Quality Evaluation Method for Underwater Image Communication

Fei Yuan, Ji Zhang, En Cheng *
Key Laboratory of Underwater Acoustic Communication and Marine Information Technology (Xiamen University), Ministry of Education, P.R.C
*corresponding author: chengen@xmu.edu.cn

***Abstract*—A simulation based on Gilbert-Elliot packet loss model is developed to simulate an image transmitting system in underwater acoustic channel. This developed system is applied as a platform to study the relation between image quality assessment parameter PSNR, image activity measure (IAM) and channel's packet loss rate. A group of sample images were transmitted in this communication system and a formula of PSNR, the initial value of IAM, and packet loss rate was fitted by the data from the degraded sample images. With the help of the fitted formula, then we are able to predict the possible quality of image transmission, and beforehand choices of channel or source processing techniques in the communication system becomes possible, too. Experimental results indicate that the predicting method of underwater image transmitting quality based on Gilbert-Elliot model can provide certain references for establishing strategies of underwater image transmission.**

***Index Terms*—Underwater Image Communication, Image Quality Evaluation, PSNR**

I. INTRODUCTION

As is known to public, random noise and inferences commonly exist in all channels, which means that communication systems are of much uncertainty. As a consequence, packet loss and bit error, which share the same uncertainty, are not ignorable problems in a communication system. Such phenomena are defined as random processes mathematically, noted as sample functions. A statistical model can be established in this way to help researchers solve packet loss and bit error problems by virtue of a knowledge on probability, statistics and high-speed computers.

Underwater acoustic communication (UAC), similar to wireless communication, is a typical burst channel. Though Doppler effects and multipath effects make it one of the most challenging academical subject in the world, the researchers have developed advanced techniques for UAC researches. Researches in [1] involved a Gilbert-Elliot model to simulate packet loss events, and the relation between audio quality and packet loss rate was derived from the simulation. Since statistical models are not directly relevant to channel's physical features, the same model as in [1] can be used in simulation of an underwater system. According to the above considerations, a Gilbert-Elliot model based simulation of an underwater image transmitting system is proposed to predict image transmitting quality in this paper.

This paper is organized as follows. An introduction of Gilbert-Elliot model is given in Section II. Also the application of the referred model for UAC environment is described in the same section. In Section III, two kinds of image quality evaluation approaches for evaluating the quality of image transmitting system are introduced. Section IV is devoted to dealing with the simulation of an image transmitting system based on Gilbert-Elliot model. In this part, we talk about the system framework and obtain a formula for predicting the PSNR of a degraded image by analyzing the experimental results. Then Section V presents the conclusions.

II. GILBERT-ELLIOT MODELING

A. Gilbert-Elliot Packet Loss Model

According to literature [2], we know that previous researches took balanced binary channel, which is without memory, to model noise channel. In fact, however, communication systems are definitely with memory, because there is a temporary correlation between the lost packets. Research [3] studied a Markov model, which reflects the memory of channel, to model a packet loss pattern. When the system keeps a memory of last state, Markov model can be noted as two states. This form is namely Gilbert-Elliot model, which was proposed by E.N.Gilbert in 1960, and is now commonly used to describe various packet loss patterns. Set a random variable 'state' to represent separated events in relation to data packets, as is shown as follows.

$$\begin{cases} \text{state}=0\text{, indicates successful transmission of a packet} \\ \text{state}=1\text{, indicates a packet loss} \end{cases}$$

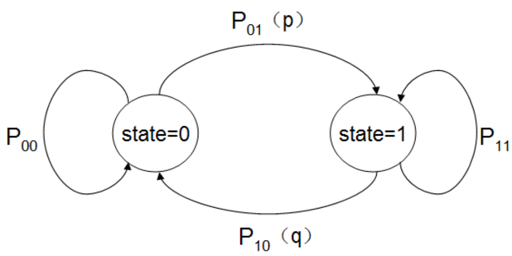


Figure 1. Gilbert-Elliot packet loss model

doi:10.4304/jcp.8.9.2313-2321

The alphabet p represents the probability that a packet loss event occurs under circumstances that the previous packet has been successfully received, i.e. the probability that the state changes from "0" to "1". So p is also expressed as P_{01}. The alphabet q represents the probability that a successful packet reception with a previous packet loss occurs, i.e. the probability that the state changes from "1" to "0". And q is also expressed as P_{10}. The transition probability matrix is written as

$$P = \begin{bmatrix} 1-q & q \\ p & 1-p \end{bmatrix} \quad (1)$$

Set $|P - \lambda E| = 0$, and the eigenvalues of (1) can be derived: $\lambda_1 = 1 - p - q$, $\lambda_2 = 1$. Correspondingly, the eigenvectors are written as

$$\alpha_1 = \begin{pmatrix} q \\ -p \end{pmatrix}, \quad \alpha_2 = \begin{pmatrix} 1 \\ 1 \end{pmatrix}$$

