Quality of Experience Assessment of 3D Video Synchronised with Multisensorial Media Components

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***Abstract*—While traditional multimedia has primarily focused on vision and hearing, a new form of rich media known as "multiple sensorial media" (mulsemedia) is actively growing and developing. Mulsemedia represents a revolutionary type of media which integrates additional components capable to target other senses (e.g. touch, olfactory, gustatory) alongside multimedia content. In the context of classic multimedia applications, user quality of experience (QoE) has been extensively studied. Some QoE related research has also been performed in case of 2D video based mulsemedia content, demonstrating the fact that mulsemedia increases user QoE as compared to classic multimedia. However, there is a need for further studies on the user QoE when experiencing mulsemedia. This paper performs an extensive subjective study in order to investigate for the first time in the literature user QoE when subject to 3D video based mulsemedia. The results obtained from tests run for the 3D video based mulsemedia are discussed and analysed in comparison with the results obtained for the same tests performed with 2D video. The results show how user QoE associated to the 3D video based mulsemedia is higher than the user QoE associated to the 2D video based experience.**

***Index Terms*—mulsemedia, QoE, olfaction, haptic, air-flow, multimedia, 3D video**

I. Introduction

TRADITIONALLY, multimedia has targeted two human senses, vision and hearing and exposes humans to video, audio, text and still images-based content. Despite the increased quality content provided by nowadays multimedia applications, this technology continues to engage the same two human senses. A new concept called multiple sensorial media, or mulsemedia, involves different sensorial media content being synchronized together (e.g. olfaction, gustatory, haptic, etc.) and targets three of more human senses. Mulsemedia applications intend to produce a complex user experience and aim to improve user's sense of reality. Recent research [1] and [2] has demonstrated the possibilities of mulsemedia for delivering an increased level of experience to the user as well as further immersion into the content. The user quality of experience (QoE) is a topic of great interest among media delivery research. User QoE of mulsemedia content synchronised with 2D video has already been researched in the past. However, to the best of authors knowledge, no study on user QoE of 3D video content synchronised with multiple sensorial components has been performed to date.

Visual media has typically been delivered as 2D content. Recent advancements in recording techniques and video capture technologies have allowed for 3D to become more available in modern films. While it would have been uncommon a few years ago, it is now very common to see cinemas with 3D screenings available. Moreover, 3D televisions, computers and projectors are now available for home use. Consequently, 3D content is rapidly growing in popularity.

As underlined before, some pioneering research demonstrated mulsemedia to be promising for improving user QoE. Nonetheless, more research is required to be done in this field. For instance, all the QoE studies related to mulsemedia were done using 2D videos. In this context, there is a stringent need for mulsemedia QoE assessment based on 3D content. This paper performs an extensive comparative study on the 3D based mulsemedia QoE versus 2D based mulsemedia QoE. In this purpose, a mulsemedia test-bed was built, involving both hardware and software development. The test-bed incorporated devices for producing three sensorial effects: haptic, air-flow and olfaction and synchronising them with audiovisual content. On the basis of the built test-bed, extensive subjective testing was carried out involving a range of voluntary candidates from different backgrounds. The results of these tests are presented and discussed in this paper.

The paper is organized as follows. Section II introduces related works on mulsemedia QoE assessment and synchronisation. Section III presents the mulsemedia test-bed used to perform extensive subjective testing. The testing procedure is also fully described. Section IV analyses and discusses the results obtained. Finally, section V concludes the paper.

II. Related Work

While mulsemedia is still a relatively new area of research, a number of publications and even implementations of this technology are becoming available. Theme parks and amusement parks have created special "4-D experiences" which make use of multiple senses (e.g. Ice Age 4-D[1] or Shrek 4-D[2]). With the price, size, and the specialities required for the equipment, these experiences are still quite rare. However, with the current state of the art devices, such as the Oculus Rift[3],

[1] http://www.sandiegozoo.org/iceage/

[2] https://www.universalorlando.com/Rides/Universal-Studios-Florida/Shrek-4-D.aspx

[3] https://www.oculus.com/

these experiences are becoming more and more accessible to the general public. Mulsemedia has recently been used in Technology Enhanced Learning (TEL) to improve the learning process and outcome [3][4].

