

The Impact of Temporal Impairment on Quality of Experience (QoE) in Video Streaming: A No Reference (NR) Subjective and Objective Study

Muhammad Arslan Usman, Muhammad Rehan Usman, Soo Young Shin

Abstract—Live video streaming is one of the most widely used service among end users, yet it is a big challenge for the network operators in terms of quality. The only way to provide excellent Quality of Experience (QoE) to the end users is continuous monitoring of live video streaming. For this purpose, there are several objective algorithms available that monitor the quality of the video in a live stream. Subjective tests play a very important role in fine tuning the results of objective algorithms. As human perception is considered to be the most reliable source for assessing the quality of a video stream subjective tests are conducted in order to develop more reliable objective algorithms. Temporal impairments in a live video stream can have a negative impact on the end users. In this paper we have conducted subjective evaluation tests on a set of video sequences containing temporal impairment known as frame freezing. Frame Freezing is considered as a transmission error as well as a hardware error which can result in loss of video frames on the reception side of a transmission system. In our subjective tests, we have performed tests on videos that contain a single freezing event and also for videos that contain multiple freezing events. We have recorded our subjective test results for all the videos in order to give a comparison on the available No Reference (NR) objective algorithms. Finally, we have shown the performance of no reference algorithms used for objective evaluation of videos and suggested the algorithm that works better. The outcome of this study shows the importance of QoE and its effect on human perception. The results for the subjective evaluation can serve the purpose for validating objective algorithms.

Keywords—Objective evaluation, subjective evaluation, quality of experience (QoE), video quality assessment (VQA).

I. INTRODUCTION

THE recent development in digital video transmission has resulted in explosive growth in end users as well as in multimedia devices such as smart phones and tablets. Live video streaming through broadcast and multicast services is no more an alien technology in developed countries. In a recent study, researchers found out that 66% of the global mobile traffic will be occupied by Videos transmitted to and from smart mobile devices [1]. Services such as IPTV, web TV e.g. Netflix, live television broadcasts and multicasts have gained interest from most of the mobile users. In live video transmission there is always a chance of some error to be introduced in the videos. The reason can be the hardware or

some error prone channel. Packet loss due to an error prone channel is one of the cases in which the transmitted video sequence is not received properly on the reception side. This kind of phenomenon can lead to impairments such as ringing, blocking or freezing of videos [2]. Keeping in view the growing fashion [3] for end consumers to use content on mobile devices, which are often installed in error-prone wireless network environments, it is important to consider the potential impact of temporal impairments on perceived video quality in order to ensure high QoE.

On the reception side, frame freezing is a phenomenon in which a frame is copied over the successive frames until the next correct frame is received [4]. This repetition of frames is employed intentionally sometimes as an error concealment process. At the transmission side, there is a buffer which is responsible for maintaining the bitrates of the videos and if the buffer fails to do so then there is a chance that an error can occur and resultantly the frame freezing takes place. Frame freezing is a type of temporal impairment. The temporal information is calculated as the difference between the pixel values at the same location in space but at successive frames of a video [5], [6].

To ensure high QoE, network operators are forced to employ some mechanism which can monitor the quality of the video which is transmitted through their network. There are several objective algorithms that monitor the quality of the video automatically. But in order to fine tune these algorithms always there is a need for subjective quality assessment tests. Subjective quality assessment test are means of collecting perceptual information of video streaming from end users/consumers. A panel of viewers is subjected to view a video database and give every video a quality rating. This quality rating is then used to fine tune the results of objective video quality algorithms. The objective quality algorithms work on three methods namely full reference (FR), reduced reference (RR) and no reference (NR) methods. The examples of all these three methods can be found in [7]-[10].

In this paper our study is about no reference video quality assessment. In NR method, the objective algorithm assesses the quality of the received videos without any reference of the original video. Our work emphasizes firstly on providing a subjective quality evaluation of a video database that we collected from the Video Quality Evaluation Group (VQEG). The description of all the test video sequences is given in Table II. Single freeze experiment was conducted in which every video was introduced with frozen frames on a particular

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instant. Also, a multiple freeze experiment was conducted in which multiple freezes, namely freezes events were introduced on different instants in every video sequence. Then objective algorithms, [8]-[10] were studied and they were implemented on MATLAB. Then the objective algorithms are used to assess the quality of all the test video sequences and their results are recorded. Finally, a comparison of the results from the objective algorithms and the subjective evaluation is presented and the objective algorithm that performs best under certain conditions has been proposed. The videos taken for this study are from two different frame rates i.e. 30 frames per second (fps) and 25 fps. These two frame rates are generally employed by network operators in order to stream live videos.