Diagonalize matrix (1), and we have

$$P = H \Lambda H^{-1}$$

in which

$$H = (\alpha_1, \alpha_2), \quad \Lambda = \begin{pmatrix} \lambda_1 & 0 \\ 0 & \lambda_2 \end{pmatrix}$$

Hence the n-step transition probability matrix can be written as:

$$P(n) = P^n = H \Lambda^n H^{-1} \quad (2)$$

When step n tends to infinity, matrix (2) tends to become equation (3).

$$\lim_{n \to \infty} P(n) = \frac{1}{p+q} \begin{pmatrix} p & -1 \\ -pq & q \end{pmatrix} \quad (3)$$

Set P_1 as the overall average packet loss rate, and P0 as the overall average no-packet-loss rate. P_1 is also noted as ulp（Unconditional Loss Probability）[4]。ulp can derived from (3)：

$$ulp = \frac{p}{p+q} \quad (4)$$

The clp (Conditional Loss Probability) is equivalent to the consecutive packet loss rate of the system, written as:

$$clp = 1 - q \quad (5)$$

B. Gilbert-Elliot Model in UAC

In accordance with literature [1], Gilbert-Elliot model has four dominant parameters: the packet loss rate (ulp), consecutive packet loss rate (clp), transition probability q and transition probability p. Any two of the four parameters can derive from another two by formula (4) and (5). In the UAC packet loss model proposed in this paper, the value of ulp and clp need to be set in simulation.

As is learned from literature [5], underwater acoustic channel is a time-space-frequency variable channel, with random Doppler effects and multipath effects. The factors that affect the features of underwater channel include density of the sea water, rhythm of the undulating waves, submarine topography, temperature and even biological activities. Consequently, underwater channel is one of the most complicated wireless channel, and it is undoubtedly impossible to give a complete clear description of underwater channel.

Viewed as a random process, the variation of underwater acoustic channel can be traced within limited time. If we establish a mathematical model in relation to statistical properties, such as packet loss rate and bit error rate, the physical features are neglectable. A UAC packet loss model is studied in this paper. The actual clp value and actual ulp value in UAC can be calculated with the experimental data. The actual values will be set to the proposed cyber-simulation, in which way a UAC packet loss model will be established.

We can obtain several groups of bit error rate data in experiments conducted in water pools by referring to [6]. Applying Gilbert theory to bit error rate, we can set up a similar mathematical model. In this model, state 0 indicates that a bit arrives at the destination accurately, while state 1 indicates that a bit error occurs. In this way, ulp stands for bit error rate, while clp stands for consecutive bit error rate. Obviously bit error model and packet loss model are the same statistically. Setting clp value properly according to [7], we obtain seven groups of actual UAC parameters, which have been simulated in the established Gilbert-Elliot model, and the simulated results are shown in TABLE I.

TABLE I.

SEVEN GROUPS OF UAC PACKET LOSS PARAMETERS AND THE SIMULATION RESULTS

	Condition1	Condition2	Condition3	Condition4	Condition5	Condition6	Condition7
ULP	0.0880	0.0105	0.0118	0.0182	0.0395	0.0540	0.1814
CLP	0.1760	0.0210	0.0236	0.0364	0.0790	0.1079	0.3628
CLP_Sim	0.0920	0.0095	0.0127	0.0195	0.0388	0.0583	0.1833

In this proposed simulation, whether the data packet is abandoned and which packet is abandoned will be recorded in a packer loss tracing vector. The results indicate that simulated ulp values are approximately equal to the given ulp values. The errors are within 10%, which is mathematically tolerable.

III. Image Quality Evaluation Approaches

The UAC system, a low-speed communication system with the carrier of acoustic wave, primarily transmits information like images and characters. As for an image transmitting system, the quality of degraded images at the receiver needs to be evaluated in order to estimate the systemic performance and then decide an optimization strategy. In practice, subjective evaluation is significantly time-consuming and difficult to be realized. What is more, the subjective evaluation results are not only determined by simply the image quality, but the evaluators' knowledge, intelligence and perception to a great extent. On that account, objective evaluation is necessarily employed in usual, including methods such as Mean Square Error (MSE), Peak Signal to Noise Ratio (PSNR), correlation coefficient, structural similarity (SSIM), and Image Activity Measure (IAM). In this article, the concepts of PSNR and IAM are introduced to assess image quality.

A. Peak Signal to Noise Ratio(PSNR)

PSNR is defined as this: given a digital image $f(x,y)$ with the size $M \times N$ and its degraded counterpart $f_0(x,y)$, the PSNR of the degradation is written as

$$PSNR = 10\lg \frac{f^2 \max}{MSE} \tag{6}$$

where $f_{\max}$ represents the maximum value of $f(x,y)$. As for 8-bit gray level images, $f_{\max} = 2^8 - 1 = 255$. MSE (Mean Square Error) is written as

$$MSE = \frac{1}{MN} \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} \left[f(x,y) - f_0(x,y) \right] \tag{7}$$

Theoretically a higher PSNR value indicates a higher image quality. Though sensitive to pixel shift, PSNR has an obvious shortcoming, which is that PSNR does not contain any specific information of the structure, color, or resolution of the evaluated image.