The delivery of smells has proven to be particular difficult. While haptic and air-flow effects can be started and stopped as desired, olfaction requires particular timings and distances to be compared and adjusted appropriately. Odours have a number of properties which make them particularly troublesome. A smell will linger in the air for a period of time before fully clearing. This time can also vary depending on the particular odour. Also, based on the environment and the distance of the olfaction dispenser from the user, each smell requires a certain amount of time to be detected. A number of studies have been conducted to investigate the acceptable skews for olfaction delivery with multiple and single scents present [5], [6].

Some research has been carried out involving haptic effects synchronised with audio and visual content. It is apparent that participants enjoy the experience provided by haptic effects [1], [2]. Varying intensity levels were found to be preferred with strong effects being among the most popular within those test groups.

Air-flow has been introduced into a number of studies as an additional effect including [1], [2]. From these previous works, it is clear that users appreciate the addition of an air-flow effect. In fact, most users prefer to have a strong wind effect than to have none at all. No previous work could be found regarding the synchronisation of air-flow effects with audio and visual components.

Subjective testing was previously used as a form of assessment of QoE when mulsemedia applications are employed and have provided significant results. Research on QoE involving 2D video content delivery has been performed in the literature: all of the papers discussed in this section involved 2D video. Whereas the work performed so far in the area of mulsemedia expresses high interest in this technology, no study considered addition of 3D effects to mulsemedia content. Moreover, very few QoE studies involving 3D video content have been conducted in general. Even the commonly used ITU-T standards [7] must consider further improvement in order to have a better relevance to the analysis of 3D QoE. These issues are discussed in [8] along with a number of problems encountered during 3D video delivery. A 3D video quality metric was introduced in [9] and mapping between objective quality measurements and subjective quality metrics in [10].

III. Mulsemedia QoE Assessment

This section describes the study performed in order to assess the mulsemedia content impact on user QoE when using 2D and 3D videos, respectively. First the development of the test-bed used for delivering the mulsemedia content to the participants in the study is presented. The following subsections present the description of participants, mulsemedia sequences considered and the experimental procedure.

Fig. 1: Testbed setup with devices shown

A. Test-bed Description

In order to build the mulsemedia delivery test-bed, special equipment and development of new software were required. Three hardware devices (Figure 1) were used to generate the required sensorial effects: a gaming vest for haptic effects, an olfaction dispenser for olfaction effects and an USB fan for generating air movement effects. A C++ based software was created in order to control these devices. The haptic vest from TN Games [4], which can be seen on the candidate in Figure 1, was used to allow users to interact with the virtual environment through the sense of touch. The vest provides a fully programmable interface which allows for the haptic effects to be programmed based on intensity, type and duration. The vest presents 8 pneumatic actuators (four positioned in the front part of the body and four on the back) which inflate and deflate in order to generate pushes towards the human body. Through the use of this vest simulation of various effects such as: bullet fire, explosions and a multitude of environmental effects is possible. A standard desktop fan was controlled through the use of an USBmicro interface [5] to simulate an air-flow effect. It can be seen elevated to the right of the user in Figure 1. Finally, the olfaction dispenser [6] is placed to the left of the subject. This device presents four individual fans which generate a variety of smells based on the scent filters placed inside the machine.

Similar to the previous approaches in the literature (e.g. [11]), synchronization between the sensorial components and the multimedia content was achieved manually. Guidelines from these approaches were used in order to achieve a good synchronization. For each video sequence included, the time when the sensorial effects occurred as well as the duration of the effects was measured. These timings were stored in ".csv" files and used as data for the synchronization. A C# program was developed to access the data included in these files and correlate it with the C++ programming making the call to the devices. A graphical user interface was also implemented for displaying the video content and the necessary QoE related questions addressed to the participants.

The testbed was positioned in a separate laboratory room, as shown in Figure 1. This room presented minimal outside disturbance and is located in the Performance Engineering Lab

[4]TN Games website, http://tngames.com
[5]USB Micro website, http://usbmicro.com/inder.html
[6]DaleAir website, http://www.daleair.com/vortex-activ

TABLE I: Clip Sequences from "Jurassic Park" Associated with Haptic, Olfaction and Air Flow Effects

Clip No.	Effect Type	Effect Content	Olfaction Aroma
1	None	Dinosaur Walking	
2	Haptic	Dinosaur attack	
3	Olfaction	Eating Sweets	Fruity Sweets
4	Air flow	Helicopter landing	
5	Haptic, Olfaction	Dinosaur attack and forest	Forest
6	Haptic, Air flow	Dinosaur attack and wind	
7	Olfaction, Air flow	Wind and Smoke	Burnt Wood
8	Haptic, Olfaction, Air Flow	Dinosaur attack, wind and toilet smell	Urine

