Immersive Virtual&Augmented Reality - Education and Autism Research

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Abstract. We present a complex Virtual Reality and AR architecture for 360º content delivery designed to create closed-loop interactive experiences modulated by real-time measurements. We demonstrate the effectiveness and usability of our solution in three use cases covering basic scientific studies that focus on socially capable humanoid robots in an AR application, collective assessment of mood, comparative evaluation of smartphone-based HMD devices, and postural control training with visual feedback in Autism.

Introduction

Immersive Interactive Reality is a form of virtual content presentation for research, where 360º panoramic imagery, 3D computer model environments, Augmented Reality tools and digital virtual humans [1,2] are combined for seamless interaction in virtual experiences, while biofeedback measurements and validated psychological tests are used to qualitatively assess user performance and reactions to the experience itself. The key challenge lies in the fact that "simulation of reality (VR) strongly relies on the adequate selection of specific perceptual cues to activate emotions. Emotional experiences in turn are related to presence, another important concept in VR, which describes the user's sense of being in a VR environment." [3]. Additionally, recent results indicate that the use of *wider fields of view* in visual displays, *stereoscopic visuals* and increased levels of *user-tracking* are some of the most significant factors to increase the effectiveness of a mediated experience. [4]. The resulting *emotional engagement*, in turn, is a key factor of success in educational applications [5], where the digital literacy and visual culture of a young and mobile generation requires almost cinematic presentation techniques and applications to run on smart phones and portable projection systems that can be quickly set up and operated in any environment.

In this paper we introduce an integrated research framework that addresses these challenges simultaneously in a modular architecture, and show how it is being used in specific scientific experiments via independent user studies. Fig. 1 summarizes the key elements of our solution which includes:

- Socially capable virtual humanoid robots with advanced photo-realistic facial animation (to support increased *emotional engagement* – Fig.1/Left),
- Smart-phone based Augmented- and Virtual Reality interface for content presentation (to support *stereoscopic visuals* and advanced *user tracking* – Fig.1/Center), and a
- Portable surround projection system with real-time biofeedback (to support *wider fields of view* – Fig.1/Right) to engage peripheral vision and effect the balance system.

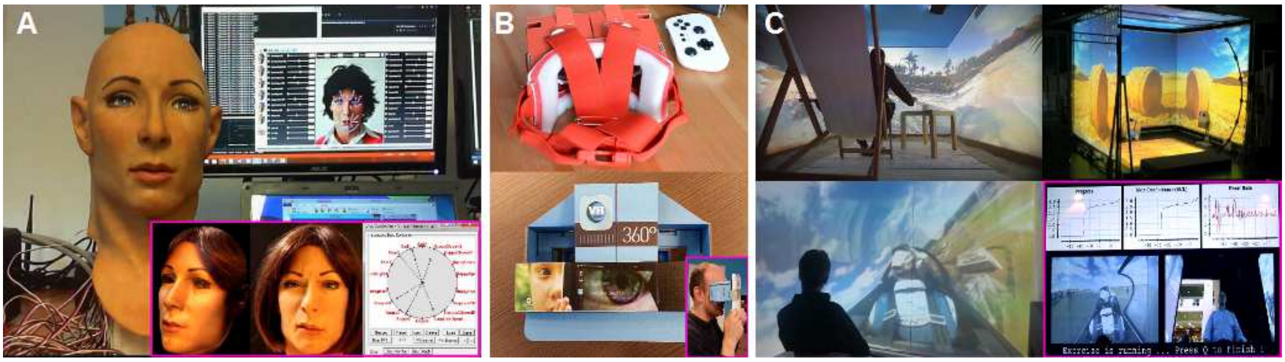

Figure 1. Summary of key elements of our system: **A)** Socially capable FACE robot and its photo-realistic digital 3D model controlled by our Temporal Disc Controller mechanism, **B)** Smartphone-based Augmented Reality viewers (HMD and tablet [6]) **C)** Portable low-cost surround projection system with biofeedback and tracking module for immersive experiences and experiments.

We demonstrate the use and effectiveness of our platform via three use cases, as detailed in the following sections. Specifically, our first example involves socially capable robots (Expressive Agents for Symbiotic Education and Learning - EASEL[7]), where we have developed a control architecture to support seamless interaction between physical robots as well as their virtual avatars with users carrying out a learning task. Augmented Reality (AR) is also part of that solution, whereas the virtual robot models can be perceived and interacted with via the head mounted viewers (see Fig 1. above) and the smartphone AR application.

