MPEG-2 in HD (1920×1080 pixels) with three video clips and conclude that the proposed T-model achieves better accuracy than ITU-T G.1070 video model under burst loss conditions.

C. A. Raake et al.: T-V Model

In [12] A. Raake et al. have presented the “T-V Model”, a parametric model for video quality estimation for SD and HD TV. The model has a similar form than the ITU-T G.107 E-Model, according to equations (10) to (12).

$$V_q = Q_o - I_c - I_t \tag{10}$$

$$I_c = a_3 - a_1 e^{-a_2 b} \tag{11}$$

$$I_t = (b_o - I_c)\frac{p}{b_1 + p} \tag{12}$$

where Q_o is the maximum achievable quality, b is the bit rate, p is the percentage of packet loss and a_1-a_3, b_o-b_1 are coefficients that must be calculated for each codec and display size. Video content is not taken into account.

The same authors, in [13], have made an analysis of the influence of video content, but only qualitative results were presented. In [14] an extension to the model is presented, for IPTV in HD, in order to take into account video content. The new model applies only to the degradation introduced in the encoding process, according to equation (13)

$$I_c = a_3 + a_6 MV_1 - a_1 e^{-a_2 b + a_4 QP_1} \tag{13}$$

where the new parameters are MV_1 (the average of the standard deviation of the horizontal components of the Motion Vectors) and QP_1 (Quantization Parameter per macro-block averaged over each I-frame).

In [15], Raake et al. presented a modification to the transmission impairment I_t, based on the evaluation of the visibility of each lost packet. A “visibility classifier” module is described, and two parameters are extracted: the “estimated error" (**d_{mb}** the induced distortion, in terms of MSE, of the corrupted macroblocks which were noticeable in the frame where the loss occurred) and the "error propagation" (**d_{prop}** total number of impaired pixels due to error propagation), corresponding only to the packet classified as "visible". The new **I_t** formula is described in equation (14).

$$I_t = a_4 d_{mb} + d_{prop}^{a_5} + a_6 \tag{14}$$

D. H. Koumaras et al.: MPQoS Model

In [16] H. Koumaras et al. have presented the MPQoS (Mean Perceived Quality of Service) model. This model was designed for MPEG-4, in CIF (Common Intermediate Format, 352×288 pixels) and QCIF (Quarter CIF, 176×144 pixels) display sizes for multimedia applications. According to this model, the video quality estimation can be estimated as described in equation (15).

$$V_q = I_c = [PQ_H - PQ_L](1 - e^{-\alpha(b - BR_L)}) + PQ_L - 1 \tag{15}$$

where **b** is the bit rate and **PQ_H**, **PQ_L**, **BR_L** and **α** are the four model coefficients. In this work, video quality was evaluated using the MPQoS metric, based on the PQM Picture Quality Metric proposed in [17]. According to the authors, the model coefficient can be derived from only one parameter **x** that depends on video content, according to equations (16). The impairments due to transmission factors (**I_t**) were not modeled.

$$\alpha = f_1(x), BR_L = f_2(x), PQ_H = f_3(x) \tag{16}$$

In [18] we have shown that the "T-V Model" represented in Equation (11) and the MPQoS model represented in Equation (15) are equivalent , using the coefficients relations detailed in Equations (17).

$$a_1 = (PQ_H - PQ_L)e^{\alpha BR_L}, a_2 = \alpha, a_3 = PQ_H - 1 \tag{17}$$

E. M. Ries et al. Model

In [19] M. Ries et al. have proposed a model for video quality estimation according to Equation (18).

$$V_q = I_c = A + Bb + \frac{C}{b} + Df + \frac{E}{f} \tag{18}$$

where **b** is the bit rate, **f** is the frame rate, and **A**, **B**, **C**, **D**, **E** are the model coefficients. The authors have proposed to classify the video clips according to the video content, and for each class, a different set of coefficients are used. The authors show an algorithm to determine the content type and to make a classification into five classes. The degradation introduced in the transmission process is not evaluated. The **A**, **B**, **C**, **D**, **E** model coefficients are calculated for H.264 with frame rates between 5 and 15 fps and bit rates between 24 and 105 kb/s.