TABLE II: Clip Sequences from "Up" Associated with Haptic, Olfaction and Air Flow Effects

Clip No.	Effect Type	Effect Content	Olfaction Aroma
1	None	Flying into action	
2	Haptic	Accidental injury	
3	Olfaction	Feeding animal into rain forest	Rain Forest
4	Air flow	Wind while flying with opened window	
5	Haptic, Olfaction	Child playing outdoors	Cut grass
6	Haptic, Air flow	Falling and climbing outside	
7	Olfaction, Air flow	Wind and Burning House	Burnt Wood
8	Haptic, Olfaction, Air Flow	Crashing, wind and foggy air	Ozone

at Dublin City University, Ireland. All the windows of the room were kept closed during the testing session. Tests were organized following the ITU-T recommendations P.910 [12], P.911 [13] and P.913 [7].

In order to not to interfere with the test results, the position of the devices was the same for the entire testing session. On the right hand of the user, was positioned the USB fan, at a distance of 40 cm form the edge of the desk. The fan was placed on the top of a box of height 17 cm in order for the user to be able to feel the air-flow effects. On the left hand side of the user was positioned the olfaction dispenser, at a distance of 50 cm from the edge of the desk. This device was placed on the top of a box of 24 cm in height in order to be close to the user but not to have any impact on the user assessment environment.

The haptic vest was positioned on the user's body. Due to the different body structure of each participant involved, no exact position can be defined for this device. For the correct usage of the vest, when placed on the user's body, the vest was zipped and positioned comfortably (not to tight, but tight enough for the user to feel the effects). All users were positioned on a computer chair, facing the monitor perpendicularly. The chair was adjusted to the participant height in order to have a clear view of the screen and to be aligned with the other devices. Due to the smells produced by the olfaction dispenser, an hour was used for room ventilation between two consecutive tests run.

B. Study Participants

A number of 44 users, including 37 males and 7 females from different backgrounds (e.g. students, education, engineering, computer science, science, sales, construction, security etc.) participated in the subjective tests. The study was promoted via institutional email. The youngest participant was 20 years old and the oldest 60. 68% of the participants were aged between 20 and 30, 11% between 30 and 40 and the remaining participants were over 40 years old. For the purpose of this study, 50% of the participants took part in 2D based mulsemedia content testing while the other 50% took part in 3D based mulsemedia content testing. The participant division was made random, but preserving the balance between the two groups of participants in terms of gender, age, profession, etc. 73% of the participants taking part on the study had not been exposed to any mulsemedia subjective quality assessment before the tests. All of the participants involved in the testing read or were read an information form regarding the content and procedure of the test. A consent form was completed prior of initiating the test by each of the participants in order to obtain written participant agreement to take part in the test. Participants were screened against colour blindness and colour weakness. Participation on the test was volunteer, no compensation was given to any of the participants involved in the study. It took in average 20 minutes for each participant to complete the whole test.

C. Mulsemedia Sequences

A set of 16 video sequences were selected from two movies: "Jurassic Park" and "Up" both in 2D and 3D video format, respectively. Eight of the sixteen video clips are taken from "Jurassic Park" while the other half are from "Up". Exact start time and duration of each video sequences was required in order to assure the sixteen 2D video sequences and the sixteen 3D video sequence are the same. Each video clip used was chosen to be 20 seconds long in order to comply with ITU-T recommendations and in order to maintain consistency between video sequences and keep the duration of the entire test in an acceptable time range. The sequences used were chosen based on the content they presented, which had to be favourable for synchronizing the three sensorial effects. One of the video clips used (one from "Jurassic Park" and one from "Up") were used to represent traditional 2D or 3D video content respectively, the rest were chosen in order to present all possible combinations of the effects (i.e. haptic, olfaction and wind).

