A Study of Learning Experience with a DASH-based Mulsemedia Delivery System

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***Abstract*—This paper describes the experimental deployment of a DASH-based Multi-Sensory Media Delivery System (DASHMS) to support multi-sensorial media-enhanced learning. Multi-sensorial media (mulsemedia) combines multimedia components (video and audio) and emerging technologies targeting other human senses (e.g. touch & haptics, smell and taste). This paper studies learning experience with olfaction and haptic-based mulsemedia when employing DASHMS in a real-life subjective experiment with 40 participants. The tests performed evaluate the user-perceived quality of experience (QoE) and the effects of mulsemedia on user learning.**

***Index Terms*—Multi-Sensory Media Delivery, Olfaction, DASH, Learner Experience, QoE**

I. Introduction

In multimedia applications, research and technology developments usually target two human senses only and focus on improving the image and/or sound quality. This limitation stimulates the disconnection between the user and the represented scene, undermining the enhancement of the interaction in digital media through combinations of audiovisual content with one or several different types of other stimuli (e.g., haptic and/or olfactory).

This paper presents a research study on learner experience using a new DASH-based Multi-Sensory Media Delivery System (DASHMS). DASHMS is used in the class to enhance user experience with multi-sensorial media (mulsemedia) elements, engaging three or more human senses and allows for adjustment of the content delivery in a heterogeneous network context.

This study is part of the EU Horizon 2020-funded NEWTON project[1] whiuch bridges the gap between the development of latest technologies and classic education by providing educators and students with modern tools to enable improved and more attractive teaching and learning.

The research study described in this paper delivers mulsemedia content and assesses the benefit of employing the latest technologies in the learning process in terms of learner satisfaction, quality of experience and learning outcome. These technologies shift the focus from a teacher-centred to a student-centred approach.

[1]NEWTON project webpage, http://newtonproject.eu

Pedagogically, these technologies enable a constructivist approach of learning where a student constructs their own learning experience rather than strictly receiving knowledge.

The paper is organized as follows. Section 2 introduces the state-of-the-art related works in mulsemedia communications and user-perceived QoE. Sections 3 and 4 give an overview of DASHMS and present the research methodology of the case study and its results. Finally, Section 5 concludes the paper.

II. Related Works

There have been very few studies investigating the user-perceived experience associated with the use of media objects such as tactile (touch) and olfaction. As the use of these media objects is relatively new, most of these perceptual studies have focused on the practicality and possibility of using these media objects into applications.

Examples of such studies involve a virtual reality (VR) learning system called VIREPSE using both olfactory and haptic feedback [1] and a mulsemedia VR learning environment which investigates the effects of olfaction on learning, retention, and recall of complex 3D structures such as organic molecules in chemical structures [2]. However, neither of these include any detailed evaluation, limiting the discussion to the significance of developing mulsemedia virtual environments for education.

The synchronization of different types of media is a recurring issue. An example of this can be found in studies like [3] where researchers offer a perceptual study establishing an algorithm to provide high-quality inter-media stream synchronization (haptic and audio) in a virtual environment. Similar studies, such as [4] exploring synchronization of olfactory media with audio-visual content and [5] investigating synchronization issues and the integration of video and haptics in resource-constrained communication networks, are closely related to the work described in this study.

To the best of authors' knowledge, only Yuan et al. explore adaptive mulsemedia proposing an ADAptive MulSemedia Delivery Solution (ADAMS) [6] for delivering scalable video and sensorial data to users through three joint adaptation dimensions: video, sensorial source, and network optimization. Using an MPEG-7 description scheme, ADAMS recommends

