QoE of Syntax, Freeze, and Texture Repair Techniques for Digital Multimedia Broadcasting

(Invited Paper)

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***Abstract*—Given the nature of broadcasting systems having limited feedback to the transmitter, impairments induced during transmission need to be coped with at the receiver. In this paper, we focus on digital multimedia broadcasting (DMB) which is deployed in South Korea. An extensive measurement campaign conduced in a live DMB system resulted in a set of videos containing a wide range of syntax, freeze, and texture impairments. Subjective tests were conducted with participants from the Asia region which rated the quality of DMB video clips with syntax, freeze, and texture impairments and the related repaired clips. The analysis of the obtained quality ratings has revealed the potential of quality of experience (QoE) improvement of each of the three impairment types. The results support the conjecture that syntax repair offers the largest QoE improvement followed by freeze repair and texture repair. This finding can assist system developers of digital broadcasting systems in deciding about the range of repair techniques to be engaged subject to, e.g., QoE, complexity, and latency constraints.**

***Index Terms*—QoE, Digital Multimedia Broadcasting, MPEG-2, Experimental Design, Subjective Tests, MOS.**

I. INTRODUCTION

Digital broadcasting systems use digital transmission (TV) which allows efficient utilization of bandwidth and offers high-quality video and audio. Digital broadcasting of digital TV may be delivered using satellites, cables, and terrestrial broadcasting infrastructure. Several related open standards have been developed over the years such as digital video broadcasting (DVB) [1], digital multimedia broadcasting (DMB) [2]–[4], and DMB+ [5]. Digital broadcasting systems transform data into packets of compressed data and have only a limited set of return channels, if at all. Common to these systems is the use of MPEG-2 [6] for compression of audio and video signals. Physical layer technologies for digital broadcasting systems have been comprehensively studied, e.g., [7]–[10].

On the other hand, assessing effective techniques for quality of experience (QoE) improvement of such digital broadcasting systems is less developed. Considering terrestrial digital broadcasting systems, degradation to QoE may be caused by syntax errors to the packet structure, freezing of videos, and impairments to the texture based on the spatial arrangement of color, intensity, sharpness, and distortions. The measurement guidelines of the European Telecommunications Standards Institute (ETSI) Technical Report ETR290 [11] suggest setups for hardware testing of digital TV systems but do not advice techniques for dealing with erroneous transport stream packets. Several studies have been conducted aiming to reveal the error sensitivity of MPEG-2 transport streams (TS) and MPEG-2 video codec resilience against errors [12]–[15]. The results of these works suggest to prioritize the repair of the header syntax of the MPEG-2 TS packet format. Similarly, numerous techniques have been advised for coping with video freezes and texture impairments, e.g., [16]–[19]. However, to the best of our knowledge, a more holistic assessment and comparison of syntax, freeze, and texture repair techniques on there potential to improve QoE are missing. Motivated by all of the above, we focus on the QoE assessment of syntax, freeze, and texture repair techniques for DMB systems. In view of the findings in [12]–[15], without loss of generality, we will focus on header syntax repair and refer to it as syntax repair for brevity.

In particular, the DMB videos used in this study were recorded by our industry partner during a large measurement campaign in a live DMB system in South Korea. These DMB videos comprise a wide range of syntax, freeze, and texture impairments as experienced in real-world deployments. This paper reports the results from three subjective tests in which DMB video clips with syntax, freeze, and texture impairments and their repaired counterparts were rated. Given the intended target market being South Korea, the majority of participants in these subjective tests were from the Asia region. The mean opinion scores (MOSs) deduced from the recorded quality ratings not only reveal the effectiveness of each video repair technique on QoE but also show to which extent each technique can improve QoE. Note that the developed DMB video repair techniques will only be briefly described here as need for the understanding of the subjective tests. The full details of these techniques can be found in our papers [20], [21] and patents [22], [23].

The rest of this paper is organized as follows. Section II describes the experimental design including reference and

(a) Commercial (b) Conversation

(c) Action scene (d) News

(e) Sports

Fig. 1. Sample video frames of the considered genres.

test material; syntax, freeze, and texture repair techniques; test method, equipment, and software; test panels and test scenarios. In Section III, the data analysis of the quality ratings obtained in the subjective tests is provided. In particular, the MOS values of the test videos before and after syntax, freeze, and texture repair are discussed which gives insight on their impact on QoE of DMB systems. Conclusions and future work are given in Section IV.