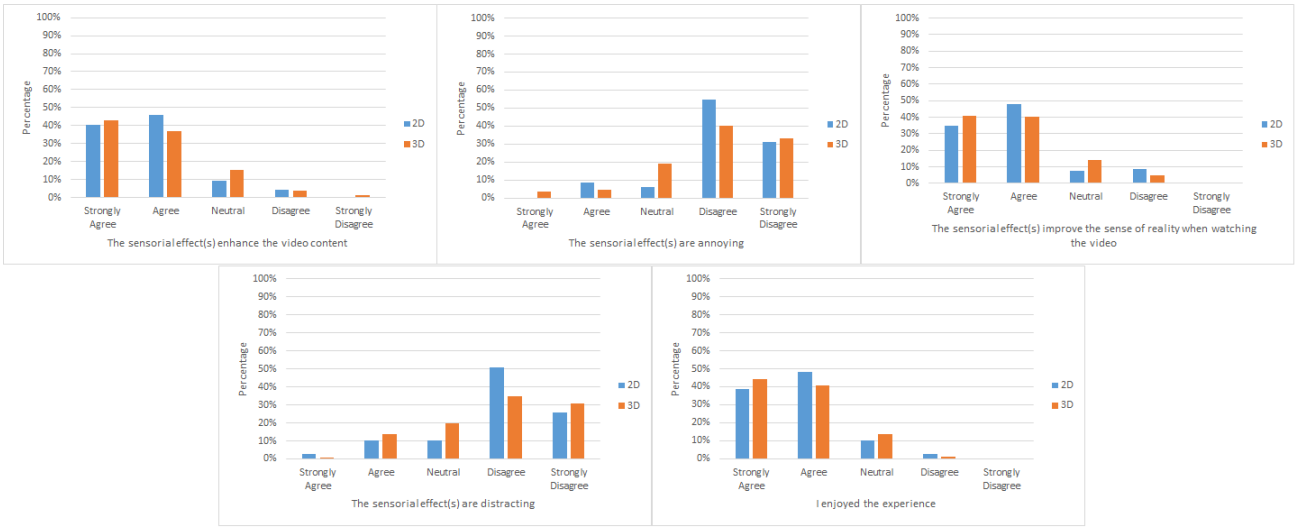

Fig. 2: Impact of 3D based mulsemedia vs 2D based mulsemedia on user QoE - graphic overview

All video sequences (2D and 3D version) used during testing presented the same codec settings (i.e. a resolution of 1920x1080 pixels, frame rate of 29 frames per second, and a bit-rate of 131 Kbps). Table I and Table II present the clips used with details of the sensorial effects employed (if applicable) in conjunction with each of the video clips.

The choice for the two movies was based on their availability in both 2D and 3D. The two movies also present the necessary amount of scenes with content favourable to reproduce haptic, olfaction and air-flow or combinations of these effects. The intensity of the air-flow effect was maintained constant [2]. The intensity of the effect is irrelevant for this study since this paper intends to investigate user quality of experience through comparison of 2D-based and 3D-based mulsemedia content.

D. Experimental Procedure

The participants were divided into two equal groups which took part in tests involving 2D-based mulsemedia content and 3D-based mulsemedia content, respectively. The users were divided as such in order to avoid exposing them to the same clip multiple times and also to limit the number of external interruptions (i.e. putting the 3D glasses on and off). A total of 16 video clips were used, 8 from "Jurassic Park" and 8 from "Up". The same 16 video sequences (available in both 2D and 3D), described in section III-C were used for both groups. A basic algorithm was used in order to randomize the order in which the video clips appear in each test. Each of the 44 participants watched a number of 8 video clips. Every possible combination of the three effects was demonstrated during these clips. After each mulsemedia presentation, each participant was asked eight questions related to the experience. The following Likert scale was used *Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree*. A test included clips from both movies. No two clips used in a test presented the same combination of effects. Prior to each test, the participant read or was read an information form describing the test procedure. Each participant involved in the study was asked to complete and sign a consent form. No test was conducted until the participant consent was obtained.

IV. Results and Analysis

The results obtained from the responses of the candidates are analysed in this section. Fig. 2 presents the data gathered related to user experience during the clips. Next, the responses of the users to the QoE-related questions addressed during the test are analysed in detail.

A. Impact of 3D based Mulsemedia vs 2D based Mulsemedia on User QoE

1) The sensorial effect(s) enhance the video content: Users opinions of the video content with additional sensorial effects were collected (Fig. 2(a)). The percentage of users who *Strongly Agree* and *Agree* for 2D are 40% and 46% respectively. For 3D, *Strongly Agree* and *Agree* received 43% and 37% respectively. First, it can be concluded from these results that the users believe that the additional sensorial effects enhance the video content. This matches with previously found results [1]. While 3D has a slightly higher *Strongly Agree* percentage, a total of 5% answered below *Neutral* with 1% in *Strongly Disagree*. This is similar to 5% in 2D below *Neutral* while 0% is in *Strongly Disagree*. It can be concluded from this that the additional sensorial effects enhanced the 2D video content more than the 3D one.