In order to establish the effectiveness and usability of these new generation of low-cost HMD solutions that recently became broadly available on the mass-market and affordable by most average users, our second use case involves a comparison study of these devices. These devices and 360 content as well as AR modules, still face multiple rendering challenges [8] that would have to be addressed both from technical and psychological aspects. Finally, the 3D rendering and balance measurement capabilities of our system have been used in basic research to show that balance training with visual feedback improves deficient postural control in children with Autism [9].

Socially Capable Virtual Robots for Education (UseCase#1)

Using our framework above we have developed a unified modular control architecture that combines two types of physical robots (*FACE* [10] and *Zeno* [11]), and their virtual representations with active perception in order to drive low- and high level reactive behaviors for supporting educational and pedagogical goals. The model involves a “black box” architecture, where independently operating elements were glued together via a message-exchange communication architecture (YARP), and provide input to our central module, called cascaded Temporal Disc Controllers (TDC). These TDCs represent emotions and body gestures in a normalized coordinate space that is independent of physical manifestations. As such, they are responsible for mixing low- and high level robot behavior commands to create an infinite set of responses from a small number of well designed key expressions with a certain degree of randomness thereby making reactions more “human-like”. Multiple TDCs are cascaded to create a complex behavior animation representation involving emotional reactions, body poses and complex gestures.

For the *FACE* robot we created a TDC for the emotion-space based on reference videos. This photo-realistic interactive model then was tested in a public event (a FORBES innovation conference) using an HTML5 on-line implementation. In the experiment, we asked visitors to set the virtual face (running on a tablet or phone) that best described their current mood and feelings about the event. They could do so by simply touching the screen and exploring the possibilities, and eventually submit their contribution to be added up as a measure of collective mood of the audience. To demonstrate the transformation capabilities of the TDC representation, the display system remapped this cumulative score in real-time onto another face of a fashion-model exhibited on large-format display, showing how the collective mood evolved over time (Fig 2.)

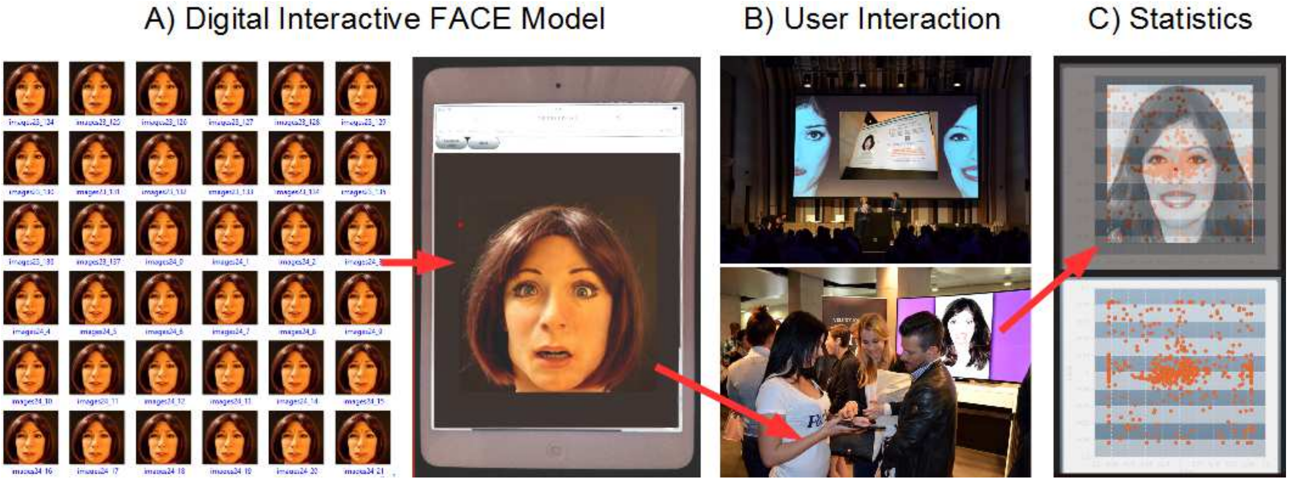

Figure 2. **(A)** The photo-realistic FACE robot model runs an HTML5 implementation of the TDC **(B)** Users input their emotions via touch-based interaction while the system collects 'votes' and shows - on another face - the collective mood of the audience on a large format display. **(C)** Research data is analyzed and visualized in real-time for statistics.

