Cost effective visualization of research data for cognitive development using mobile Augmented Reality

C. Onime
The Abdus Salam International Centre for Theoretical Physics (ICTP)
Trieste, Italy
onime@ictp.it

J. O. Uhomoibhi
Ulster University
Belfast, Northern Ireland
j.uhomoibhi@ulster.ac.uk

ABSTRACT

In many fields of science, the numerical output of research work require proper interpretation in relation to real world situations. Graphical visualization is often used to ensure better comprehension of data (research outputs) by researchers, learners and other stakeholders. However, in the modern era, large scale experimentation as well as computer-based simulations are generating massive amounts of numeric data that are almost impossible to visualize using traditional plots and graphs as they are limited in both dimensions and scale. Video has gained increasing popularity for presenting data due to its ability to convey motion and time. While, such video presentations are undoubtedly useful, they provide limited contributions to cognitive development. In this paper, we examine a cost effective use of mobile Augmented Reality (AR) in the visualization of scientific research data highlighting two use-cases that show the Three Dimensional (3D) semi-immersive and interactive environment in both educational and non-educational contexts.

CCS Concepts

•**Computing methodologies** → **Mixed / augmented reality;** •**Applied computing** → *Computer-assisted instruction;*

Keywords

mobile Augmented Reality; Computer Assisted Instruction

1. INTRODUCTION

Computers and other Information and Communication Technology (ICT) tools present information (data) using different media types and formats such as text, graphics, video and animations. For example, a simple hand-held computer device could present alphanumeric text such as the American Standard Code for Information Interchange (ASCII) characters on a monochromatic Liquid Crystal Display (LCD) digital display, while, the Personal Computer (PC) has evolved over the last three decades in their ability to present information in multimedia, that is using a mix of computer generated characters, graphics, animations or digital video, all on a color visual display unit.

AVI 2016 Bari, Italy
© 2016 ACM. ISBN 978-1-4503-2138-9…$15.00
DOI: 10.1145/1235

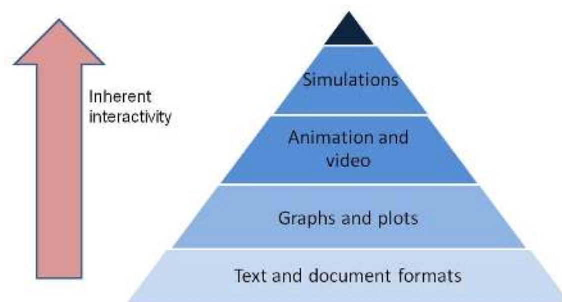

Figure 1: Information and digital-format relationship diagram. [28]

Figure 1 provide a visual comparison of the information carrying ability of different forms of (electronic) formats/media commonly used by computers and ICT tools in presenting data.

The "text and document" formats at the bottom of the pyramid (Figure 1) employs significantly more symbols in conveying the same amount of information as a graphical plot (image) and many images are needed to convey the same information as a video animation. In practical terms, Figure 1 implies that it requires significantly larger amount of text and graphs/plots to show (replicate) the volume of time-dependent data presented in an animation or audio /video fragment /clip. This is supported by the the current trend in on-line/distance learning, where Massive Open Online Course (MOOC) platforms favor the use of audio/visual clips and animations over traditional textual/image presentations for the delivery of knowledge (or voluminous information) to a vast audience of learners .

Researchers regularly employ computers and ICT tools in the acquisition, storage, processing and presentation of data[9, 11]. For example, data about real world events may be digitized by appropriate sensors during acquisition and stored on suitable media such as magnetic or optical media or other solid-state devices. A suitable computer application is then used to process data and perform functionalities such as checking for accuracy and also quantitative or qualitative analysis. During this stage, the data may be described, summarized (or reduced), compared to other datasets and/or prepared for interpretation. Subsequently, the processed data may be represented in one or more suitable formats for presentation. For example, tables or descriptive text be used may provide summary information about data, graphical representations are useful in providing an overview, while animations and videos are especially suited to conveying additional information such as motion, progress or movement. In this position paper, we use the term "research data" to describe the outputs obtained from a scientific investigation process.