B. Image Activity Measure (IAM)

IAM is introduced to describe structural characteristics of images. Defining the edges and textures as active regions of the image, the more active and more complex the active regions are, the higher image activity (IAM) the images are. There are chiefly four methods for calculating the value of IAM, including contrastive variance detection, edge information detection, wavelet coefficient detection and image gradient detection.

Literature [8] had proved that compared to other three methods, the image gradient detection with a broader range of parameters has a optimal performance for discriminating different images. For an $M \times N$ image, setting i and j to represent a single pixel's location, IAM derived from image gradient detection is defined as follows:

$$IAM = \frac{1}{M * N} \left[\sum_{i=1}^{M-1} \sum_{j=1}^{N} \left| I(i,j) - I(i+1,j) \right| + \sum_{i=1}^{M} \sum_{j=1}^{N-1} \left| I(i,j) - I(i,j+1) \right| \right] \tag{8}$$

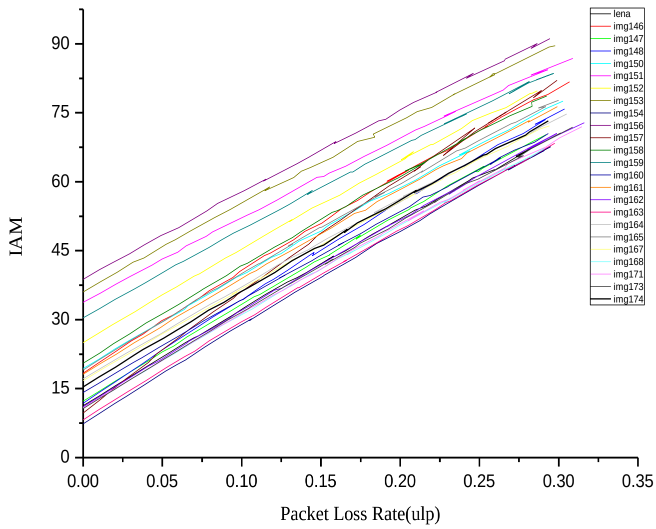


Figure 2. IAM values of sample images versus packet loss rate

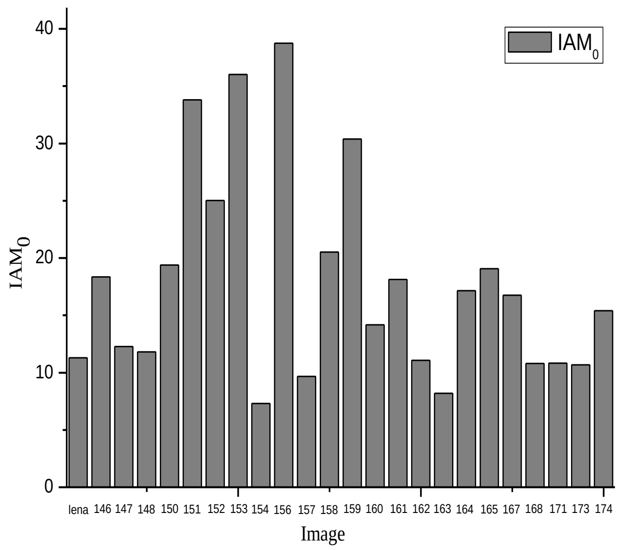


Figure 3. IAM_0 values of sample images

(a) No.150

(b) No.154

(c) No.156

Figure 4. Three sample images

Generally speaking, the higher IAM is, the more seriously image degrades. Set IAM_0 to initial IAM value, which is a fixed value, reflecting the origin image structural features. For researching purposes, we have selected 24 pictures as examinees of the proposed simulation. Fig. 2 shows the linear relation between the IAM values of the selected sample images and the the packet loss rate of the channel. We can easily come to a conclusion according to Fig. 2 that a higher packet loss rate leads to a higher IAM value, meaning a worse degradation, in which the edges and textures of the image become much more complex and different than the original one. Fig. 3 shows each sample image IAM_0 value, which is translated as a y intercept of each straight line.

According to Fig. 3, IAM_0 varies with image numbers. Fig. 4 shows 3 sample pictures, No.154 with an IAM_0 of less than 10, No.156 with a highest IAM_0 of nearly 40 and No.150 with a moderate IAM_0 of 20. Then take a look at the contents. There are two parrots in No.154, which is clean-cut and with relatively simple textures. The one with the highest IAM_0, No.156, describes a house and an adjacent path with grass, flowers and trees, whose textures are quite complicated. And the moderate one, No.150, seems to be neither simpler than No.154, nor more complicated than No.156. Obviously, values of IAM_0 mirrors structural features of the origin digital images.

