Application of Immersive Technologies for Education: State Of The Art

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***Abstract*—Existing multimedia systems used in education mostly address only two senses by using two communication channels (visual and audio) of the five human senses (sight, hearing, taste, smell, and touch), limiting the potential efficiency of learning. This paper presents a survey on existing technical opportunities for the development of an immersive learning environment. Four components of the immersive environment – visual, audio, olfactory, and haptic are described and discussed in the paper. In particular 3D displays, head mounted devices, 3D sound systems, olfactory displays, haptic devices, and interaction devices are presented.**

Keywords—immersive technology; mulsemedia; 3D display; 3D sound system; olfactory display; haptic device

I. INTRODUCTION

The generally recognized fact discovered in psychology is that the more informational channels we involve into communication process in education, the better perception of the information by a learner can be achieved. However existing multimedia systems used in education mostly address only two senses by using two communication channels (visual and audio) of the five human senses (sight, hearing, taste, smell, and touch), limiting the potential efficiency of learning. At the same time modern immersive technologies enable to employ not only visual and audio, but also olfactory and haptic media. The purpose of this paper is to present existing hardware of immersive technologies and in this way to encourage educators to use them in their practical work.

II. 3D VISUALIZATION TECHNOLOGY

There are 3D displays available, both commercially and in the research laboratories that can be used for multi-user learning / teaching scenarios. However, for a group of naked eye viewers distributed in a reasonably wide field of view, currently available technologies find it very difficult, if not impossible, to render moving high-resolution images so that they can be actually perceived as 3D, with proper occlusion relations and at an appropriate scale.

Stereoscopic displays based on glasses [7] (e.g. those used in current 3DTVs ad 3D cinemas) are cheap and simple solutions, and are indeed used in many education settings. When using these solutions, all viewers have to wear some sort of 3D glasses (active or passive), and see the same left-right image pair. If the stereoscopic image pair is the same regardless of the position of the viewer(s), no motion parallax can be supported, and is therefore most suitable for seated presentations. Motion parallax can only be supported by tracking the viewer, and updating the stereoscopic image pair accordingly, which can only be supported for a single user. This approach is often utilized in CAVE [8] systems.

Fig. 1. NVIDIA 3D Vision Glasses. Image courtesy of NVIDIA Corporation

The virtual reality / augmented reality glasses that recently made a comeback (such as Oculus Rift, Microsoft HoloLens, Google Cardboard) are also stereoscopic displays with viewer tracking. Apart from a potentially wider Field Of View, they represent the well known stereoscopic display techniques. Using a cheap solution like the Google Cardboard, and utilizing a smartphone, one can provide virtual 3D experiences that surround the viewer for a reasonably low cost.

Going beyond glasses-based stereoscopic solutions, a huge number of approaches have been proposed to support naked-eye 3D visualization. The key technical feature characterizing these 3D displays is direction-selective light emission, which is obtained most commonly by volumetric, holographic, or multi-view approaches.

Fig. 2. Google Cardboard VR glass using a smartphone

Typical multi-view displays, often based on parallax barrier or lenticular lens array, show multiple 2D images in multiple zones in space. They support multiple simultaneous viewers, but at the cost of restricting them to be within a limited viewing angle. A number of manufacturers [9], [10] produce monitors based on variations of this technology. Typical state-of-the-art displays use 8–10 directions, at the expense of resolution. A 3D stereo effect is obtained when the left eye and the right eye see different but matching information. It must be noted that parallax barrier based stereoscopic 3D displays can be found in several mobile devices, such as the LG Optimus 3D phone, or the Nintendo 3DS mobile gaming console, which can also be used for presenting 3D material in an educational setting, as well as for capturing stereoscopic images and videos.

Fig. 3. LG Optimus 3D mobile phone equipped with parallax-barrier based autostereoscopic 3Dscreen and stereo camera

Volumetric displays synthesize light fields by projecting light beams on refractive/reflective media positioned or moved in space [11]. Commercial displays are readily available. The main disadvantages are the limited scalability of the approach, and the difficulty in presenting occlusion effects. The latter problem has been solved in displays which employ an anisotropic diffuser covering a rapidly spinning mirror illuminated by a single high speed video projector synchronized with mirror rotation[12].

Computational holographic / electro-holographic techniques are based on generating holographic patterns to reconstruct the light wave front originating from the displayed object[13], using acousto-optic materials, optically addressed spatial light modulators, or digital micro-mirror devices. Although this approach can theoretically provide the most compelling imagery, current implementations have serious limitations on realistically achievable image size and resolution, alongside enormous computing capacity required to produce images.