F. J. Gustafsson et al. Model

J. Gustafsson et al. have proposed in [20] a model that takes into account the combined effects of packet loss and buffering. The model makes the video quality estimation based on the MOS for the original video clip, the buffer size in the receiver, the re-buffering time during reproduction and the packet loss in the network, and was evaluated for MPEG4 in QCIF display size with bit rates up to 256 kb/s. Nevertheless, the referred paper does not describe the implementation details or the used formula for video quality estimation. Only the general form of the formula is presented, according to equation (19).

$$V_q = 1 + I_c I_b I_t \tag{19}$$

In this case **I_b** represents the degradation introduced by the "buffering" effects.

G. A. Khan et al. Model

In [21] A. Khan et al. have proposed a model for video quality estimation according to Equations (20) to (22)

$$V_q = I_c I_t \tag{20}$$

$$I_c = a_1 + a_2 f + a_3 \ln(b) \tag{21}$$

$$I_t = \frac{1}{1 + a_4 p + a_5 p^2} \tag{22}$$

where **b** is the bit rate, **f** is the frame rate, **p** is the packet loss, and **a_1-a_5** are the model coefficients. The authors have developed the model using five video contents coded in H.264 in QCIF display size They proposed to classify the video clips in three categories: "Slight Movement", "Gentle Walking" and "Rapid Movement".

The model was tested by the authors in QCIF display size, with frame rates between 10 fps and 30 fps and bit rates between 18 kb/s and 512 kb/s and with packet loss between 1% and 20%. The results were compared using the PSNR metric. No subjective tests were performed.

The same authors, in [22] have presented a similar model, according to equations (23) to (25). This model was developed using five video contents coded in H.264 in QCIF display size.

$$V_q = a_1 + I_c I_t \tag{23}$$

$$I_c = a_2 e^f + a_3 \ln(b) + CT\left(a_4 + a_5 \ln(b)\right) \tag{24}$$

$$I_t = \frac{1}{1+\left(a_6 p + a_7 p^2\right)a_8 B} \tag{25}$$

where the new parameters are ***CT*** (Content Type) and ***B*** (Burst Length).

H. Quan Huynh-Thu et al. Model

Quan Huynh-Thu et al. [23] have proposed a model of the impact of frame rate decimation, according to equation (26)

$$V_q = a_1 + \frac{a_2 - a_1}{1+e^{a_3 f + a_4}} \tag{26}$$

where ***f*** is the frame rate, and a_1-a_4 are the model coefficients. The model was designed using seven video clips in QCIF display size, with frame rates between 2.5 fps and 30 fps. The authors analyze the relation between the video quality and video content, using the moving vectors as the estimation for the video motion content. But the results were not modeled in a parametric formula.

I. Yen-Fu Ou et al. Model

In [24] Yen-Fu Ou et al. have presented a model of the effect of frame rate, according to equation (27)

$$V_q = V_{q_{\max}} \frac{1-e^{-c\frac{f}{f_{\max}}}}{1-e^{-c}} \tag{27}$$

where V_{qmax} is the video quality obtained at the maximum frame rate f_{max} (30 fps in this case), ***f*** is the frame rate and ***c*** is the model coefficient. The model was derived using six video clips in CIF and QCIF display sizes with no degradations due to the encoding process. The frame rates used were between 6 fps and 30 fps. The authors state that the ***c*** coefficient depends on the video content, but an explicit formula for deriving ***c*** from video content was not presented.

In [25] the same authors made an evaluation of the impact of frame rate decimation in video clips with degradation produced in the encoding process.

J. Jose Joskowicz et al. Model

In [26] Jose Joskowicz et al. have proposed a model that combines the effects of frame rate, bit rate, display size and video content. The model can be expressed as shown in equations (28) to (30).

$$V_q = 1 + I_c \tag{28}$$

$$I_c = v_3\left(1-\frac{1}{1+\left(\frac{ab}{v_4}\right)^{v_5}}\right) \tag{29}$$

$$\begin{aligned} v_3 &= 4+4(f_{\max}-f)(k_1 s + k_2 e^{-k_3(f_{\max}-f)ab}) \\ v_4 &= c_1 s^{c_2} + c_3 \\ v_5 &= c_4 s^{c_5} + c_6 \end{aligned} \tag{30}$$

where ***b*** is the bit rate, ***f*** is the frame rate, f_{max} is 25 fps, ***a*** is a constant that depends on display size, ***s*** is the average SAD (Sum of Average Differences) per pixel and c_1-c_6 and k_1-k_3 are the model coefficients. The model was derived using ten video clips, coded in H.264/AVC in VGA, CIF and QCIF display sizes at bit rates from 25 kb/s to 6 Mb/s and with frame rates from 5 fps to 25 fps.