IV. Simulation and Analysis

A. *Structure of the Simulation System*

A simulation of the image transmitting system based on Gilbert-Elliot model is proposed for UAC (as Fig. 5 shows). The transmitting end of the simulation system loads the origin images firstly, then transforms the data type from decimal to binary. In the encoder, binary data is packed into 512-bit packets. After packing, the packets travel through the simulated Gilbert-Elliot packet loss channel and some packets are discarded due to a setting of packet loss rate to the system. At the receiver, packets are regrouped and the data inside will be decoded to reform an image, which is a degradation as a result of packet losses. Eventually the degraded images will accept a PSNR assessment from the system. In this way, we evaluate the quality of the image transmitting system by judging from the PSNR value.

Set a vector to trace packet loss events, and initialize the state with 0. As a packet enters into the Gilbert-Elliot channel, a decision has to be made simultaneously. If the previous state is 0 and the probability p event occurs, the state turns to 1, and the packet being transmitted is to be discarded, otherwise the state stays in 0, and the packet arrived at the receiver successfully. If the previous state is 1 and the probability q event occurs, the state turns to 0, and the packet being transmitted is signed as a successful reception, or the state stays, and the packet gets discarded. In addition, this system ensures completeness of the transmitted images by implementing an interpolation with a random binary value. Due to emphasizing concerns, interpolation algorithm will not be discussed in detail here.

B. *Results of PSNR Assessment*

Set the packet loss rate of the channel to vary within the range from 0 to 0.3, and the PSNR of distinguishing images tend to decrease as the packet loss rate increases, as is shown in Fig. 6.

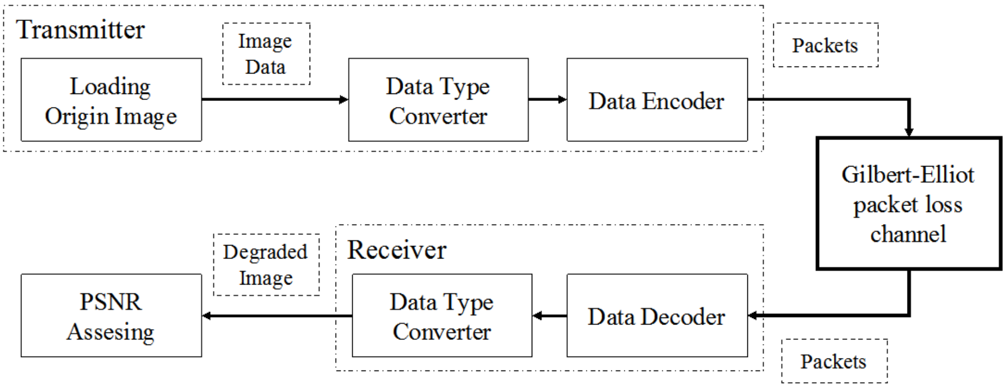


Figure 5. UAC image transmitting system based on Gilbert-Elliot model

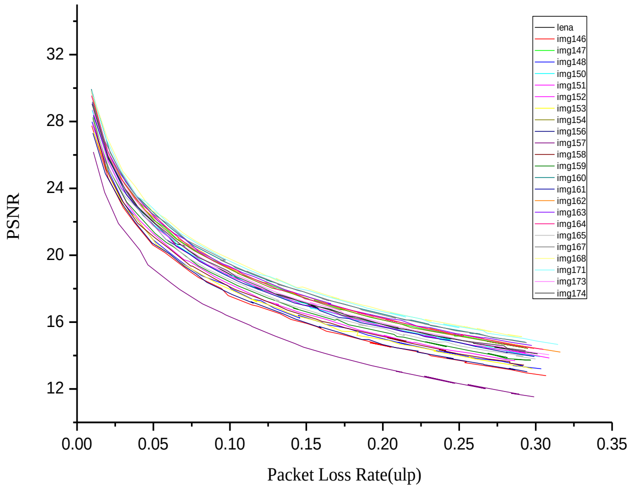


Figure 6. PSNR performance of sample images versus packet loss rate

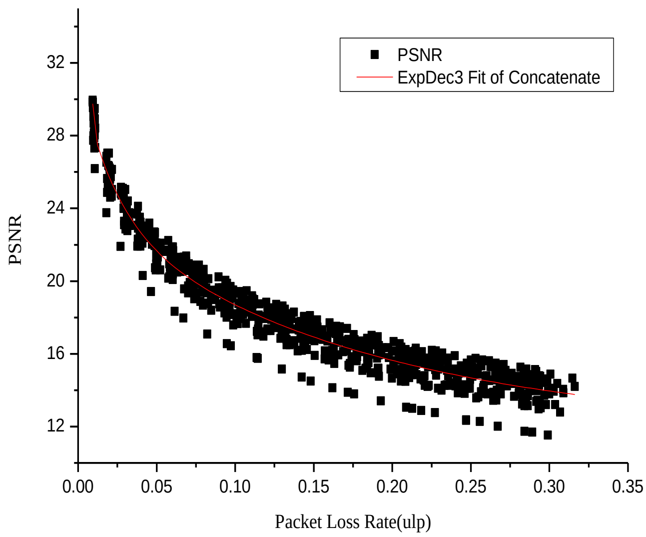


Figure 7. Scatter plots of PSNR versus packet loss rate and the exponential fitted curve