Light-field 3D displays [14] are an alternative to the full holographic approach described above. Instead of a complex laser and mirror control system, this technology uses specially arranged array of projection engines and a holographic screen. Each point (voxel) of the holographic screen emits light beams of different colour and intensity to the various directions, in a controlled manner. The light beams are generated through a light modulation system arranged in a specific geometry and the holographic screen makes the necessary optical transformation to compose these beams into a continuous 3D view. With proper software control, the light beams leaving the various pixels can be made to propagate in directions, as if they were emitted from a common point behind the screen or they cross each other in front of the screen. In this way, viewers will perceive the points in objects behind the screen or floating in the air in front of the screen, respectively.

III. 3D Sound Technology

Binaural recording systems are known as systems for simulating the functionality of the human head during audio retrieval. The anatomy of our head (and many other species, as well) explains how we retrieve and process the sounds we hear: with two ears on opposite of our head, we hear sounds entering our left and right ears at various times. The sound coming from one side will also be louder in one ear than the other. Furthermore, sound waves are influenced by the anatomy of the listener's head creating listener-specific variations otherwise known as head-related transfer function. The brain evaluates these differences of time and strength in order to localize sound with immaculate precision.

We distinguish principally audio recordings using two methods: mono and stereo. Mono recording uses one microphone to record sound, while stereo uses two locally separated microphones. Binaural recording is a specific approach of the stereo recording. Two microphones are located in a place of two ears either directly on the human head, or on an artificial head. In this way microphones record the audio stream as it is heard and processed by the human. Headphones are the natural and most effective way to reproduce such a sound.

The first binaural audio system named Theatrophone was introduced in 1881 by French engineer Ader. Two microphones covered the stereo sound direction, the signals were transmitted over telephone lines within Paris and with 2 separate receivers, one on each ear, the 3D audio sound could be recognised by the listener.

The famous mechanical dummy named Oscar was built by AT&T Bell Laboratories in 1933. Oscar had a microphone placed on each ear and was placed in a glass room, while listeners could hear the sound as if they were in a glass room using headphones.

In headphones, in this case, the user will obtain a simulation of three-dimensional sound of the real source. This effect is of course a principally different system as a surround sound system. Surround sound is produced by many speakers positioned in the space to create 360 degree sound effect in the room. In this simulation you hear various sounds from various locations of the room, so the user has an impression as if he/she were directly in the scene.

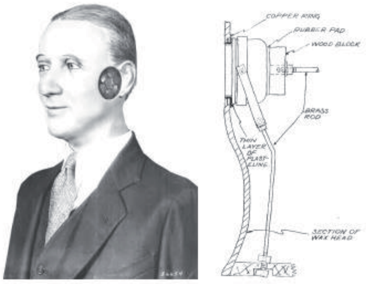

Fig. 4. Oscar from AT&T, an early binaural recording dummy. Image via ACTA Acustica.

The surround system benefits from a feature, that it creates exact positioning of the various sound sources, while 3D sound system or binaural audio produces more natural 3D sound as user normally hears it without expensive set of speakers.

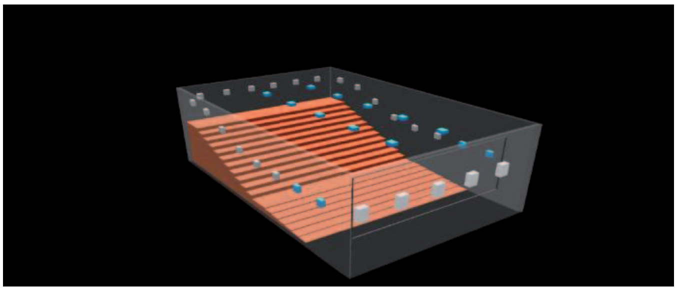

Fig. 5. A theater equipped with Dolby Atmos technology company

The basic problem of a binaural audio system is a dynamic directional orientation. For instance, using headphones the user hears a sound coming to his left ear. Turning his head to the left in the direction of the coming sound, the user suppose to hear the sound from the front. If he still hears the sound coming from the left, the 3D illusion is over.

Several systems are known, which try to address this problem, e.g. using several pairs of ear microphones around the dummy head and combining the pair of audio stream into the same direction independently of the position of the headphones.

Using 3D audio sound system and surround sound system increase dramatically virtual reality not only for educational purposes based on immersive technologies but in many other situations in real life.

Fig. 6. 3Dio's omni-binaural recording set-up. Image via futureofstorytelling

IV. OLFACTORY TECHNOLOGY

Of all immersive technologies, Olfaction or the sense of smell is the least well incorporated across a range of application domains. Two articles in the literature have extensively surveyed the use of olfaction; in [15] application areas of entertainment, virtual reality, movies whilst [16] considered olfaction in education, tourism and health. [17] and [18] highlight future application and perspectives for MulSemedia whilst another recent article [19] highlighted the association between smell and users stories. They defined a number of scent categories to which the use of scent can be applied: (a) associating the past with scent (b) remembering through smell (c) scent as a stimulant (d) scent creating a desire (e) scent allowing identification and detection (f) overwhelming power of scent (g) scent invading public / private places (h) how social interactions are affected by scent (i) scent changing mood and behaviour (j) how scent affects expectation.