The breakdown of this paper is as follows: Section II contains the survey of related works followed by the subjective evaluation in Section III. Then in Section IV the objective evaluation has been performed. Results and conclusion are discussed in Sections V and VI respectively.

II. RELATED WORK

In [11], the authors have performed subjective evaluation for videos that are encoded with H. 264 video encoder. They are using low resolution videos with CIF and QCIF formats. Also, the authors have performed the subjective tests on different frame rates and bitrates. [12] presents the subjective video quality evaluation of the latest video encoder employed by ITU known as H. 265/ HEVC video encoder. They have also performed a performance analysis of some objective algorithms but there is no references objective algorithms are not kept in focus. In [13], the author aims to present how perceived quality of a video varies as the frame rate changes. The impact of motion intensity in videos on the perceptual quality of videos has also been discussed. Similarly, in [14] studies have been conducted in order to estimate the impact of single and multiple freezes on video quality. Also, in [15], the authors perform a subjective evaluation on a database of image sequences.

We have performed subjective evaluation for different set of parameters and have taken the video database from the Video Quality Experts Group (VQEG). The subjective evaluation is discussed thoroughly in the next section.

III. SUBJECTIVE EVALUATION

As stated earlier, in order to fine tune the results of Objective video quality algorithms, subjective tests have to be performed. Subjective tests are considered so far the best way to predict the quality of a video in a perfect and correct manner. These tests help in recording the QoE of end users so that the objective algorithms can be improved in order to fulfill the latest requirements for video quality estimation. In our subjective tests 22 test subjects took part that was from 3 different categories as shown in Fig. 1. The subjective tests were designed in accordance with the recommendation of ITU-R BT 500-12 [5] [6]. The ages of the test subjects ranged between 18 and 40. Out of these 22 test subjects, 10 were from the experts group who had prior knowledge of video quality

assessment. 6 of them were from the non-expert category and the remaining 6 were from the youth category i.e. below the age of 20. The breakdown of test subjects/ participants is given in Fig. 1.

TABLE I
ABSOLUTE CATEGORY RATING (ACR)

| Category Rating (Quality) | Mean Opinion Score (MOS) |
|---------------------------|--------------------------|
| Excellent | 5 |
| Good | 4 |
| Fair | 3 |
| Poor | 2 |
| Bad | 1 |

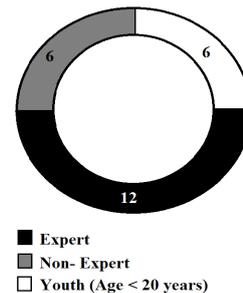


Fig. 1 Distribution of Test Subjects by Categories

All the participants of the subjective tests were contacted formally beforehand and they took part in the test willingly as a sincere contribution to this research topic. The tests were conducted within one week and the break down for conducting the tests was simple. In [14], two different types of experiments have been conducted and we have followed the same pattern as explained in the next sections.



Fig. 2 A snapshot of the test video sequences with 25 frames per second (fps)

A. Test Environment

A very comfortable environment was arranged for the test subjects in a cubical room which was allocated for these tests for a period of one week. The room did not contain any extra material/ furniture other than the required items, so that the attention of the test subject/ participant could be fully utilized for the tests. A flat 19 inches LCD/ TFT screen with non-glare surface treatment was used for displaying the test video sequences. The resolution for the monitor was 1600x900 with 5 ms response time and its colour was set in RGB mode. A

desktop *Asus* system having 3.2 GHz Intel processor and 6 GB RAM was used for these tests. Participants were seated at a distance of three to four times the height of the display size of a video sequence as recommended [5] [6]. A software tool was used to automate the process of presenting the videos in the centre of the screen.