The model takes into account the video content (using SAD as a characterization of the video content), but does not take into account the degradation introduced in the transmission process (i.e. packet loss).

III. MODELS COMPARISON

As can be seen from the previous section, many different parametric models have been proposed in last years. Each of the models were designed and/or tested at different conditions, taking into account specific parameters (i.e. bit rate, frame rate, video content, packet loss and so). A summary of the models is shown at Table I. In this section we will show the results of the performance of the different models.

First, the performance of the models with respect to the I_c factor is presented. In this comparison, only the degradation introduced in the encoding process is evaluated (i.e., there are no packet loss or other degradations introduced in the transmission process). Then the I_t factor of the models is included and another comparison is made.

The video clips available in the VQEG web page [27] were used for the models comparison. Each clip was coded in H.264/AVC in bit rates from 100 kb/s to 6 Mb/s and in frame rates from 5 fps to 25 fps. Transmission impairment where performed with percentage of packet losses between 0% and 2%. We have classified the clips in three different classes, according to the spatial and temporal activity: “High”, “Medium” and “Low”. For each model, the best set of coefficients where calculated. For the models that includes content classification, a different set of coefficients where calculated for each class of spatial and temporal activity (High, Medium, Low).

TABLE I. MODELS COMPARISION

Ref	Author	Equations	Bit Rate	Frame Rate	Packet Loss	Packet Loss Burst	Packet Loss Visibility	Video Content	Disp Size	Re-Buff	# Coef	Tested Conditions
A	K. Yamagishi ITU-T G.1070	2-7	Yes	Yes	Yes	No	No	No	No	No	12	VGA,QVGA; MPEG4
B	Fenghua You	8-9	Yes	Yes	Yes	Yes	No	No	No	No	2	HD, MPEG2
C1	A. Raake T-V Model	10-12	Yes	No	Yes	No	No	No	No	No	5	SD, HD; MPEG2, H.264
C2	A. Raake T-V Model	13	Yes	No	Yes	No	No	Yes - MV and QP	No	No	7	HD; H.264
C3	A. Raake	14	Yes	No	No	No	Yes	No	No	No	6	SD, HD; H.264
D	H. Koumaras: MPQoS Model	15	Yes	No	No	No	No	No	No	No	3	CIF, QCIF; MPEG4
E	M. Ries	18	Yes	Yes	No	No	No	Yes -Content Classes	No	No	5	CIF, QCIF, SIF; H.264
F	J. Gustafsson	19	?	No	Yes	No	No	No	No	Yes	?	QCIF; MPEG4
G1	A. Khan	20-22	Yes	Yes	Yes	No	No	Yes -Content Classes	No	No	5	QCIF; MPEG4
G2	A. Khan	23-25	Yes	Yes	Yes	Yes	No	Yes - ?	No	No	8	QCIF; H.264
H	Q. Huynh-Thu	26	No	Yes	No	No	No	No	No	No	4	QCIF
I	Yen-Fu Ou	27	No	Yes	No	No	No	No	No	No	1	CIF, QCIF
J	Jose Joskowicz	28-30	Yes	Yes	No	No	No	Yes - SAD	Yes	No	9	CIF, QCIF, VGA; H.264

We have used the "Low Bandwidth Reduced Reference Model" proposed by NTIA (National Telecommunications and Information Administration), standardized in Recommendation ITU-T J.249 [4] and available in [28] as the VQM (Video Quality Metric) for the models performance comparison. In [26] we have shown that this model performs very well for small display formats (i.e. VGA) and different bit rates and frame rates.

For each video clips pair (original and degraded), the NTIA model provides a VQM, with values between 0 and 1 (0 when there are no perceived differences and 1 for maximum degradation). Multiplying this value by 100 a metric is obtained which corresponds to the DSCQS (Double Stimulus Continuous Quality Scale) [29] and can be directly associated with the DMOS (Difference Mean Opinion Scores). The DMOS values returned from the NTIA model can be related to the typical 5 points MOS (Mean Opinion Score) using Equation (31).

$$MOS = 5 - 4DMOS \tag{31}$$

For the encoding degradation (I_c), the performance of each model was compared against the results of the NTIA model, using 10 different clips, coded in VGA with bit rates from 100 kb/s to 6 Mb/s and frame rates from 5 to 25 fps. More than 230 encoded video clips were used for the comparison. The results are shown in Table II. The PC (Pearson Correlation), the RMSE (Root Mean Square Error), and the percentage of outlier points are presented (points outside the +/- 15% range). The models that perform better for the encoded degradation (I_c) take into account video content, bit rate and frame rate (models "J", "E" and "G1"). The best performance is obtained by model "J", which uses the average SAD per pixel as a measure of the video content. The other two best performed models makes a video classification and uses different set of coefficients for each class.