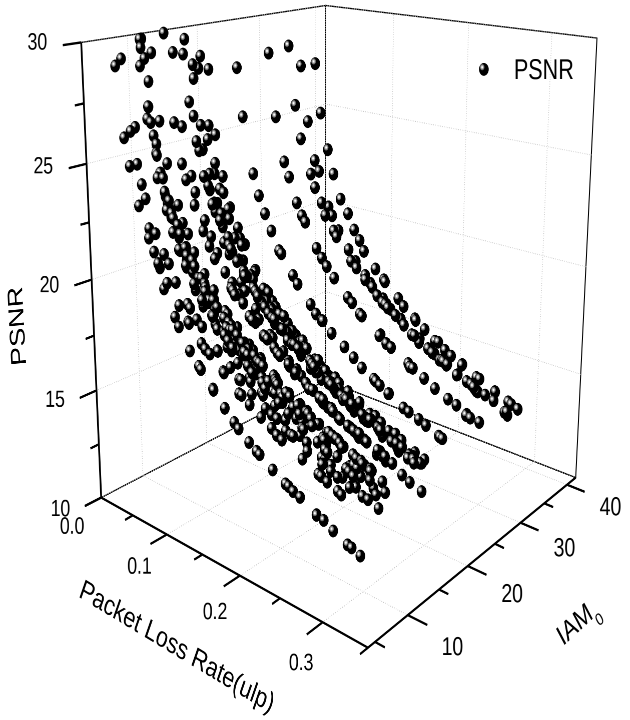


Figure 8. 3-D scatters mapping of PSNR, packet loss rate and IAM_0

By fitting the sample data points with an exponential function, we obtain a new function, shown as a curve in red solid line in Fig. 7. The function of PSNR in relation to ulp is written as

$$\begin{aligned} PSNR = & 1.407E6 * \exp(\text{-ulp}/6.7E\text{-}4) \\ & + 7.789 * \exp(\text{-ulp}/0.02187) \\ & + 12.11 * \exp(\text{-ulp}/0.1754) + 11.77 \end{aligned} \tag{9}$$

In Fig. 7, the exponential fitted curve accurately reflects the law all images share that how PSNR varies with ulp. However, evidently it is referable only to minor images, since there are numerous sample data points around the curve. Thus, a further research is carried out by taking image structural properties into account, aiming to find out a new equation to describe the variation of PSNR commonly.

C. Prediction of PSNR

In the further study, IAM_0, which is representative of the initial value of IAM, gets involved as an influential factor of the proposed system. As a consequence of the simulation, the relation between PSNR, packet loss rate, and IAM_0 is given by Fig. 8. The discrete sample data points stand for the PSNR values of various packet loss rates and different IAM_0 values.

In order to describe the relation between PSNR, packet loss rate and IAM_0 mathematically, we take use of an application software Origin8.0 to analyze and fit the data to a formula, which allows us to find out an optimal solution. Several surface fitting approaches are tested in experiment, among which there are three available fitted formulas shown as follows:

The formula of parabola2D fitting is given by the following formula.

$$\begin{aligned} PSNR = 27.18 - 95.18*ulp \\ -0.00336*IAM_0 + 182.4*ulp^2 \\ -6.224E-4*IAM_0{}^2 \end{aligned} \tag{10}$$

The poly2D fitting is an improved one of parabola2D fitting, and the formula is

$$\begin{aligned} PSNR = 27.25 - 95.67*ulp - 0.00756*IAM_0 \\ +182.4*ulp^2 - 6.224E-4*IAM_0{}^2 \\ +0.02708*ulp*IAM_0 \end{aligned} \tag{11}$$

The formula of polynomial2D fitting is

$$\begin{aligned} PSNR = 36.17 - 311.5*ulp + 3306*pow(ulp,2) \\ -1.918E4*pow(ulp,3) + 5.432E4*pow(ulp,4) \\ -5.908E4*pow(ulp,5) - 1.758*IAM_0 \\ +0.2262*pow(IAM_0,2) - 0.01308*pow(IAM_0,3) \\ +3.407E-4*pow(IAM_0,4) \\ -3.258E-6*pow(IAM_0,5) \end{aligned} \tag{12}$$

in which the function pow(A,B) is equivalent to the B-th power of A .