Of all the considered domains, the use of olfaction in education is least reported. Kaye [20][21]carried out pioneering work on how olfaction as a media component could be used to convey information. The classifications of olfactory *icons* and *smicons* was defined. These classifications are based on the relationship an olfaction component has with other media components presented i.e., if a direct relationship with the other stimuli presented exists, it is classified as an olfactory *icon whereas if* if no such relationship exists, the term *smicons* was proposed. Both of these categorizations are applicable to immersive educations technology development i.e. icons could be used in addition to other stimuli to spread relevant information across all of the senses, and as a consequence lighten the processing load on the audio/visual sense. From an attention retrieval perspective, a conflicting olfactory queue presented at particular times during a multiple sensorial presentation may have the effect of capturing a student's attention.

The majority of research recent works to date have focused on whether or not, the presentation of olfaction as a media component enhances the users Quality of Experience (QoE) [22-31]. Applied to education, the literature generally focuses on the effect olfaction has on the ability to recall information or how it is associated with memories. Ademoye in [32] reported that the presence of an information recall task did not adversely affect

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the user QoE of olfaction enhanced multimedia. This suggests multisensory learning as an approach can lead to high levels of user QoE. [33] found that the inclusion of an olfactory component had a positive effect on users' ability to recall the details of an environment. [34] described their "Smart Ambience for Affected Learning" (SAMAL) system which uses olfactory data with a number of modalities to provide an effective evocative learning environment. The preliminary results suggest that the SAMAL system positively influences learning effectiveness. Childers et al. discussed the role of olfactory data in serious gaming, mental training and therapy in [35] and highlighted advantages including: reinforcement, real life authentic learning, retention of information, improvement of concentration levels, promotion of independent thinking and familiarity. Outside of these articles, little work has been published on olfaction with education as the key focus. Notwithstanding this, significant potential exists for the development of an immersive system which includes olfaction. A key impediment to date, has been the lack of commercially available olfactory displays. In the remainder of this section on olfactory technology, the authors focus on providing an overview of their operation.

In [16], the authors classified olfactory displays in terms of where they are placed: "In the environment" and "Wearable" and within each of these classifications, scent generation technique. Here the focus is on reviewing commercially available olfactory displays that's can be incorporated as part of Immersive technology system for effective learning.

Olfactory displays which have a similar operational principal is the vortex active from Dale Air [36] and SBiX from Exhalia [37]. Both of these devices are placed in the environment as opposed to being wearable and deliver scents to users based on the presence of 4 fans. Numerous works that have used these displays recommend that they be placed between 0.5 and 1 meter from the user. The reason for this is that both devices can be susceptible to scents being emitted without fans being turned on due to air movement. The key difference between these two olfactory displays is the scent cartridges. The cartridges for the vortex active are cotton pads soaked in scented oils. The cartridges for the SBiX are made from scented polymer balls. Both types of cartridges last approximately 1 month before noticeable differences can be detected by users. This can obviously have significant issues in terms of presenting scents at the incorrect times. Another device placed in the environment, but does not present scent based on the use of fans is the scent cube again from Dale Air. It delivers scented air based on natural air movement. Clearly the issue with this type of display is the slow movement of the scent and its susceptibility of delivery to natural air movement [36]. The *GameSkunk* from SensoryAcumen [38] is another olfactory display that similar design principals to emits scent by blowing air around scented substrates (solid). The *GameSkunkdevice* can store up to 12 cartridges.

[39] provides a number of different olfactory displays with differing modes of operation. The *ScentCube* is similar to the scent cube from Dale air. Its application is for ambient scent presentation. It uses natural vapourization for scent delivery. The *Scense* device presents odor by using air flow through replaceable scent gel cartridges similar to the vortex active and SBiX devices.. The *ScentDiffuser.aircon* device is a scented oils-based OD. It presents scent through micro-nebulization. *ScentAir* [40] provide three scent delivery systems, *ScentWave*, *ScentDirect* and *ScentStream*, which are based on dry-air cartridge or a diffusion technology to convert scented oils into vapor for emission. *Olfacom* have a number of commercially available devices, the *OlfacTest*, the *OlfaCom* and *OlfaMag* [41]. These systems are based on a fan blowing air through a scent cartridge made from scented polymer material.