II. Experimental Design

A. Reference Material

A set of 13 reference DMB video clips was established. In particular, 6 videos were produced by clipping the DMB videos provided by our industry partner *Blinded, will be visible if accepted*. An additional 7 DMB video clips were obtained from the Internet allowing to expand the set of test material. These reference videos were selected to cover a range of genres: Commercials (2 videos), conversation (4 videos), action scene (3 videos), news (2 videos), sports (2 videos). Fig. 7 shows sample frames for each of the five genres.

B. Test Material

This section provides a brief description of the generation of the test material containing syntax errors, freezes, and texture impairments along with the principles behind the approaches used for repairing the various impairments. A full description of the algorithms used for syntax, freeze, and texture repair can be found in our papers [20], [21] and patents [22], [23].

1) Syntax Errors and Syntax Repair: Syntax errors were induced to the header of MPEG-2 TS packets complying with the recommended parameters outlined in ETR290 [11]. A set of 36 video clips of 10-15 s duration was produced by imposing such errors to the headers of the 13 reference video clips.

Syntax repair was based on the concept of header masks which capture the syntactical structure of a variety of video packet types. Resorting on concepts of error control coding, each header mask is considered as the center of a decoding sphere. In the considered context, the spheres around the header masks are mutually disjoint with their centers being at least of minimum distance apart. If a received header mask belongs to a sphere, it is decoded to the origin of this sphere, i.e., a valid header mask. Error detection without correction is performed if the received header mask does not belong to any sphere.

2) Freezes and Freeze Repair: The videos recorded during the measurement campaign in the live DMB broadcasting system in South Korea contained freezes as the most common temporal impairment. Further, weak received signals typically still carry some information but displaying this information after decoding would be accompanied by different types of impairments. In some cases, it is preferred to freeze the video streaming on the last best received frame rather than showing a video of poor or bad quality. The considered 8 test video clips were obtained by cutting the recorded DMB videos to 19-44 s to account for freezes at different time instants and different freeze durations.

The above problems were tackled by focusing on the last best received frame to create a virtual environment from this frame. By implementing a virtual camera movement, it is possible to render new frames that replace the original video stream during the period of freezing. An effective way of estimating a 3D geometry in a frozen frame is to look at the problem in terms of a statistical learning process rather than trying to explicitly compute all of the required geometrical parameters from the frozen frame. Given either indoor or outdoor scenes, common geometrical information associated with such frames can be found to furnish the information about the frozen frame in an implicit way through recognition. In contrast to most recognition approaches, which model semantic classes, the 3D estimation problem can be rephrased as to model geometric classes that depend on the orientation of a physical object with relation to the scene.

3) Texture Impairments and Texture Repair: A set of 23 test video clips of 10 s duration was produced from the videos that were recorded during the field test in the DMB system in South Korea.

Texture analysis and repair commences with contrast and sharpness analysis followed by their enhancement. On this basis, texture repair aims at concealing blocks and block displacements for the duration of a scene. The contrast enhancement partially follows the bio-inspired method reported in [24], which is applied on the color filter array image. This approach is inspired by the retinal processing where an image is acquired by a mosaic of cones. Adaptive non-linear functions are applied before interpolation to achieve a high dynamic range mapping. Our contrast enhancement algorithm primarily separates the original image into chromatic and luminance components implementing a mosaic process. A sharpness filter resorting on a negative Laplacian in conjunction with a complex diffusion process [25] is used in the processing of the test video clips. The diffusion process tunes and increases the accuracy of sharpness. The texture of each frame is then enhanced either by contrast enhancement, sharpness enhancement, or both depending on the quality of the frame which is estimated automatically.

The texture concealment process that facilitates texture repair uses information of a series of three frames, i.e. the actual, previous, and second previous frame. Several processing steps are performed on the basis of the texture information of these frames such as scene cut and impairment analysis; detection and position of impaired blocks; processing in the impaired patches bank, impaired blocks bank, and non-impaired patches bank; before feeding the outcome to an adaptive Gaussian mixture model [26]. Three templates in the form of binary images are generated, namely, impaired blocks bank, impaired patches bank, and non-impaired patches bank. Using these three templates the impaired block information is replaced by the most recent and relevant non-impaired information.

C. Test Method, Equipment, and Software

The absolute category rating (ACR) method was chosen to assess the quality of the presented DMB video clips on a five-level quality scale: (5) Excellent, (4) Good, (3) Fair, (2) Poor, (1) Bad. A total of 32 test sessions were conducted with up to 4 test subjects participating in a session. Each subjective test session comprised of a pair of two different test sections. One section showed DMB video clips with syntax, freeze, and texture impairments and the other section showed the repaired DMB video clips.