TABLE II
CONTENT DESCRIPTION OF USED VIDEOS

| Frame Rate of Video (fps) | Name of Video Sequence | Content | Video Resolution |
|---------------------------|------------------------|---|--------------------------|
| 25 Frames per second | City | A Camera panning over a City from Above | Native: VGA 640 × 480 |
| | Crew | A space shuttle crew walking through the aisle | Native: VGA 640 × 480 |
| | Harbour | View of Boats moving in a Harbour | Native: VGA 640 × 480 |
| | Ice | People skating in an Ice skating arena | Native: VGA 640 × 480 |
| 30 Frames per second | Mother & Child | A talking mother and a child sitting in her lap | Native: VGA 640 × 480 |
| | Children | Two children talking and playing with toys | Native: VGA 640 × 480 |

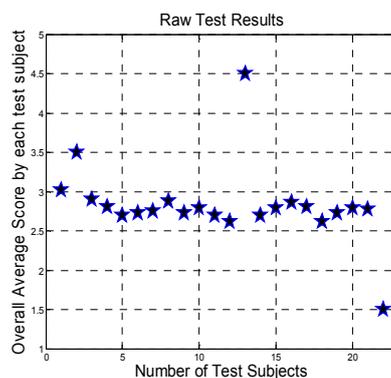
All the test video sequences were played in a random order for each participant with insertion of the standard gaps (10 sec.) in between for grading according to the absolute category rating (ACR) scale shown in Table I. The ACR scale is one of the scales used to record QoE of subjective tests recommended by ITU [5], [6]. The participants were not given any chance to repeat a video at any particular instant as the software used for the tests had no configuration access for the users/participants, only the admin could configure the software with a protected password.

All the test results were automatically stored in a excel work sheet with the name, age and category of the test subject. The expert category of the participants was mostly from Masters' level studies and a few were from PhD level studies. All the videos used in the tests were slightly altered to fit in our requirements. All the videos were kept in their native resolution i.e. VGA 640 × 480 and also the bitrates were kept unaltered. All the videos were uncompressed and the freezes/freeze events, as explained later, were introduced in the videos using MATLAB. The audio of the videos was removed, using the software *virtual dub*, to avoid any distraction for the participants. Fig. 2 contains the snapshots of original videos with a frame rate of 25 fps. A short description about the content of all the videos is given in Table II. In order to obtain reliable results, the test results were verified later on by performing a 2 stage check process. Firstly, the test subjects whose Mean Opinion Score (MOS) was found deviant from the average MOS of all the test subjects, were excluded from the final results. Secondly, the test subjects whose score had no systematic change i.e. they scored all the videos in almost the same manner, they were also excluded. From Fig. 3 (a), the raw data has been plotted for all the 22 test subjects. After excluding the aforementioned test subjects, the results were more refined and they are explained in Fig. 3 (b).

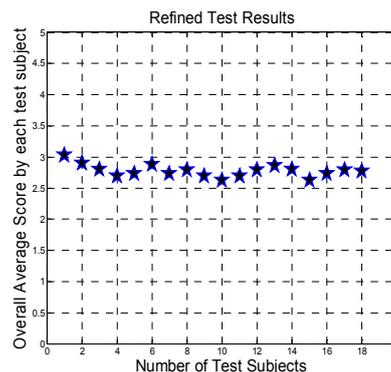
In the next sections, the experiments, single freeze and multiple freezes have been discussed briefly.

B. Single Freeze

In the single Freeze Experiment, frozen frames were introduced in each video sequence i.e. a particular frame was copied and repeated on its successive frames in order to show a freeze event in the video sequence. Table III shows the total number of videos, their respective durations and the durations of freeze event for the single freeze experiment.



(a) Raw Results



(b) Refined Results

Fig. 3 Overall average score by each test subject

The Single freeze experiment was conducted in two days of time as on the first day, only the expert's category took part and on the proceeding day, remaining of the participants, who included non-expert and youth category, took part in the test. The expert category group consisting of 12 participants took the single freeze test on first day and the remaining, non-expert and youth category, took the test on the second day. The total duration of the test was kept between 20 to 30 minutes in order to make the tests not so hectic for the participants.

C. Multiple Freeze

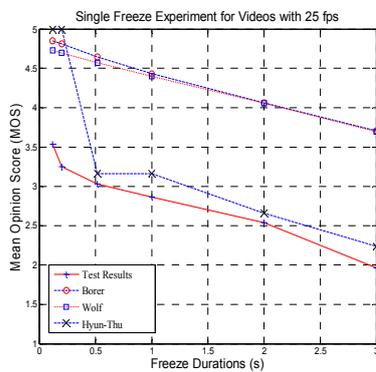
In the Multiple freeze experiment, every video sequence contained more than one freeze event. Table IV shows the total number of videos, their respective durations, the number of freeze events and the durations of freeze events for the

multiple freeze experiment. The Multiple freeze experiment took 4 days as the number of videos in this test were much more than the single freeze experiment and the duration recommended by ITU [5], [6] had to be kept in mind. So, we divided the test in 2 parts. Each part was of 30 minutes with the same configuration as the preceding test.