General cognitive improvements may be derived from external stimuli such as drinking caffeinated beverages, the use of prescription medication or other suitable operant conditioning[37]. In most academic institutions, transfer of knowledge and cognitive development, that is encouraging intellectual reasoning and creating knowledge or know-how occurs within preset environments such as a classroom for face-to-face teaching/learning or on-line learning platforms. Sometimes, during classroom lessons, the display of video or animation are included as part of some active learning processes, while the earlier mentioned MOOCs and other on-line environments simulate cognitive development in both non-formal and formal learning context. Indeed, when learning with objects such as research data, the academic reasoning process is highly simulated by interactivity such as human-to-human [21] communication and/or other forms of interactivity[28]. It may be said that the contributions to cognitive development become significantly enhanced when learning objects such as research data are presented/studied with interactivity.

Researchers are increasingly tasked with studying and understanding systems with increased complexities or sometimes in dimensions (scales) that are difficult to achieve experimentally. Often, the solution is the use of simulations that allows them to explore in details the item or situation under study. Within a simulation, the researcher can quickly effect variations and with minimum delay, obtain the resulting output for subsequent analysis[10]. Simulations are important tools in scientific research as they also enable researchers to predict, test and understand systems before attempting to building them[22]. In general, the output of simulations require interpretation (and visualization) for proper or adequate relation to real world situations.

In different domains of science, physical experiments such as the LHC (CERN, Geneva), Genome related sequencing and planned SKA, are already producing massive volumes of data. Research output from both simulations and physical experiments have increased exponentially in volume (and dimension) thanks to the demand for increasing complex simulations as well as the need to study and analyze things with higher fine-grain resolutions. Graphical visualization of voluminous or large or big datasets for research is becoming increasing challenging even when it is often the only useful means of ensuring better comprehension of otherwise numeric data. In addition, deriving adequate cognitive development from these outputs requires the ability to interact with and explore the data to a much higher level or degree. As shown, in Figure 1, some presentation formats such as simulations permit higher levels of inherent interactivity.

This paper presents a technique for the visualization of research data with higher interactivity. The rest of this paper is organised as follows, section 2 discusses a mobile scope for Augmented Reality technology in relation to Virtual Reality. Section 3 presents the visualization of research data using mobile Augmented Reality in the form of two use-cases. Section 4 concludes this paper after presenting the future work.

2. BACKGROUND

Virtual Reality (VR) and similar emerging technologies have demonstrated superiority over the traditional Human Computer Interface (HCI) of an alphanumeric keyboard and Visual Display Unit (VDU) with a pointing device (mouse)[31]. Broadly speaking, VR as a technology seeks to facilitate 3D interactions with a computer in new ways. In VR, the goal is to completely replace the real (physical) environment around a user with a computer generated or virtual one, where the user is still able to perceive and interact with objects using the human senses of sight, sound and touch as suitable haptic devices allow users to touch surfaces, grasp and move virtual objects as well as obtain feedback/reactions from them[36, 6].

In scientific research, VR systems have reportedly been used in the simulation of complex (multi-user) systems, in fast or slow time and with a high degree of interactivity[10, 34]. The 3D computer-generated environment provided by VR allows users to interact at various levels in a more natural manner using interface devices and peripherals such as 3D eye-wear and trackers[10]. In main-stream computing, aspects of VR related research such as voice and gesture based computing are allowing computers and ICT devices to use audible instructions and complex sequences of motion as inputs. In this section, we discuss a VR related technology known as Augmented Reality and its cost effective deployment on mobile platforms.