Key findings: Of the 878 people who have used the interactive system and casted their votes, not one could tell that the digital model was not showing a real person, but rather a robot, while all facial expressions used were correctly identified by these human observers. This psychologically validated the facial expression space of both the digital model and the robot.

For the *ZENO* robot we implemented the above multi-TDC mechanism for facial expression and body motion in *Unity3D* [7]. The YARP-based robot control architecture was designed to ensure that the virtual and physical robots are linked and move at the same time. Finally, an Augmented Reality module was also added to allow children and the robot to interact seamlessly in a pedagogical scenario. To do this, they would use their tablet devices (EASEL scope) or use a low-cost HMD with their own smartphone placed in it, where their head motion and other performance metrics are tracked, while real-time biofeedback regarding the internal physiological state of the user is measured via wearable devices, such as *FitBit* and *Apple Watch*. This is shown in Figure 3. The Zeno robot was designed with Autistic children in mind [11] and our plan is to further extend these robotic experiments to the realm of special education (see UseCase#3 below).

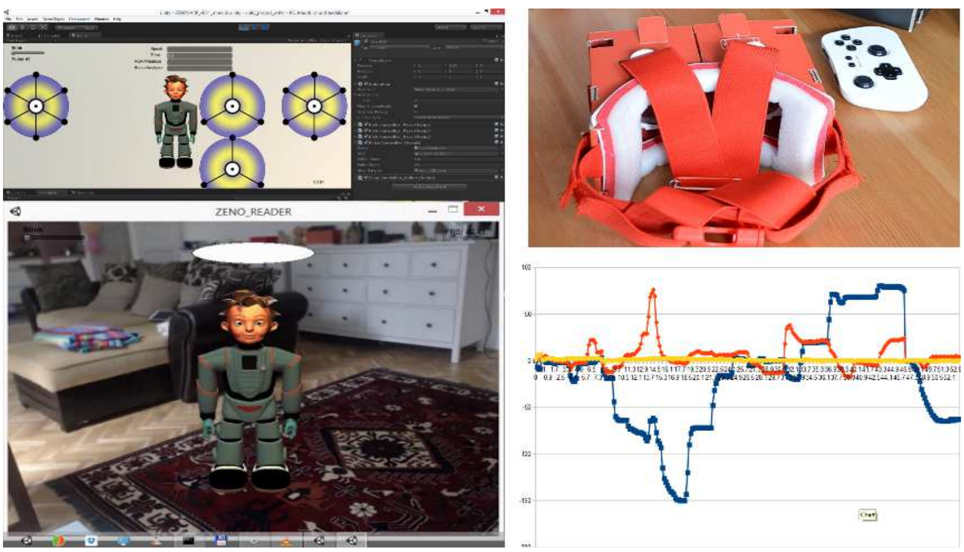

Figure 3. A socially capable robot ZENO is used in an Augmented Reality application as part of an EU research project on Expressive Agents for symbiotic Education and Learning.

Smartphone VR Headsets: A Comparative Evaluation (UseCase#2)

In recent years the accelerated development of computational and rendering power of smartphones have revolutionized the virtual- and augmented reality device market. While these solutions are already part of daily productions in event-based and entertainment applications, such as panoramic broadcasting [6], the prolonged use and effectiveness of these devices from a psychological and usability point of view still needs to be assessed especially for education and in the context of children with autism. At the same time, cost effectiveness and performance metrics are also important for business applications, where brand strengthening and loyalty are key elements. Here too reliable solutions that go beyond personal device setting, but rather can be administered to a large number of people in very short time-frames (e.g. a trade-show) needs to be delivered.

To assess the potential differences to be used in our EASEL Scope in a head mounted format in a double randomized trial we compared the performance of 5 commercially available HMD headsets that employ smart phones, specifically Samsung Gear with a Galaxy NOTE4 [12], Zeiss One [13], Homido [14], PanoCAST [6], Google Cardboard [15], respectively, with the latter 4 using an Iphone6 for the experiments. These are shown in Fig 4. Two of these devices are made of paper (show on the right with open flaps) offer a low-cost alternative to achieve for full immersion.