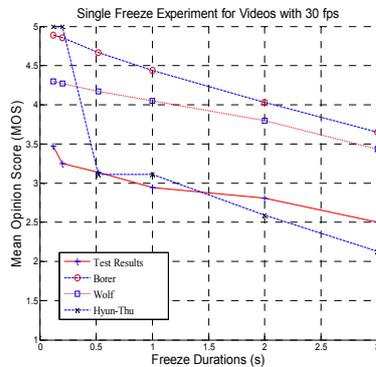
of every video sequence and then it was recorded in order to make a comparison with the subjective test scores. Implementation of these algorithms was done on MATLAB and then the objective evaluation of all the test video sequences was performed.

TABLE III
DESCRIPTION OF USED VIDEOS FOR SINGLE FREEZE EXPERIMENT

| Temporal Resolutions (fps) | Video Sequences | Total Duration (s) | Freeze Durations (s) |
|----------------------------|-----------------|--------------------|--------------------------|
| 25 Frames per second | City | 12 | 0.12, 0.2, 0.52, 1, 2, 3 |
| | Crew | 12 | 0.12, 0.2, 0.52, 1, 2, 3 |
| | Harbour | 12 | 0.12, 0.2, 0.52, 1, 2, 3 |
| | Ice | 10 | 0.12, 0.2, 0.52, 1, 2, 3 |
| 30 Frames per second | Mother & Child | 12 | 0.12, 0.2, 0.52, 1, 2, 3 |
| | Children | 12 | 0.12, 0.2, 0.52, 1, 2, 3 |



Single Freeze Experiment for Videos with a frame rate of 25 fps

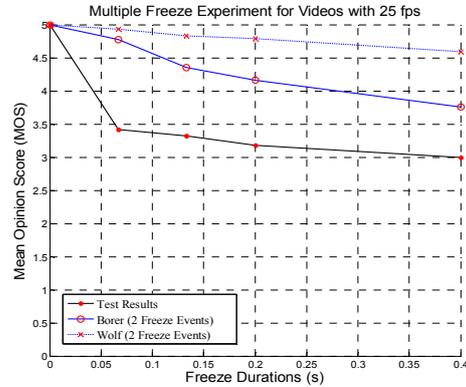


Single Freeze Experiment for Videos with a frame rate of 30 fps

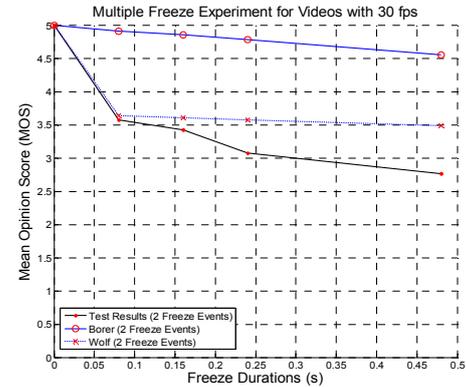
Fig. 4 Subjective and Objective Evaluation Results of Single Freeze Experiment for Videos with a different frame rates

IV. OBJECTIVE EVALUATION

After successfully conducting the subjective tests and recording the results, we made a survey on available state of the art objective NR algorithms. After the survey, we were able to select three algorithms after a careful study. These three algorithms, [8]-[10], also contain their own subjective quality assessment tests but their test parameters are different than what we have presented in our paper in the previous section. All these 3 algorithms were used to assess the quality



Multiple Freeze Experiment for Videos with a frame rate of 25 fps and 2 Freeze Events



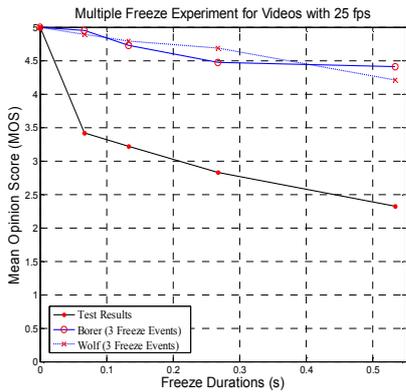
Multiple Freeze Experiment for Videos with frame rate of 30 fps and 2 Freeze Events