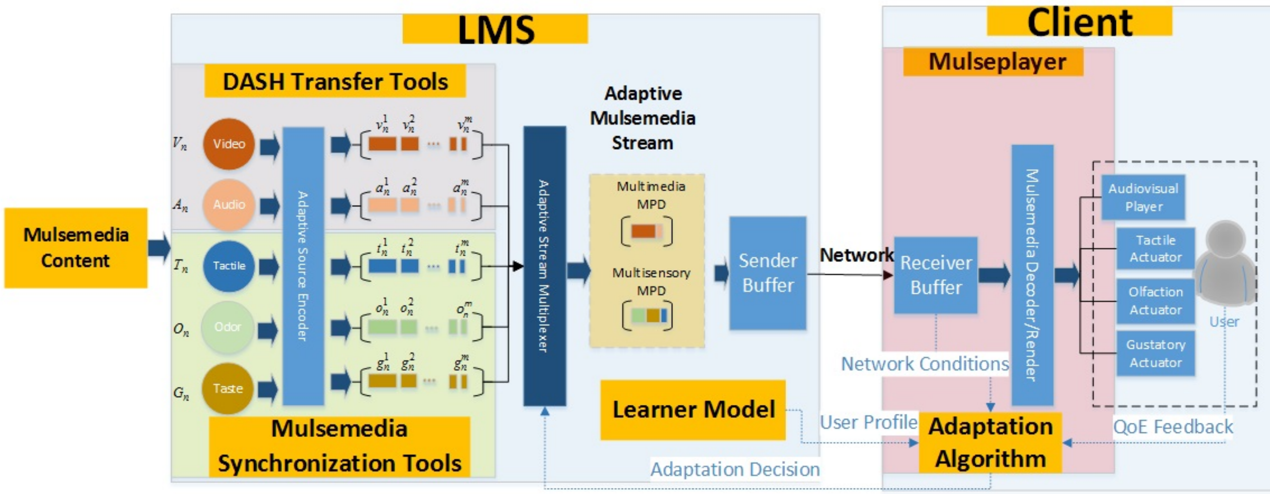

Fig. 1: DASH-based Multi-Sensory Media Delivery System

the integration of multiple sensorial effects (i.e., haptic, olfaction, air motion, etc.) as metadata into multimedia streams and includes both coarse- and fine-grained adaptation at the server side - using mulsemedia flow adaptation and packet priority scheduling. However, as it is not based on the standard DASH, ADAM cannot be employed in conjunction with DASH videos and cannot be easily embedded in future streaming systems. This emphasizes the importance of designing a DASH-based solution to support adaptive mulsemedia content delivery.

III. System Architecture

The DASHMS architecture illustrated in Figure 1 has two major components. On the Learning Model-based Server (LMS) side, a cloud-based platform annotates different sense information and encodes all information into an adaptive mulsemedia stream, associating it with a Media Presentation Description (MPD) file, enhanced with multi-sensorial metadata. On the client side, a mulsemedia player (mulseplayer) renders various sense segments into video/audio streaming and multi-sensorial effects (haptic, olfaction, etc.).

A. Encoding

The encoding for DASHMS in Figure 1 shows that the mulsemedia content can be divided into two parts: multimedia content and sensory content/information. In this system, open source DASH transfer tools, such as *MP4Box* and *Bento4*, are used to encode the video & audio content in MPEG DASH. For all other senses content/information, a mulsemedia synchronization tool is proposed to generate the MPD and its annotations.

B. Delivery and Playout

After encoding, the sender receives requests for diverse segments from the DASH-client and delivers the adapted mulsemedia stream, as requested. The requests are made by the client based on network condition, QoE feedback and user preference. After receiving the content, decoding and rendering it, the mulseplayer at the client side will perform both video/audio content play out and control of the multi-sensory devices to generate the user multi-sensory experience.

IV. Case Study

The goal of the research study is to investigate learner experience when education material involving multi-sensorial content is used in class in the teaching process. Knowledge on "Energy Harvesting" and "Network Performance", part of a Dublin City University (DCU)-based course on Data and Computer Networks was delivered to undergraduate students using mulsemedia. This section presents the case study set-up, evaluation methodology and results analysis.

A. Research Methodology

The evaluation included a group of 40 undergraduate students in the 19-25 age range, from DCU, Ireland. The learning activity took place during the normal class hours, and it was prepared and supported by the members of DCU's Performance Engineering Laboratory (PEL)[2].

The case study benefited from DCU Ethics Committee approval. All required documents were provided: informed consent forms, plain language statement and data management plan. Table I shows the 7 steps followed by the researchers:

TABLE I: Evaluation process

Ethics requirements	1) Collection of the consent forms 2) Description of the research study 3) Collection of assent forms
Learner process	4) Pretest questionnaire 5) Learning experience 6) Post test questionnaire 7) Learner satisfaction questionnaire

The plain language statement included a detailed description of the testing scenario, information on study purpose, participant identity protection info, etc.

The students had roughly 30 minutes to watch 6 mulsemedia clips via DASHMS, each clip with two-question pre-test

[2]DCU Performance Engineering Lab (PEL), http://www.eeng.dcu.ie/~pel

and five-question post-test questionnaires to evaluate learner experience. The post-test questionnaire can be downloaded from this link: https://goo.gl/Wa8iEP.

Finally, a learner satisfaction questionnaire assessed the student level of experience and DASHMS usability. In these tests, all questionnaires were provided on paper and transcribed in digital format later on.