TABLE II. I_C MODELS PERFORMANCE COMPARISON

Ref.	Author	PC	RMSE	Outliers
A, B	K. Yamagishi	0.67	0.89	32%
C1, D	A. Raake / H. Koumaras	0.61	0.65	34%
E	M. Ries	0.77	0.51	21%
G1	A. Khan	0.76	0.54	25%
H	Quan Huynh-Thu	0.65	0.72	28%
I	Yen-Fu Ou	0.70	0.70	31%
J	J. Joskowicz	0.90	0.36	8%

For the transmission degradation (I_t), the performance of the models that includes a "packet loss" parameter where compared against the results of the NTIA model. The comparison was performed using three video clips, encoded in VGA in more than 110 different configurations, with bit rates from 500 kb/s to 3 Mb/s, and percentage of packet loss from 0% to 2%., with random distribution. Frame rate was fixed at 25 fps. The results are shown in Table III. The model that best performs for packet loss degradations is model "A". In this model, I_t depends not only on the percentage of packet loss, but also on the bit rate and frame.

Finally, a set of subjective tests where performed. The same three video clips used for the transmission degradation evaluation where used, coded in VGA, in 8 different combinations of bit rates (from 500 kb/s to 3 Mb/s) and packet losses (from 0.2% to 2%). The models that include a "packet loss" parameter where compared to the subjective scores and the results are presented in Table IV. In this comparison, the model "A" has again the best Pearson Correlation with the subjective tests, but model C1 has the best RMSE and outliers points.

TABLE III. I_T MODELS PERFORMANCE COMPARISON

Ref.	Author	PC	RMSE	Outliers
A	K. Yamagishi	0.82	0.47	13%
C1	A. Raake	0.69	0.58	25%
G1	A. Khan	0.63	0.63	32%

TABLE IV. MODELS PERFORMANCE COMPARISON VS SUBJECTIVE SCORES (PACKET LOSS FROM 0.2% TO 2%)

Ref.	Author	PC	RMSE	Outliers
A	K. Yamagishi	0.70	0.63	38%
C1	A. Raake	0.48	0.55	25%
G1	A. Khan	0.24	0.58	38%

IV. TOWARDS A GENERAL PARAMETRIC MODEL

Bit rate, frame rate, packet loss, display size, codec and video content are all relevant to make an estimation of the perceived quality for a given video clip. Each of the current proposed parametric models take into account only a subset of these parameters. The models that performs better for the estimation of the encoding degradation (model "J") takes into account video content, bit rate and frame rate, and is the only model that explicitly includes the display size as a parameter. The model that performs better for the transmission degradation takes into account the percentage of packet loss in combination with the bit rate and the frame rate. None of the evaluated models explicitly takes into account video content in the transmission degradation.

According to the results, a more *general* model may be derived from a combination of Model "J" for the estimation of the encoding degradation and Model "A" for the estimation of transmission degradation. Probably a modification can be performed to Model "A" in order to include video content in the I_t estimation.

Other factors that were not evaluated may also affect the perceived quality, such as bandwidth (causing re-buffering), GOP size and structure, packet loss concealment strategy, video filters at receiver, codec specific configurations and display type, among others. These parameters are not explored in the proposed parametric models, but should be evaluated towards a more *general* model.

V. CONCLUSION

Parametric models for video quality estimation proposed by ten different groups of authors and organizations in last years were presented an analyzed. A performance comparison was performed for the encoding and transmission impairments estimation. From the obtained results, it can be seen that the model that performs better for the encoding impairments estimation is the proposed by Jose Joskowicz et al. in [26], and the model that performs better for the transmission impairments estimation is the proposed in ITU-T G.1070. Towards a more general model, a combination of both models can be evaluated, and the incorporation of video content in the transmission impairments estimation of ITU-T G.1070 should be performed. Other factors (such as GOP size and structure, packet loss concealment strategy, video filters at receiver, codec specific configurations and display type,) have not been explored yet, and should also be incorporated in a *general* parametric model for video quality estimation.

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