Augmented Reality (AR) is defined as the real-time integration of virtual (computer-generated) objects and information into a three dimensional real world environment[26, 5]. Visually, AR may be considered as a form of VR in which the user has a clear (transparent) view of the real world. However, unlike in VR, where the goal is to completely immerse the user in the virtual environment, the goal in AR is to blend the virtual objects into the real world in order to enhance or compliment the real world objects and provide a semi-immersive or a window-in-the-world kind of experience. Just like VR, AR is not limited to the visual domain as augmentation is possible in the audible or haptic domains. For example, audible sound with spatial effects may be used to indicate direction, that is, sound effects growing louder (in intensity and volume) as the hearer approaches may be used to show correct direction[41].

In AR, the combination of real/virtual objects into a seamless view and management of all interactions (between real and virtual objects as well as between end-user and virtual objects) happens in real time.

There are several examples of the use of AR and related technologies for cognitive development. For example, it has been used to study human behaviour[14], reconstruction of heritage [17], teach specific procedures to pilots, doctors and operators [30, 29, 16, 33], simulate experiments in chemistry[15], visits to museums and historic buildings [39] and visualization of complex organs within the human body as well as for medical training [1]. An AR application was used to interactively study web-based 3D model of piston in mechanical engineering[20]. Another example involved the use of head mounted (see-through) AR viewer to augment a normal story book providing a 3D animated view of the characters from the story book[8]. In all these examples, the use of AR and/or related technology stimulated cognitive development (prior knowledge[32] and academic engagement[35])and eliminated the associated risks involved with studying them in real world situations.

In this paper, we consider only see-through[5] AR, where real world view of the surrounding environment (obtained from a live video feed or camera-sensor) is shown directly on the display medium as this is the predominant form on mobile or portable devices.

2.1 Cost effective mobile AR

AR and related technologies has always been considered expensive, due to their use of highly specialized equipment such as display walls, specialized projection devices, head-mounted displays (HMD), back-pack computing platforms and other custom equipment[11, 26, 24]. In this work, the term mobile AR is limited to cover only its use on portable consumer grade ICT devices such as smart-phones/tablets and their specialized peripherals such as head or chest mounting units, glasses and watches. That is, we focus on commodity mobile devices such as smart-phones and tablets and achieve cost effectiveness by eliminating the use of custom (expensive) hardware and equipment[13].

Mobile AR on smart-phones rely on the in-built loudspeaker(s), display-screen and the ability to vibrate for auditory, visual and haptic augmentations respectively, while input (and feedback from user) may be derived from a rich array of sensors such as microphone, multi-touch input (display), camera, location (gps), accelerometer, ambient light sensor[13]. Also, touchscreen enabled smart-phones/tables devices allow input in the form of gestures and movements that enhance the ability to interact. For example, an expanding two-finger motion is commonly used to achieve a close-up or zooming-in effect. Improvements in mobile-device technology in areas such as vision, interfacing[18] and sensor accuracy are also readily translated to improvements in mobile AR.

Developing AR enabled applications on mobile platforms has been simplified by the availability of standard Application Programming Interfaces (API), libraries, frameworks and Software Development Kits (SDK). The latter offers a hardware-abstracted solution in form of a high-level API that can compensating for many types of problems[23]. For example, the free Android SDK provides manufacturer independent tools and interfaces for programming or developing software for all smart-phones running the Android Operating System[12], while also addressing inconsistent hardware behavior even for commons problems such as poor camera resolution due to distance, motion blur and poor lighting/contrast situations. The free android SDK already contains some 3D/image-processing functions, however other more specialized AR libraries are commonly used[19, 40].

Mobile AR have been used for experiments in electronics[27], power[25] and communications engineering[26], while mobiles devices have been employed in the processing and display of data[12].

3. VISUALIZATION OF RESEARCH DATA

A visionary look at computing suggests a future where multiple devices seamlessly collaborate to improve our everyday life. While the growing use of interactive surfaces on devices such as laptops, smart-boards, car entertainment / navigation systems, fitness monitoring devices and of-course smart-phones / tables, is a step in this direction, it is clear that their integration is hardly seamless as data is still largely bounded to individual applications, devices and services. For example, in the entertainment industry, thanks to the advent of on-line video streaming services, users can enjoy playback or viewing on multiple devices and sometimes with the ability to interactively change camera/viewing angles limited to selected devices.