Fig. 5 Subjective and Objective Evaluation Results of Multiple Freeze Experiment for Videos with multiple frame rates and 3 Freeze Events

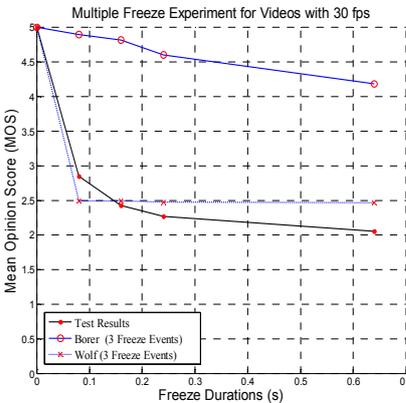
The score was recorded in the same ACR scale as used in the subjective evaluation. Following is a brief description of these algorithms, for their mathematical part it is recommended that these methods can be studied from their respective references. The methods explained in these papers are not limited to No Reference objective video quality assessment. In [8], the method of reduced reference, in which a limited reference of the video is present at the reception side, has also been discussed. But as in this research, our goal is to study the NR method only, so we do not consider the methods other than the NR method.

TABLE IV
DESCRIPTION OF USED VIDEOS FOR MULTIPLE FREEZE EXPERIMENT

| Temporal Resolutions | Video Sequences | Total Duration (s) | Number of Freeze Events & respective durations in seconds (Duration of Event (s) × No. of Events) | | | | |
|----------------------|-----------------|--------------------|--|------------------------------|----------------------------------|--------------------------------|------------------------------|
| | | | 1 | 2 | 3 | 5 | 8 |
| 25 Frames per second | City | 12 | (0.08, 0.16, 0.48, 0.96, 1.92, 3.84) × 1 | (0.08, 0.16, 0.24, 0.48) × 2 | (0.08, 0.16, 0.24, 0.64) × 3 | (0.08, 0.16, 0.4, 0.8) × 5 | (0.08, 0.16, 0.24, 0.48) × 8 |
| | Crew | 12 | (0.08, 0.16, 0.48, 0.96, 1.92, 3.84) × 1 | (0.08, 0.16, 0.24, 0.48) × 2 | (0.08, 0.16, 0.24, 0.64) × 3 | (0.08, 0.16, 0.4, 0.8) × 5 | (0.08, 0.16, 0.24, 0.48) × 8 |
| | Harbour | 12 | (0.08, 0.16, 0.48, 0.96, 1.92, 3.84) × 1 | (0.08, 0.16, 0.24, 0.48) × 2 | (0.08, 0.16, 0.24, 0.64) × 3 | (0.08, 0.16, 0.4, 0.8) × 5 | (0.08, 0.16, 0.24, 0.48) × 8 |
| | Ice | 10 | (0.08, 0.16, 0.48, 0.96, 1.92, 3.84) × 1 | (0.08, 0.16, 0.24, 0.48) × 2 | (0.08, 0.16, 0.24, 0.64) × 3 | (0.08, 0.16, 0.4, 0.8) × 5 | (0.08, 0.16, 0.24, 0.48) × 8 |
| 30 Frames per second | Mother & Child | 12 | (0.067, 0.133, 0.4, 0.8, 1.6, 3.2) × 1 | (0.067, 0.133, 0.2, 0.4) × 2 | (0.067, 0.133, 0.267, 0.533) × 3 | (0.067, 0.133, 0.33, 0.66) × 5 | (0.067, 0.133, 0.2, 0.4) × 8 |
| | Children | 12 | (0.067, 0.133, 0.4, 0.8, 1.6, 3.2) × 1 | (0.067, 0.133, 0.2, 0.4) × 2 | (0.067, 0.133, 0.267, 0.533) × 3 | (0.067, 0.133, 0.33, 0.66) × 5 | (0.067, 0.133, 0.2, 0.4) × 8 |



Multiple Freeze Experiment for Videos with a frame rate of 25 fps and 3 Freeze Events

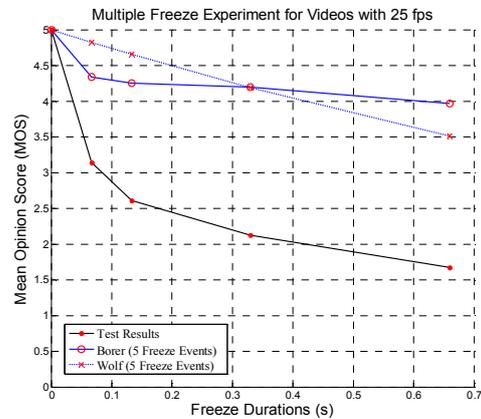


Multiple Freeze Experiment for Videos with a frame rate of 30 fps and 3 Freeze Events