The subjective tests were performed using 4 personal computers of type HP desktop 6005 Pro MT AMD. The DMB video clips were presented on an LG Flatron W1934S LCD monitor of size 19” with a native resolution of 1400×900 pixels. The JAVA-based in-house software MOStool [27] developed in the framework of a Masters thesis project was used to present the test material and to record the ratings. The background luminance in the respective subjective test sessions has been controlled below 20 lux as recommended in ITU-T P.910 [28]. The Hagner Luxmeter EC1 was used for accurate measurement of luminance. It is noted that the spectral sensitivity of the Hagner Luxmeter closely matches the visibility curve of a standard observer as defined by the International Commission on Illumination (Commission Internationale de l’Eclairage).

TABLE I
DEMOGRAPHIC INFORMATION

Subjective Test I: Syntax Error	
Size	23 non-expert participants
Age	23 to 50 years with an average of 30.7 years
Gender	4 females and 19 males
Occupation	Bachelor, Masters, Ph.D. students, Postdoctoral fellow
Nationality	10 China, 5 Vietnam, 2 Pakistan, 1 Sri Lanka, 4 Rwanda, 1 Italy
Subjective Test II: Freezes	
Size	18 non-expert participants
Age	23 to 50 years with an average of 26.7 years
Gender	4 females and 14 males
Occupation	Bachelor, Masters, Ph.D. students, Postdoctoral fellow, Teacher
Nationality	5 China, 5 Vietnam, 2 Pakistan, 1 Sri Lanka, 4 Rwanda, 1 Italy
Subjective Test III: Texture Impairments	
Size	20 non-expert participants
Age	23 to 50 years with an average of 30.6 years
Gender	4 females and 16 males
Occupation	Bachelor, Masters, Ph.D. students, Postdoctoral fellow
Nationality	7 China, 5 Vietnam, 2 Pakistan, 1 Sri Lanka, 4 Rwanda, 1 Italy

D. Test Panel and Subjective Test Scenarios

The participants were chosen to preferably comprise of Chinese and Vietnamese participants to align with the target market of this work being the Asia region. However, as a large number of subjective tests were conducted, the range of participants’ nationality was expanded to avoid repetition and fatigue. Table I summarizes the demographic information of the test panels that participated in the following three subjective tests on DMB video clips with different impairments.

- **Subjective Test I (36 video clips):** Rating the quality of video clips with syntax errors and their syntax repaired counterparts.
- **Subjective Test II (8 video clips):** Rating the quality of video clips with severe freezing and the related video clips after computer vision based concealment of freezes.
- **Subjective Test III (23 video clips):** Rating the quality of video clips with texture impairments and the related video clips that have undergone texture repair.

III. DATA ANALYSIS

A. Subjective Test I: Syntax Errors

Fig. 2 shows the MOS of the video clips containing syntax errors in decreasing order and the MOS of the syntax repaired video clips (see also Table II for numerical values). It is observed that syntax repair results in improved quality of a significant number of video clips, i.e., lifted from poor and bad quality to fair and good quality. In fact, only 1 (2.7%) of the video clips with syntax errors received fair quality ratings while 23 (63.9%) of the syntax repaired video clips received fair or better quality ratings. Overall, the quality of 26 (72%) impaired video clips was improved by engaging syntax repair. In light of the MOS of the reference video clips without errors

TABLE II
MOS OF SYNTAX ERROR IMPAIRED (I) AND REPAIRED (R) VIDEO CLIPS

Clip	I	R	Clip	I	R	Clip	I	R
1	3.38	**4.14**	13	2.10	1.95	25	1.36	**3.13**
2	3.00	**4.18**	14	2.04	**4.31**	26	1.35	**4.00**
3	2.76	2.54	15	1.90	**4.22**	27	1.33	1.09
4	2.57	**2.59**	16	1.90	1.40	28	1.33	**3.09**
5	2.55	**3.09**	17	1.68	1.40	29	1.31	1.09
6	2.54	**3.72**	18	1.66	**3.77**	30	1.27	**4.18**
7	2.54	**3.77**	19	1.57	**4.04**	31	1.27	**2.95**
8	2.54	**3.18**	20	1.54	1.50	32	1.22	**4.27**
9	2.36	**4.18**	21	1.47	**3.63**	33	1.19	1.04
10	2.25	**2.31**	22	1.47	**3.18**	34	1.14	**4.18**
11	2.14	**4.22**	23	1.42	1.18	35	1.13	**4.13**
12	2.14	2.09	24	1.40	**3.54**	36	1.09	**3.72**