2) The sensorial effect(s) are annoying: A statement was included to analyse the potential annoyance caused by the sensorial effects to the users. Levels of annoyance for the 2D tests reached 8% with majority of the users disagreeing with the statement. A percentage total of 8% found the effects annoying with 3D also. However, 3% selected *Strongly Agree* while 2D had 0% in this category. This would suggest that the users found the additional components slightly more annoying during the 3D tests than during the 2D. This additional annoyance is presumable due to 3D glasses (as some of the users mentioned in the answers given to the last question that is discussed in the last section) and/or the 3D effect itself.

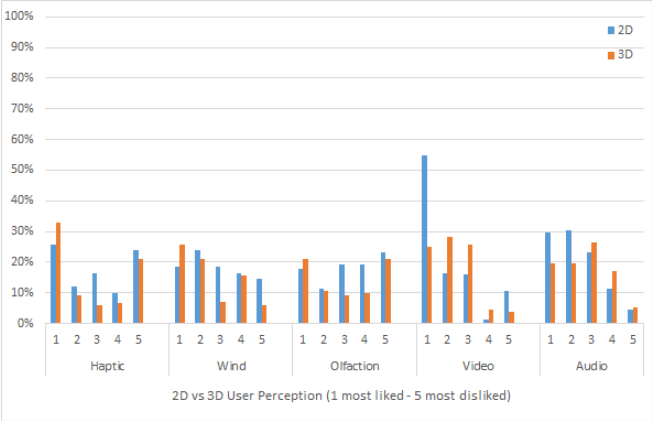

Fig. 3: Users degree of preference for each sensorial effect

3) The sensorial effect(s) improve the sense of reality when watching the video: One major aim with Mulsemedia is to increase the users' sense of reality and immersion. The percentage of users that *Strongly Agree* and *Agree* with an improvement in the sense of reality for 2D are 35% and 48% respectively. For 3D, similar results were achieved with *Strongly Agree* and *Agree* gaining 41% and 40% respectively. In total, a slightly higher percentage believed the sense of reality was improved for 2D. However, 9% of the 2D participants gave negative opinions while only 6% of the 3D results were negative. Consequently, the sense of reality was improved in the context of 3D based mulsemedia as compared to 2D version. These results correlated with the above results obtained for the first question lead to the conclusion that this improvement is due to the 3D content itself.

4) The sensorial effect(s) are distracting: Results gathered from the users with regards to the distraction caused by the sensorial effects (Fig. 2(d)). In case of 2D, a percentage of 13% of candidates agreed that the components were distracting with 3% selecting *Strongly Agree*. This means that the vast majority of users do not find the Mulsemedia components distracting. This conclusion matches the findings in [1]. Similar results were obtained for 3D with 14% of the users answering *Agree*, but only 1% selecting *Strongly Agree*. Overall, it can be concluded that the users were not distracted by the sensorial components.

5) I enjoyed the experience: User enjoyment is a major indicator of the users' QoE. Therefore, results were gathered which were related to the enjoyment of the experience (Fig. 2(e)). Results for the 2D experience for *Strongly Agree* and *Agree* were 39% and 48% respectively. Only 3% did not enjoy the experience. As for the 3D tests, 44% were *Strongly Agree* and 41% were *Agree*. Only 1% of participants did not enjoy the experience. Consequently, it can be concluded that the 3D based mulsemedia was more enjoyable than the 2D one.

B. User Effect Preferences

As different sensorial effects were used, an interesting idea was to find out what effects were the most preferred. Fig. 3 shows the results that were gathered from the participants of both 2D and 3D tests. This section will highlight the various effects and discuss their influences. Candidates were allowed to skip this question as some components were not relevant to all clips, this resulted in a number of '0' values. These values affect the percentages but are ignored in the analysis of this data.