B. Case Study Set-up

The mulsemedia sequences were generated by enhancing multimedia videos (with a resolution of 1920x1080 pixels and a frame rate of 30.3 fps) with multi-sensorial content, i.e., haptic, air and/or olfaction effects. The video content focuses on energy harvesting and data networking, as follows:

- Solar: energy harvesting from solar and electromagnetic field sources.
- Kinetic: energy harvesting from kinetic sources (e.g. by spinning the mobile devices or the vibration on a car).
- Hydro: Energy harvesting from hydro based sources.
- Football: Multimedia content adaptation when watching a football match in a park.
- Coffee shop: Multimedia content adaptation during a video call in a coffee shop.
- Car: Multimedia content adaptation when remotely attending a concert while on a car.

Table II details the duration and multi-sensorial effect settings related to each mulsemedia sequence.

TABLE II: Duration of the mulsemedia effect of each video

Video	Duration (m)	Mulsemedia effects and sync time (s)		
		Air	Haptic	scent
Solar	1:13	23s-28s	51s-60s	Oak: 31s-40s
Kinetic	0:53	42s-50s	07s-18s	Diesel: 32s-40s
Hydro	1:25	68s-75s	27s-32s	Oak: 4s-14s Ocean: 37s-52s
Football	1:24	36s-48s	67s-75s	Oak: 50s-62s
Coffee Shop	0:57	00s-10s	10s-20s	Chocolate: 33s-45s
Car	0:49	00s-10s	15s-25s	Diesel: 28s-38s

Three different scenarios are set with all 6 mulsemedia sequences. In scenario 1, no multi-sensory effect happens during the video display; in scenario 2, all three multi-sensory effects (wind, haptic, olfaction) occur and the olfaction scent is relevant to the video content; in scenario 3, all three multi-sensory effects occur, but the olfaction scent is always ”Tutty color”, regardless of the content scent.

To present the mulsemedia effect to the end users, the DASHMS mulseplayer makes use of additional multi-sensory actuator equipment. A gaming haptic mouse, an Exhalia scent diffuser and an Arduino-based programmable CPU fan were used to simulate haptic, olfaction and air-flow effects in sync with multimedia content.

According to the content scenario, the multi-sensory effects were manually synchronized with the corresponding sensorial content in the multimedia clips by setting the start and end timestamps. Then, the ”mulsemedia segment file” is generated by a multi-sensory data annotation tool in DASHMS.

Figure 2 shows the equipment and test-bed employed in the tests. The Arduino-based programmable controlled fan, Figure 2(a), provides the air-flow effect - the fan’s on/off state and strength is controlled by a C++ program.

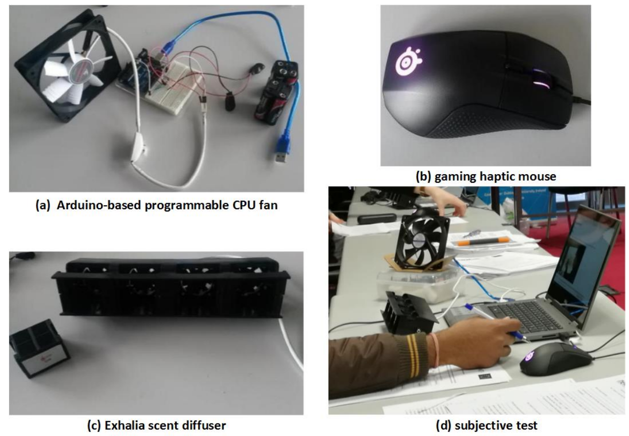

Fig. 2: Mulsemedia Equipment and Test-bed

The gaming haptic mouse, SteelSeries Rival, illustrated in Figure 2(b), supports full control of the haptic effect in terms of frequency and duration. The Exhalia device (Figure 2(c)) diffuses scents from each of its four small fans. This subjective test-bed was assembled in a separate room in DCU’s Performance Engineering Lab. The testing environment was set up obeying all the recommendations of ITU-T R.P.910[3], ITU-T R.P.911[4] and ITU-T R.P.913[5].

C. Result Analysis

1) Learning Outcome: For all scenarios, the participants have answered 5 post-test questionnaires after each mulsemedia clip. Each of the correct answers is associated with 1 point, so the maximum score is 5 points. Figure 3 presents the average score in 3 different scenarios. Scenario 1 with no multi-sensory effect received the lowest average score of 3.15. Scenario 3 with all three multi-sensory effects, but with no olfaction scent relevant to the video content scored the second highest average score of 3.2. Scenario 2 with all three multi-sensory effects and olfaction scent matching the video content obtained the highest average score of 3.27. These results show how, by employing multi-sensorial effects, the students benefit in terms of learning outcome, although not with a high margin.

A test for consistency of our questionnaire revealed a Cronbach alpha value of 0.95, which present excellent internal consistency [7]. On an ANOVA test on the post-test questionnaire results of the 3 scenarios, the p-value of the statistical data, in terms of learning outcome, was 0.0104 ($p<0.05$), indicating strong evidence against the null hypothesis and a statistically significant difference between the results data.