TABLE III
MOS OF FREEZING IMPAIRED (I) AND REPAIRED (R) VIDEO CLIPS

Clip	I	R
1	3.56	**3.83**
2	3.33	**3.44**
3	3.28	**3.35**
4	3.17	**4.06**
5	3.17	**3.72**
6	3.11	**3.28**
7	3.06	**3.28**
8	2.94	**3.41**

being between MOS $= 2.82$ to 4.56, the quality improvements are indeed remarkable and come close to the reference video clips. Figs. 3(a)-(b) illustrate the large quality improvement that can be obtained by engaging syntax repair.

B. Subjective Test II: Freezes

A set of 8 video clips containing freezes were rated in this subjective test. Fig. 4 compares the MOS values of the video clips containing freezes in decreasing order with their counterparts after freezes were repaired (see also Table III for numerical values). The subjective quality of all video clips improved after computer vision based freeze concealment with MOS > 3, some even close to MOS $= 4$, and the best reached MOS $= 4.06$. Additional studies may be conducted to retrieve more evidence whether there is different perception among different frame synthesis approaches regarding the percentage of viewing area accounted for. Overall, the results indicate that continuing with the dynamics contained in a sequence of frames was preferred by the participants compared to leaving a clip frozen.

C. Subjective Test III: Texture Impairments

Apart from getting a feeling on when to engage texture concealment algorithms, this subjective test is also used to get an initial feedback on the usefulness of color and sharpness enhancements. However, the color and sharpness enhancements would likely need to be fine-tuned on the perception preferences of the target market.

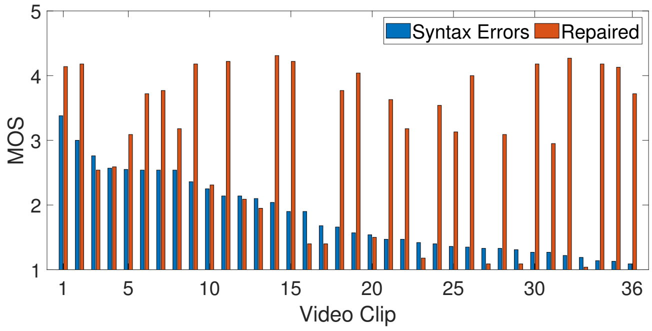
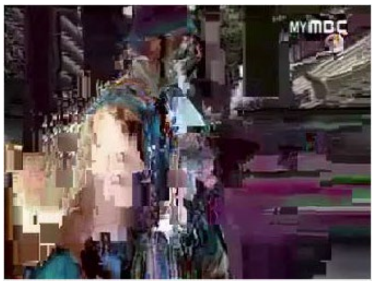


Fig. 2. MOS of video clips with syntax error and after syntax repair.



(a)

(b)

Fig. 3. Syntax Repair: (a) Impaired frame, (b) Repaired frame.

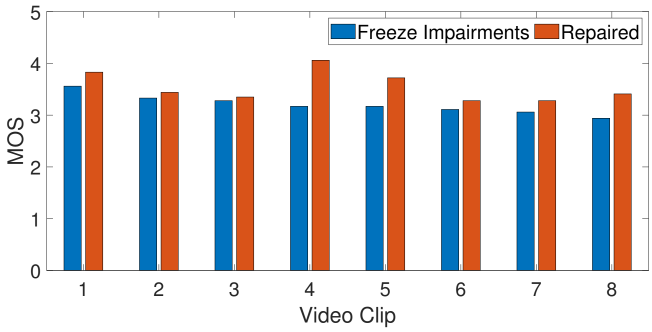


Fig. 4. MOS of video clips containing freezes and after repair.

Fig. 5 compares the MOS values of the texture impaired video clips in decreasing order with the texture repaired video clips (see also Table IV for numerical values). The subjective quality of the impaired video clips spans over a wide range from MOS $= 4.85$ (excellent) to MOS $= 1.00$ (bad). The numerical results provided in Table IV suggest that texture repair is not beneficial for video clips that have excellent and good quality, has little impact on video clips of fair quality, and tends to improve quality for bad and poor video clips. This behavior may be explained by the play-out speed of the video clips in frames per second (fps) as follows. Although a large amount of textural impairments can be enhanced, the related improvement of an individual video frame may not be visible in the play-out of a video clip with high fps but enhancement of only severe textural impairments over a longer period of time may be noticed.