Four other selected sample pictures with different IAM_0 values have been tested on the simulation system, in which the channel packet loss rate ranges from 0 to 0.3. By doing so, we obtain a group of PSNR values to confirm the utility of the fitted formulas. Meanwhile, another group of PSNR values are worked out with formula (10), (11) and (12), which are called prediction formulas. Then we can calculate the absolute errors by comparing the two groups of PSNR data, to make it clearer, one group of experimental PSNR and one group of predicted PSNR.

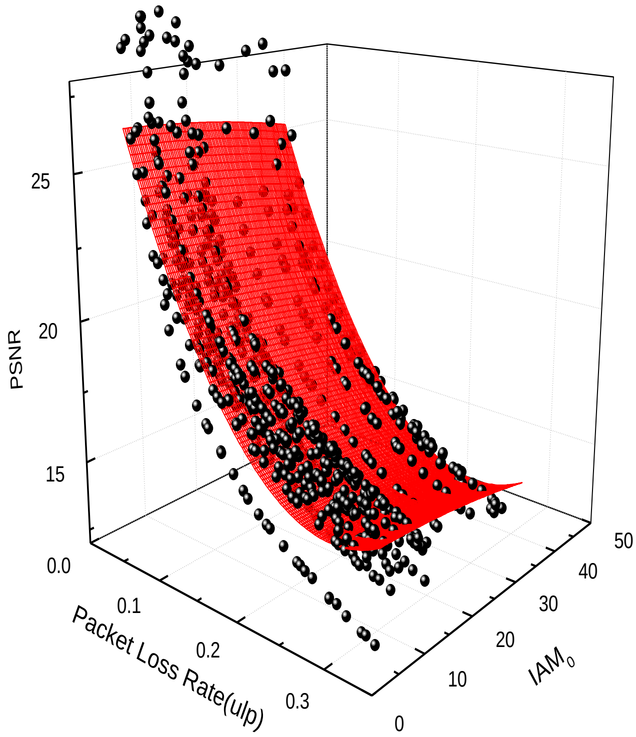
As is shown in TABLE II, polynomial2D fitting can predict the PSNR value of images with an IAM_0 between 10 and 40 efficiently. But for an image with an IAM_0 higher than 40, polynomial2D fitting seems useless because of a ridiculous error, and it also suffers high errors while predicting the PSNR values of images with an IAM_0 value as low as less than 5. In contrast, the predictive errors of parabola2D fitting and poly2D fitting are around 10%, which is tolerable practically. So parabola2D and poly2D are ideal choices for predicting the image PSNR values. We can see the fitting effects by contrasting Fig.8 and Fig. 9 (a) (b), where the fitted surfaces cover most of the sample points. However, in Fig. 9 (c), the fitted surface reaches the negative ulp panel, proving that Polynomial2D fitting is not suitable for use here.

Consequently, if we calculate the IAM_0 value from the original image in advance, we will be able to accurately predict the PSNR value of the images transmitted in a UAC channel with help of parabola2D or poly2D fitted formulas. To realize such a prediction, it is also necessary to know the values of packet loss rate in advance, which should have been set as fixed values subject to the properties of the UAC channel.

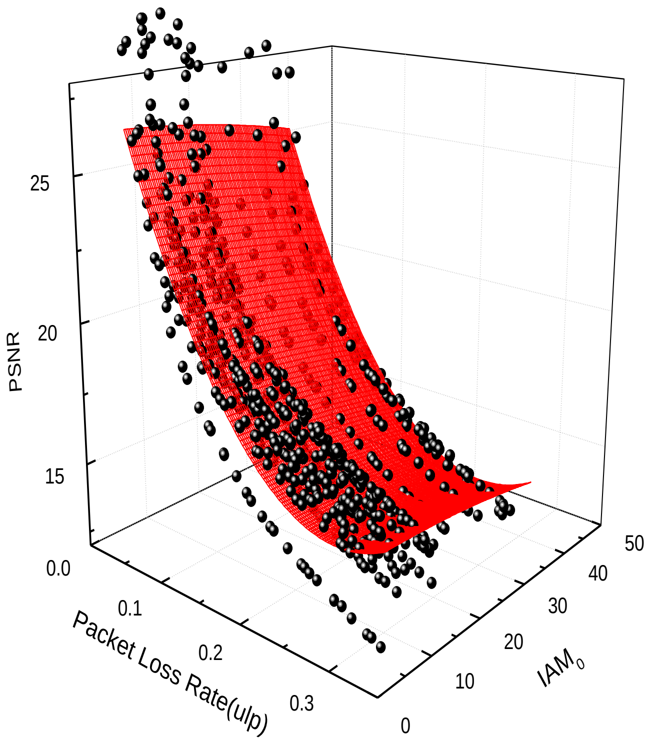
TABLE II.