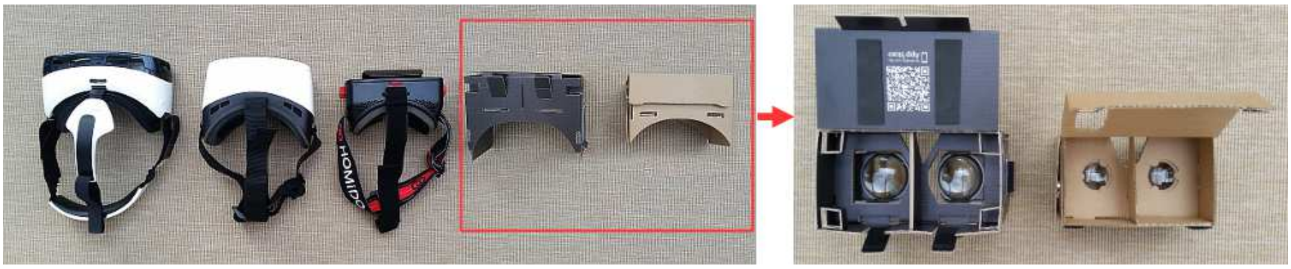

Figure 4. HMD VR devices used in our randomized evaluation study. From left to right Samsung Gear [12], Zeiss One [13], Homido [14], PanoCAST [6], Google Cardboard [15], respectively (see text).

28 subjects (age 16-25), 50% of which were university students and half went to high school with a 50/50 gender ration participated in a double randomized clinical trial. During these sessions participants were exposed to three 40 second (10 second blank + 30 second action) 360^{o} content pieces on three of the five devices shown in Fig 4. Both devices and 360^{o} content were randomly selected, the latter from a pool of five videos with matching “exciting” and “relaxing content. The PanoCAST player was used to present stimuli and track user head motion, while medical-grade biofeedback recorded their stress levels, heart rate, etc. In addition, each subject was asked to fill in a set of psychological assessment questionnaires (SCL-90, Presence,SUD,Fear).

Key findings: Users found no measurable difference in experiencing Samsung Gear, Zeiss One and the PanoCAST viewer. In the high end category, they preferred Zeiss One for ease of use and comfort, while Homido ranked last. In the paper viewer category PanoCAST ranked before Google's cardboard on all measured variables including wider field of view, comfort, stability/security of firmly holding devices and ease of use.

Autism and Learning Disability Research (UseCase#3)

Because visual cues also strongly affect balancing and in reverse these capabilities have been linked to learning and reading disabilities (ADHD, Dyslexia) and autism, our final study involved a set of stabilometer exercises implemented in our VR environment, but using simple visual and auditory feedback to limit the non-phenomena related factors. In a set of 3-phase experiments, children were first asked to stand still on the balance board (force platform) during 60s without performing any movement (Baseline Condition). Followed by a 60s familiarization period used to train them on how to use the apparatus and to ensure they understood the relationship of their movement to what was represented on the screen (Training), and finally the trials lasting 60s, during which we recorded children's postural performance (Visual Feedback Condition). For the experiments we recruited 18 high-functioning children with autism (H-F CWA) aged 6-11, and also 12 age-matched typically developing (TD) children. We assessed their IQs and subsequently measured their baseline postural stability and their ability to maintain balance when provided contingent visual feedback of the movements of their center of pressure. Postural performances were measured with the force platform while governing their center of pressure (CoP) and feedback system as described above.

Key findings: Firstly, our findings confirm the developmental origins of this deficit by showing that postural stability is reduced below 12 years of age in H-F CWA, even during quiet stance. Secondly, we provided new insight into postural instability by showing that it can be easily improved in a specific, facilitating environment, which in our case consisted of providing contingent visual feedback of the child's CoP movements. Thirdly, we found that postural instability was linked to IQ. Although H-F CWA in our study were all above clinical criteria for impaired IQ, we observed that H-F CWA who had an IQ between 80 and 100 produced greater SAs than H-F CWA with an IQ above 100.

Conclusion

We described a complex Virtual Reality 360º content presentation and measurement solution and demonstrated its effectiveness in three scientific studies. Our key findings indicate that such new generation VR and AR devices, as novel multi-media tools, can be very effectively used for scientific and education experiments to assess and even significantly improve learning performance.

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