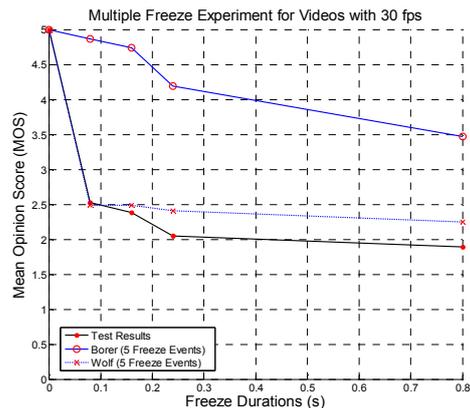
Fig. 6 Subjective and Objective Evaluation Results of Multiple Freeze Experiment for Videos with multiple frame rates and 3 Freeze Events

Wolf [8]: To estimate the potential frame freeze in a video sequence, this method follows two major steps. Firstly, image pixels are processed to compute a frame-by-frame motion energy time history of the video under investigation. The underlying value used is a simple measure of temporal information for the whole video computed through difference of pixel intensity values for consecutive frames. Secondly, the

motion energy time history is analyzed to detect the amount of dropped/repeated frames in the video. A dynamic threshold mechanism is adopted to correctly detect frame freeze, as a repeated frame may not have precisely the same values of pixel intensity as those of the prior frame.



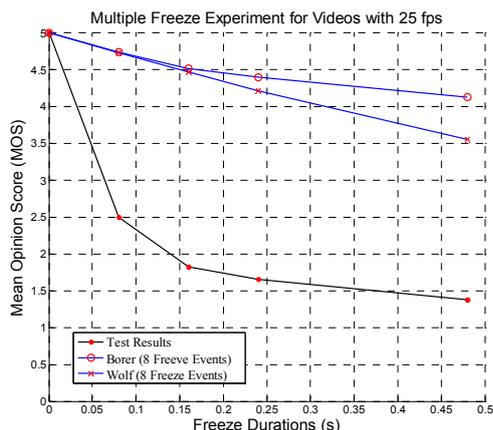
Subjective Test Results of Multiple Freeze Experiment for Videos with a frame rate of 25 fps and 5 Freeze Events



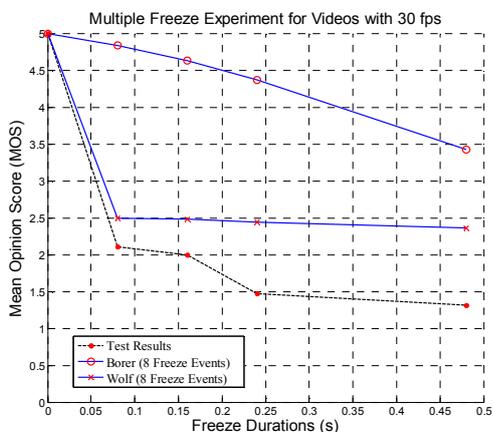
Subjective Test Results of Multiple Freeze Experiment for Videos with a frame rate of 30 fps and 5 Freeze Events

Fig. 7 Subjective and Objective Evaluation Results of Multiple Freeze Experiment for Videos with multiple frame rates and 8 Freeze Events

Hyun-Thu et al. [9]: This is a temporal quality metric that is centred around measuring the annoyance of frame freeze duration. This metric uses mean square difference (MSD) value between video frames to mark freeze events and builds a mapping function based on such durations of freeze to estimate the subjective MOS. Although the quality metric has not been compared for performance against other methods, it has promising value of correlation with the subjective scores. The performance of the VQA metric in [9] has been verified and tested in [4] both multiple and single freezes with a frame rate of 30 fps. But in this paper we have considered 25 fps and 30 fps video sequences.