As discussed in preceding sections, the interactive visualization of data enhances the ability to stimulate cognitive development and application in research environments have largely focused on room-scale visualization using Computer Assisted Virtual Environments (CAVEs) based on the VR philosophy of a completely virtualized environment. A modern room-scale environment, the Wall-sized Interaction with Large Datasets (WILD) room is presented in [7]. Where a wall-sized display is combined with a multitouch table and various mobile devices specifically to help scientists collaborate on the analysis of large and complex datasets. It was envisioned that the WILD room could be used by a group of microbiologist (co-located in the WILD room) to study how one molecule docks with another and interactively and seamlessly switch between several 3D representations, different molecular models, online databases, websites and research articles along with the ability to collaborate with remote colleagues[7].

Creating, programming and operating a room-scale interactive environment for research comes with challenges in developing software application for multi-surface or distributed interactions and rendering as well as obtaining content from multiple sources. Commodity mobile (smartphone and tablet) devices provide a single display environment with multitouch capabilities that is relatively easy to programme. In this section, we discuss the use of mobile AR for presenting research data and provide as examples two specific use-cases: the interactive and immersive visualization of abstract quantities and geophysical data.

Apart from cost effectiveness discussed in section 2, several recent improvements in AR such as the ability to use normal (arbitrary) objects as augmentation marker, advanced tracking of objects, photo-realistic rendering and automatic re-dimensioning of objects contribute to making mobile AR well suited for the visualization of research data.

3.1 Visualization of abstract quantities

Understanding the wireless transmission of signals requires studying the propagation of electromagnetic radiation. Typically, this is carried out using antenna radiation plot(s), which is the (3D) representation of the magnitude, phase and polarization of the electromagnetic field around an antenna. The plot(s) are equally applicable during either transmission or reception. Figures 2 and 3 shows the radiation plot of a 10-element yagi antenna in polar and rectangular coordinates respectively.

It is clear that Figures 2 and 3 are difficult to interpret and relate to real-world situations and so hands-on practical activity in a laboratory environment is common used to enhanced cognitive development. However, even within laboratories, it is not possible to visualize the radiation of electromagnetic waves and understanding their interactions is usually based on numerically computed or derived values obtained from field strength sensor readings. Apart from

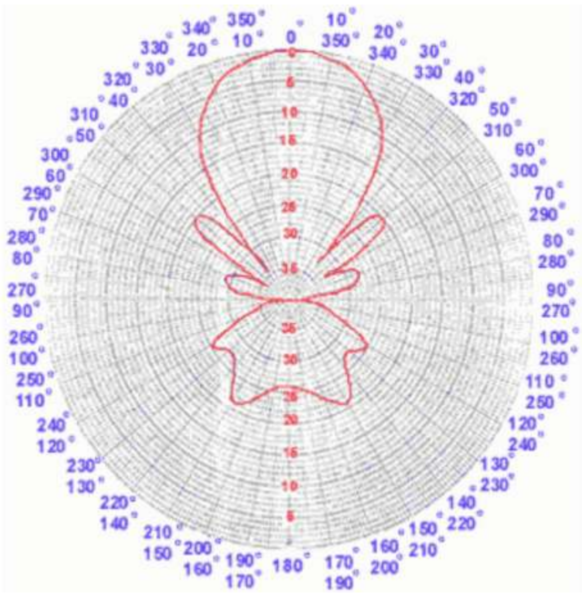

Figure 2: Polar plot of radiation pattern. [42]

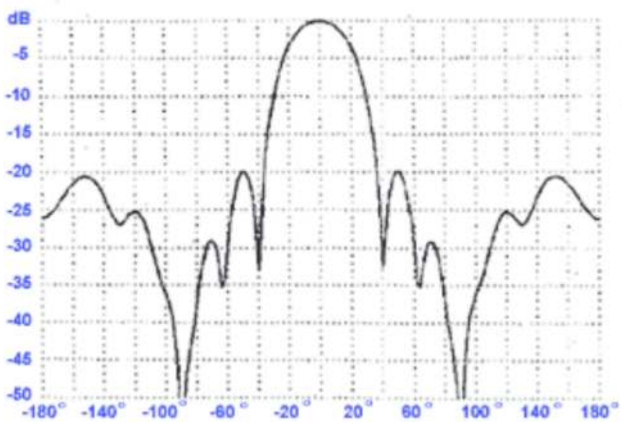

Figure 3: Rectangular plot of radiation pattern. [42]