COMPARISON BETWEEN THREE FITTING APPROACHES

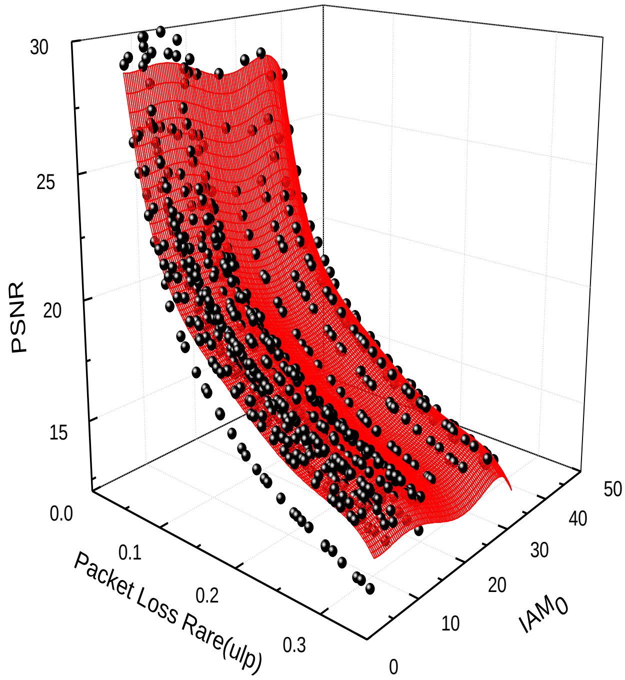
Sample Image	IAM_0	Mean Error		
		Parabola2D	Poly2D	Polynomial2D
test1	50.4459	7.59%	7.52%	262.86%
test2	31.9121	5.18%	5.23%	5.69%
test3	2.378	16.48%	16.43%	27.90%
test4	14.4817	11.46%	11.45%	11.90%



(a) Parabola2D fitting



(b) Poly2D fitting



(c) Polynomial2D fitting

Figure 9. Three kinds of Surface fitting for the experimental sample data in Fig. 8

In practice, when packet loss rate becomes greater than 0.3, the predictive errors of the above two fitting approaches will exceed 30%. This is because the data used for fitting were obtained from a simulation of UAC channel with a packet loss rate ranging from 0 to 0.3, which means that the prediction is referable only to channels with a less-than-0.3 packet loss rate. In a similar case, since the IAM_0 values of the sample images range from 7 to 40, this developed prediction is more accurate for images with an IAM_0 value in the same range. Hence we guess that it is possible to increase the predicting accuracy by fitting a formula using more sample images with different IAM_0 values and a greater range of packet loss rate.

V. Conclusion

In this paper, a simulation of UAC image transmitting system based on Gilbert-Elliot packet loss model is proposed. This simulation system is used to study the relation between image quality assessment parameters including Peak Signal to Noise Ratio (PSNR) and the origin image activity (IAM_0) and packet loss rate (also mentioned as ulp in this paper). Then we derive two formulas with two effective surface fitting approaches from the experimental data. By taking use of the fitted formulas, we can directly and accurately predict the image transmitting quality with the calculated PSNR values of the degraded images. To put it in another way, in UAC environment, if only we work out the IAM_0 value of the transmitted image, we can predict the degraded PSNR value at the receiver with the help of the known packet loss rate feature. The prediction of PSNR provides valuable references to the strategic establishment of underwater image transmission, such as channel coding and equalization.

A further research will be conducted primarily in two ways based on the achievements in this paper. For one thing, the amount of sample images for fitting the prediction formula needs to be enlarged in order to obtain a better prediction formula for a greater range of images, which has been discussed in Part C of Section IV. Especially the various images with different IAM_0 values should be included in the proposed simulation. For another, in this article the proposed Gilbert-Elliot model is used to describe packet loss events only, but in underwater image transmission, there must be bit error events influencing the transmitting quality, too, which is a far more complicated case with more specific concerns. So it is necessary to develop the packet-level model to a bit-level one for a more realistic simulation. Besides, some new image assessment parameters should be introduced to achieve an accurate, objective and efficient evaluation for a UAC image transmitting system.

ACKNOWLEDGEMENT

This work was supported by the Fundamental Research Funds for the Central Universities (2011121050, 2012121028) , the National Natural Science Foundation of China (61001142, 61071150) and the Science Technology Project of Xiamen Government (3502Z20123011).

REFERENCES

[1] ZHANG Jian-ming and YANG Da-cheng, Simulation Methodology for Speech Quality of VoIP in Mobile Communication Networks, Journal of System Simulation, VOL. 18, NO. 9, pp. 2559-2562, Sept. 2006.

[2] LAN Fan and ZHANG Yaobi, Network Packet Loss Simulation Based on Gilbert Model, Computer Engineering, VOL. 30, Supplementary Issue, pp. 200-203, Dec. 2004.