1) Haptic: For both sets of results, it can be seen that opinions towards the haptic effects are largely divided. In fact, 1 (most preferred) and 5 (least preferred) represent 50% of the user preference in both tests. For the 2D test we can say that the values are equal with 26% and 24% for most and least respectively. Only a slightly larger divide can be observed in the 3D results with most and least getting 33% and 20%. We believe this large divide in opinion can be explained by the type of device being used to generate the effect. It was required for the vest to be tight on each user which may cause discomfort for some.

2) Wind: An air-flow or wind effect was generated by a USB desktop fan. Participants who took part in the 2D tests gave a balanced mixed of opinions ranging from 1 to 5. However, the higher opinions, 1 and 2, were slightly more preferred with 19% and 24% respectively. Preferences given during the 3D tests were more decisive with 1 and 2 receiving a percentage of 26% and 21% respectively. A spike can also be noticed for 4 with a percentage of 16%. It can be seen that the fan was more appreciated as part of the 3D testing than the 2D testing.

3) Olfaction: 2D results related to the olfaction sense were quite mixed but leaned slightly more to the lower preferences, 4 and 5, with 19% and 23% respectively. However, 3D results resembled the results gathered for the haptic effect. Both 1 and 5 got a result of 21% while the values in between were much smaller. Despite the high percentages for low preferences in 2D, the olfaction device was more appreciated in average.

4) Video: With this study focussing on a comparison between 3D and 2D, it was of interest to see how much the candidates appreciated the video component of the experience. For the 2D tests, over half of the candidates rated video as there highest preference with 55%. More mixed opinions were given for the 3D tests. The top three preferences, 1 to 3, were nearly equal with 25%, 28% and 26% respectively. While more 2D had a higher top rating vote, the rest of the results were quite equal (except 4). However, 3D was consistently high with very few votes below 3. This shows a clear appreciation of the 3D video content in comparison to the 2D video content.

5) Audio: Audio was a topic of interest due to the haptic vest. This component required a noisy air-compressor in close proximity of the user. Headphones were provided to overcome this external noise but they may not have been as effective as desired. For the 2D tests, the audio is consistently ranked high with 1, 2 and 3 gaining 30%, 30% and 23% respectively. The 3D tests gathered a more mixed set of opinions. The only stand out option was 5 with 5% being the lowest. All of the other opinions were roughly 20%. This is not a component that was expected to be affected by 2D and 3D. These differences are presumably due to users' preferred volume levels and/or comfort. One aspect of 3D that may have caused a difference in opinion would have been the 3D glasses. These had to be put

Fig. 4: Eye comfort results

of under the headphones which may have caused discomfort for certain users.

C. Eye Comfort Comparison

One issue that is often associated with 3D video is visual discomfort caused by the effects [14]. As such, this issue was analysed in the study performed (Fig. 4). A scale of *Excellent, Good, Fair, Poor, Bad* was used for ranking the comfort levels. The 2D candidates experienced little to no discomfort with only 6% answering *Fair* and none below that. *Excellent* and *Good* had percentages of 69% and 25% respectively. As expected, these results show that the users were comfortable with 2D video. For 3D, a slightly broader range of results were gathered. However, these results were still mainly positive with *Excellent* and *Good* getting 32% and 43% respectively. *Fair* got a larger amount of responses with 17% while *Poor* got 2%. Based on the results, it can be concluded that the users may have been slightly more comfortable watching 2D video content, but 3D did not cause any significant discomfort.

D. Highlighted Disturbances

The final question that the participants were presented with after each clip aimed to investigate if any component was particularly disturbing. This was an optional question, and in most cases no answer or "None" was given as an answer. However, a few candidates did mention some components. Haptic was by far the most mentioned component for both 2D and 3D, a number of the candidates expressing discomfort caused by the haptic vest. Olfaction component was also mentioned by few participants as a disturbance. This is mainly due to the fact that some users simply do not like smells, as previously seen ([1]). The 3D glasses were also mentioned as a disturbance factor.

V. Conclusion

This paper conducts a novel comparison of user QoE between 2D and 3D video synchronised with mulsemedia. Subjective testing was carried out with 44 participants. Results demonstrated that despite 3D typically being associated with visual discomfort, the candidates experienced only a small decrease in comfort as compared to the 2D scenario. Moreover, the results indicate that although some of the users experience a slight discomfort due to the 3D glasses the overall 3D based mulsemedia experience had an increased user QoE as compared to the 2D one. The analysis performed demonstrated that the 3D video content lead to higher sense of reality and enjoyment than 2D.

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