Subjective Test Results of Multiple Freeze Experiment for Videos with a frame rate of 25 fps and 8 Freeze Events



Subjective Test Results of Multiple Freeze Experiment for Videos with a frame rate of 30 fps and 8 Freeze Events

Fig. 8 Subjective and Objective Evaluation Results of Multiple Freeze Experiment for Videos with multiple frame rates and 8 Freeze Events

Borer [10]: The model of jerkiness presented by Borer is also based on the MSD of video frames for measuring jerkiness (both frame jitter and frame freeze) and it has been tested for videos with resolution ranging from Quarter Common Intermediate Format (QCIF) up to High-definition (HD). This model calculates jerkiness as an accumulative

result of multiplication of three functions called relative display time, a monotonic function of display time and motion intensity of all frames. The display time and motion intensity values are parameterized through a mapping S shaped function, equivalent to a sigmoid function. The proposed method has reasonable correlation with subjective MOS but it does not take into account the value of the motion intensity at the start of a freezing interval.

In the next section a comparison of these three algorithms is provided along with the subjective tests. The scores from these three algorithms and the subjective tests have been plotted in order to have a better understanding of their performance.

V. RESULTS

The results for both the experiments are explained separately in the sub sections below.

A. Single Freeze

In Fig. 4 it can be seen that the subjective tests have been compared with the objective algorithms. The first plot is for the videos with 25 fps and it can be seen that only the results for Hyun-Thu et al. show a strong comparison with the subjective results, remaining two algorithms, wolf [8] and borer [10], show a strong comparison with each other but compared to the subjective results there is a great difference between the MOS. Even for higher freeze durations of 2 seconds and 3 seconds, the algorithms are not showing a nominal improvement. In the second plot of Fig. 4, it can be seen that borer [10] is producing same results even though the frame rate is much higher i.e. 30 fps. But wolf's algorithm [8] is showing slight improvement for higher frame rates, but still it is a weak comparison with the subjective tests. Whereas Hyun-Thu et al. [9] shows the same response even for the higher frame rates.

Here a noticeable point is that the results for Hyun-Thu et al. [9] are not showing any significant results for very low freeze durations. It shows results for the freezes which are higher than .052 seconds. This means that this algorithm is unable to detect freeze durations lower than 0.5 seconds. So, this algorithm will not be considered in comparison for the multiple freeze results. Also, in [4] it has been shown that even though the results for the algorithm by Hyun-Thu et al. [9] show a stronger comparison with the subjective tests but it is unable to detect frozen frames for durations lower than 0.5 seconds.

B. Multiple Freeze

It is to be noticed that Hyun-Thu et al. [9] is not included in the multiple freeze experiment as most of the freeze durations, from Table IV, are lower than 0.5 seconds. Figs. 5-6 show videos with 2 and 3 freeze events i.e. videos that are frozen on 2 and 3 different instants with different time durations respectively, as explained in the Table IV. The first plot shows the results for videos with 25 fps frame rate and it is clearly visible that both the algorithms have a very weak comparison with the subjective test. But if we take a look on the results for

30 fps, the algorithm by Wolf [8] shows a much better performance.

Similar trend can be observed for Figs. 5 and 6. For lower freeze durations in the 25 fps videos, the algorithm by Wolf [8] performing better as compared to higher freeze durations. So, for better understanding, we have taken results for a bigger number of freeze events. Figs. 7 and 8 show the results for 5 freeze events and 8 freeze events respectively. Comparatively, for higher freeze durations, the algorithm by Borer [10] is performing better but its performance is almost same for both the frame rates, 30 fps and 25 fps. Similar trend is followed by the algorithm by Wolf [8] for higher freeze events. For videos with 8 freeze events, it is obvious that the subjective MOS should be low as the video pauses at 8 instants and a lot of motion content is lost during these Freeze events. Subjective MOS has a very strong significance in fine tuning the objective algorithms for video quality assessment as mentioned earlier.

In all the results, single freeze and multiple freeze, we can say that Wolf's algorithm has better performance compared to the other two algorithms in our study. Especially for lower freeze durations such as 0.1, 0.2 and 0.3 seconds, the results are comparable between subjective MOS and Wolf's algorithm [8]. Finally we can move to the conclusion of this study.

VI. CONCLUSION

This paper presents the results of a subjective video quality assessment of videos which are impaired with temporal impairment. These subjective evaluations can be used to check the performance of objective algorithms that follow the no reference method.

Evaluation for each objective algorithm has been performed and their results can be used to further enhance these algorithms to perform better. The trend of the results from the subjective evaluation can be used to train the objective algorithms. This work can be extended further with higher frame rates, changes in spatial resolutions and with different bitrates for videos.

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