[3] H. Sanneck and G. Carle, "A framework model for packet loss metrics based on loss runlengths", Proc. SPIE/ACM SIGMM Multimedia Computing and Networking Conf., 2000.

[4] Henning S, "Packet Loss Recovery and Control for Voice Transmission over Internet", Ph.D Dissertation, Technical University of Berlin, Oct.2000.

[5] Gilbert E N. Capacity of A Burst-noise Channel, The Bell System Technical Journal,1960,39(9):1253

[6] Ou Xiao-li, "Underwater Acoustic Channel Modeling And Simulation Realization", Master Dissertation, Xiamen University, May. 2007.

[7] He Tian-ling, "Research on the Key Techniques of SC-FDE Underwater Acoustic Communication System", Master Dissertation, Xiamen University, Jun. 2012.

[8] Jean-Chrysostome Bolot, Charactering end-to-end packet delay and loss in the internet, Journal of High Speed Networks, 2 (3), pp. 289-298, Sept. 1993.

[9] Subhasis Saha and Rao Vemuri, An Analysis on the Effect of Image Features on Lossy Coding Performance, IEEE Signal Processing Letters, 7 (5), pp. 104-107, May. 2000.

[10] Yuan Fei and Liu Jin-zhe, Analysis About Content Activity of Wireless Video, Journal of Xiamen University (Nature Science), 2009.

[11] Jean-Pierre Ebert and Andreas Willig, "A Gilbert-Elliot Bit Error Model and the Efficient Use in Packet Level Simulation", TKN Technical Report TKN-99-002, Technical Univ. Berlin, Telecomm. Networks Group, Berlin, Germany, Mar. 1999.

[12] Wei Li, Xu Fang, and Sun Hai-xin, Research and simulation on underwater acoustic communication channel, Technical Acoustics, VOL. 27, NO. 1, pp. 25-29, Feb. 2008.

[13] Ye Chang-yuan, "Research on the Technology of Concealed Image Processing for Underwater Acoustic Communication"， Master Dissertation, Xiamen University, May. 2010.

[14] TONG Yu-bing, ZHANG Qi-shan, and QI Yun-ping, Image Quality Assessing by Combining PSNR with SSIM, Journal of Image and Graphics, Dec, 2006.

[15] Han Guo-qiang, Li Yong-zhen, Wang Xue-song, Xing Shi-qi, and Liu Qing-fu, Evaluation of Jamming Effect on SAR Based on Method of Modified Structural Similarity, Journal of Electronics & Information Technology, Mar. 2011.

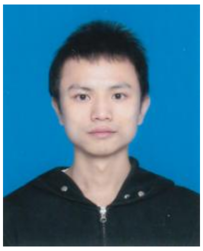
[16] He Miao, "Adaptive Image Digital Watermarking Algorithm Based on Best Scramble", B.E.Jilin: Jilin University, 2004

[17] Zhen Hua, Yewei Li, and Jinjiang Li, Image Optimization Algorithm Based on Salient Region and Layout Adjustment, Journal of Computers, VOL. 6, NO. 6, pp. 1222-1229, Jun. 2011.

[18] Chin-hsien Kung, Wei-sheng Yang, and Chin-ming Kung, A Study on Image Quality Assessment using Neural Networks and structures Similarity, Journal of Computers, VOL. 6, NO. 10, pp. 2221-2228, Oct. 2011.

[19] Yiyong Han, Junju Zhang, Benkang Chang, Yihui Yuan, and Hui Xu, Novel Fused Image Quality Measures Based on Structural Similarity, Journal of Computers, VOL. 7, NO. 3, pp. 636-644, Mar. 2012.

Yuan Fei received his Ph.D. degree from the Communication Engineering Department of Xiamen University, in 2008. He is an assistant professor of the Key Lab of Underwater Acoustic Communication and Marine Information Technology (Xiamen University), Ministry of Education, Xiamen, China. His research interests fall in the general area of underwater acoustic communication and networking, spanning from the communication networks, multi-Media signal processing and communication, video/image quality measurement and embedded system design.



Zhang Ji was born in Chongqing, China, in 1988. He received his B.E. degree from the Communication Engineering Department of Xiamen University in 2010. He is currently working on his M.E. degree identically in the Communication Engineering Department of Xiamen University, Xiamen, China. His academical interests lie in the specific area of underwater acoustic communication, including image quality measurement and channel modeling.

Cheng En received his Ph.D. degree from the Communication Engineering Department of Xiamen University, in 2006. He is a professor of the Communication Engineering Department of Xiamen University and the director of the Key Lab of Underwater Acoustic Communication and Marine Information Technology (Xiamen University), Ministry of Education, Xiamen, China. His research interests fall in the general area of underwater acoustic communication and networking, spanning from the communication networks, underwater acoustic communication, multi-Media signal processing and communication, video/image quality measurement and embedded system design.