V. HAPTIC TECHNOLOGY

Haptic technology enables natural interaction of a user with virtual objects in a 3D scene. Basic types of interaction in the 3D scene are: (1) navigation (movement of camera); (2) object selection; (3) object manipulation. Haptic technology can be used for interaction with objects in a virtual scene for two purposes: (1) sensorial feedback; (2) objects control.

Depending on a device used for interaction, kinaesthetic, tactile or vibration feelings can be involved into the interaction process. Sensorial feedback adds new dimension to computer-based learning environments, because a learner obtained one more channel of information exchange with the virtual world: the learner can discover weight of the virtual object, feel its surface features, and interact with the object physically.

In the simplest case haptic technology supports manipulation virtual objects without any sensual feedback. However even such simplification gives additional value, because it makes interaction of the user with virtual objects more natural: a learner can "take", move, rotate objects in the virtual world – in this way the learner can get information about these objects.

Haptic devices can be classified according to a number of features. In particular haptic devices can be divided into two groups by a degree of touch sense involvement: devices with feedback and devices without feedback.

The devices with sensorial feedback allow the user to feel force feedback, tactile feedback or vibratory feedback and in this way they involve extra sensorial channels for better information perception. Depending on their features devices with sensorial feedback can be referred as haptic displays, tactile displays, and haptic interfaces [1, 2].

Fig. 7. PHANTOM Omni® Haptic Device [3]

In particular a haptic display is a mechanical device for transfer of kinesthetic or tactile stimuli to the user [1]. The haptic display can be used for formation in the user some specific motor skill by restricting user's movements to predefined path. There are two types of haptic displays [1]: (1) impedance displays; (2) admittance displays. An impedance display is a device that measures movement and display force. In a contrary, an admittance display is a device that measures force and display movement.

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A haptic device that can be considered as a haptic display is PHANTOM Omni haptic device (Fig. 7). It allows the user to touch and manipulate virtual objects and feel their physical features, in particular weight.

A tactile interface is a device that enables user's interaction with an object in a 3D scene by providing a user with tactile feedback in order to let the user feel surface features, e.g. roughness of the surface.

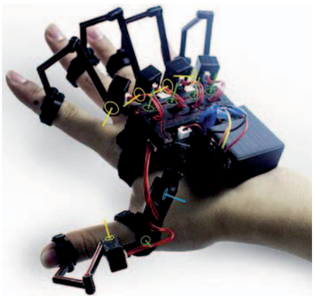

Fig. 8. Dexmo On-hand Exoskeleton [4]

A haptic interface [2] is a device that allows the user to interact with the 3D environment performing objects manipulation and exploring their properties by receiving force or tactile feedback. An on-hand exoskeleton Dexmo (Fig. 8) designed by Dexta Robotics is an example of the haptic interface [4].

The purpose of the devices without feedback is to enable objects manipulation in the 3D scene: they allow the user to select, move, rotate, and zoom objects. 5DT data glove (Fig. 9) is an example of such device [5]. The data glove is used for registration of the user's fingers movement and in this way it enables natural form of interaction with objects. The data glove should be used in combination with a tracking sensor, which can be mounted on the wrist. The 6DOF tracking system registers the hand position in 3D space while build-in sensors at fingers register motion of each specific finger.

Fig. 9. 5DT Data Glove [5]

The tracking sensors are based on ether optical or electromagnetic principle. Optical sensors can be videometric, IR-based, and laser ones. Electromagnetic sensors are AC-driven (driven by alternating current), DC-driven (driven by quasistatic direct current), and passive (based on localization of permanent magnets) sensors.

Fig. 10. 3RD Space Vest [6]

Haptic devices can be also classified by their design. There are stationary and wearable devices. Stationary haptic devices can be either desktop solutions like PHANTOM Omni® (Fig. 7) or ground-based devices.

Wearable devices are mostly on-hand and on-body ones. On-hand devices are exoskeletons (Fig. 8) and data gloves (Fig. 9). On-body devices are VR (virtual reality) suits, tactile vests and exoskeletons. 3RD Space Vest designed by TN Games [6] is an example of a tactile vest. It is developed for gaming and enables tactile feedback during the game.

Thus, haptic technology is supported by a number of devices, which enable involvement of sensorial feelings of a user as well as allow the user to interact naturally with virtual world. This opportunity can be used for the development of immersive learning environments, where the learner have freedom to touch, take, and manipulate objects as in the real world, and in this way get information necessary for learning.

VI. CONCLUSIONS

Immersive technologies open new opportunities for the development of educational multimedia systems of a new generation. Existing devices for both capture and rendering of virtual scenes, which include 3D images, 3D sound, olfaction, and haplics, enable to endow a learner with new sensory effects and in this way turn the learning into an exciting activity.

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