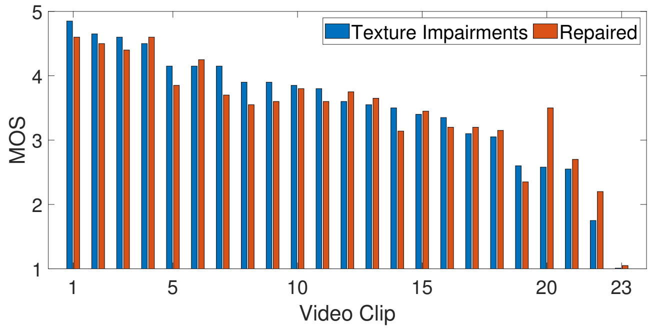


Fig. 5. MOS of video clips with texture impairments and after texture repair.

TABLE IV
MOS OF TEXTURE IMPAIRED (I) AND ENHANCED (R) VIDEO CLIPS

Clip	I	R	Clip	I	R	Clip	I	R
1	4.85	4.60	9	3.90	3.60	17	3.10	**3.20**
2	4.65	4.50	10	3.85	3.80	18	3.05	**3.15**
3	4.60	4.40	11	3.80	3.60	19	2.60	2.35
4	4.50	**4.60**	12	3.60	**3.75**	20	2.58	**3.50**
5	4.15	3.85	13	3.55	**3.65**	21	2.55	**2.70**
6	4.15	**4.25**	14	3.50	3.14	22	1.75	**2.20**
7	4.15	3.70	15	3.40	**3.45**	23	1.00	**1.05**
8	3.90	3.55	16	3.35	3.20			

To illustrate some findings in more detail, we have selected video clips with representative impairments:

- **Severe Texture Impairments.** Figs. 6(a)-(b) show a frame of a video clip with severe texture impairments and the related texture repaired frame. The improvement of subjective quality from MOS $= 2.60$ obtained for the impaired video clip to MOS $= 3.15$ of the repaired video clip is substantial. In the presence of such severe texture impairments, texture repair can indeed be used to improve subjective quality.
- **Severe Color Impairments.** Figs. 7(a)-(b) show sample frames of a severe color impaired and enhanced video clip for visual inspection. Apparently, the letters are hardly readable in the impaired frame but are clearly visible in the enhanced frame. However, the clip with severe color impairments received a rating of MOS $= 3.55$ while the color enhanced clip received only a slightly higher rating of MOS $= 3.65$. This result is thought to be due to the subjective tests having followed a single stimulus method to match with DMB being a broadcasting service. As such, the participants rated a series of impaired video clips in the first section of a session and a series of concealed and enhanced video clips in the subsequent second section. In the first section, the participants may have not even seen the missing of the text. On the other hand, the result of the second section shows that bringing back the letters by color enhancement may not contribute too much to the quality improvement. The amount of color enhancement may be too large and would need to be fine-tuned subject to the target market.

(a)

(b)

Fig. 6. Texture repair: (a) Impaired frame, (b) Repaired frame.

(a)

(b)

Fig. 7. Color enhancement: (a) Impaired frame, (b) Enhanced frame.

IV. CONCLUSIONS AND FUTURE WORK

In this paper, we have assessed the potential of syntax, freeze, and texture repair techniques regarding QoE improvement in DMB systems. The analysis of the ratings gathered in the subjective tests on DMB videos with these impairments and their repaired versions have been reported in terms of MOS. Due to the target market being South Korea, the participants of the subjective tests were in their majority from the Asia region. The results show that syntax repair offers the largest QoE improvement followed by freeze repair and texture repair. While only 1 (2.7%) of the video clips with syntax errors received a MOS of fair quality, 23 (63.9%) of the syntax repaired video clips received fair or better MOS. As such, the QoE of 72% of the impaired video clips has been improved by syntax repair. Regarding video clips with freezes, QoE of all considered video clips has been improved through freeze repair but not as much as compared to syntax repair. The results also support the conjecture that texture repair including color enhancement is useful only in case of severely texture impaired videos. The above ranking of repair techniques regarding QoE improvement may help designing digital broadcasting systems subject to constraints such as QoE, complexity, and latency.

Future research may included broadening the test panel with participants beyond the Asia region and improving on gender, age, and occupation composition. The direction toward assessing regional differences on QoE is motivated by the results obtained for color enhancement and the need of fine-tuning the respective techniques in view of the target market. Additional subjective tests may be conducted to obtain further insight into the interplay between color and sharpness within texture repair techniques for QoE improvements.

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