[3]Subjective video quality assessment methods for multimedia applications, https://www.itu.int/rec/T-REC-P.910/en

[4]Subjective audiovisual quality assessment methods for multimedia applications , https://www.itu.int/rec/T-REC-P.911/en

[5]Methods for the subjective assessment of video quality, audio quality and audiovisual quality of Internet video and distribution quality television in any environment , https://www.itu.int/rec/T-REC-P.913/en

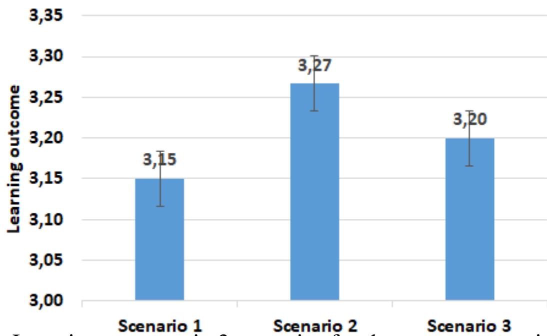

Fig. 3: Learning outcome in 3 scenarios for the post test questionnaire

2) Learning Satisfaction: The learner satisfaction (or learner quality of experience) using the DASHMS was investigated and evaluated by questions Q1 to Q7 in the Learner satisfaction questionnaire. It was analysed in terms of: number of Strongly Agree/Agree answers for Q1, Q2, Q4, Q5; and Q7 and Strongly Disagree / Disagree for Q3 and Q6. The 7 questions of the learner satisfaction, related to the **multi-sensorial experience**, are listed next:

- Q1. *It helped me to better understand the concepts.*
- Q2. *It helped me to better assimilate the concepts.*
- Q3. *It did not improve my learning experience.*
- Q4. *It helped me to engage in the learning process.*
- Q5. *I enjoyed the experience during the class.*
- Q6. *Its effects were disturbing for me during the class.*
- Q7. *I would like to have more classes/labs/courses that include multi-sensorial experience.*

The overall learner satisfaction of the participants was excellent (see Table III for detailed results). 63% confirmed that the multi-sensorial experience helped them understand better the concepts. 55% thought that the multi-sensorial experience helped them to assimilate better the concepts. 65% thought the multi-sensorial experience helped them to be more engaged in the learning process. 73% enjoyed the multi-sensorial experience during the class. 66% would like to have more activities that include multi-sensorial experience. 58% disagreed that the multi-sensorial experience did not improve their learning experience. 55% disagreed that the multi-sensorial effects were disturbing for them during the class time.

TABLE III: Learner satisfaction (%)

	Q1	Q2	Q3	Q4	Q5	Q6	Q7
Strongly Disagree	0	5	15	7	0	20	5
Disagree	20	18	42	18	10	35	15
Neutral	18	23	15	10	18	15	15
Agree	47	39	23	45	47	23	37
Strongly Agree	15	15	5	20	25	7	28

3) Multi-sensorial Experience: A very interesting result is the order of the preferred multi-sensorial effect. In the final learner satisfaction questionnaire, the participants were asked to indicate the preferred multi-sensorial effects in order. The results are shown in Table IV, with the first option associated with a Gold Medal, the second option with a Silver medal and the third option with A Bronze medal. The air effect got half of the Gold medals from all participants, and 43.75% of the Silver medals. The olfaction effect obtained 34.3% of both Gold and Silver medals, whereas the haptic effect received 65.6% of the Bronze medals. One possible reason is the fact that in these experiments the haptic effect is generated via a haptic mouse and the effect is similar to a phone vibrating, which has a high potential to distract the learners.

TABLE IV: Learner experience: preferred multi-sensorial effect (%)

	Gold Medal	Silver Medal	Bronze Medal
Air	50.000	43.750	06.250
Haptic	15.625	21.875	65.625
Olfaction	34.375	34.375	28.125

V. Conclusion

This paper introduces, describes and tests a DASH-based adaptive mulsemedia delivery system: DASHMS. Some important concepts such as the "Mulsemedia MPD" is introduced. This study delivers mulsemedia content and assesses the benefit of employing the DASHMS in the learning process in terms of learner satisfaction, quality of experience and learning outcome.

An analysis of the results collected in a case study conducted on a group of 40 students was presented in the paper. Learner outcome with the DASHMS and learning satisfaction experience were investigated. The analysis of the survey questionnaire results shows that the majority of the students were satisfied with the multi-sensorial experience: 73% of them enjoyed the DASHMS. The survey also shows that the students appreciated various multi-sensorial effects and that they enhanced the learning outcome.

The overall learner experience was excellent so 66% of students would like to have more classes/labs/courses that include multi-sensorial experience.

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