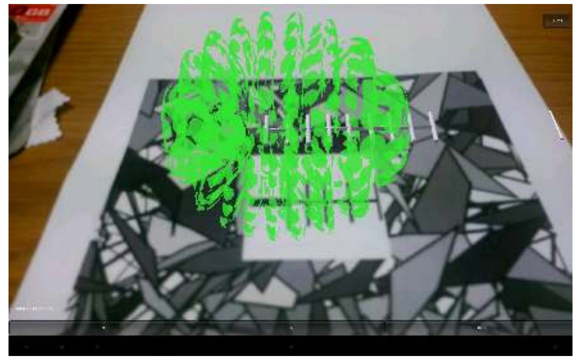

Figure 4: AR 3D visualization of antenna radiation pattern[26].

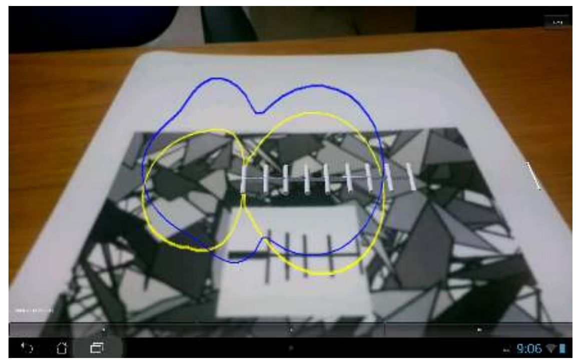

Figure 5: AR 2D visualization of antenna radiation pattern.

hands-on laboratory experiments, computer software applications/tools exist for the simulation of antenna patterns. Most of these tools produce numerical output and graphical views based on radiation plots, some are capable of generating 3D plots with limited interactivity.

Figures 4 and 5 shows the 3D and 2D view of the radiation pattern from a 9-element yagi antenna as produced by a mobile AR application developed as part of a joint collaboration between the Ulster University (UU) and the International Centre for Theoretical Physics (ICTP). In figure 5, the light coloured line is the horizontal plane, while the dark coloured line is for the vertical plane.

The same application was used for the visualization of three different datasets generated from numerical simulations with the 4nec2[38] software tool; each dataset represented a different type of antenna. The application automatically selected the right datasets based on the recognition of a corresponding AR marker (see Figure 6 for spider antenna) and also included additional contextual controls for interactively changing several parameters including angle of grounding plane, diameter, number of elements and operational frequency, the resulting change in radiation patterns are immediately visible[26].

During viewing, the 3D model dataset ensures researchers can immersively explore the realistic radiation pattern interactively, scaling (zoom) by simply moving the mobile device closer to the marker. The ability to switch between 2D and 3D stimulated better comprehension of antenna radiation patterns and even understanding of the associated plots.

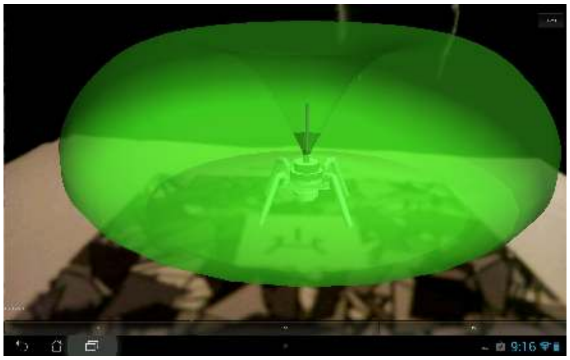

Figure 6: AR 3D visualization of spider antenna radiation pattern[26].

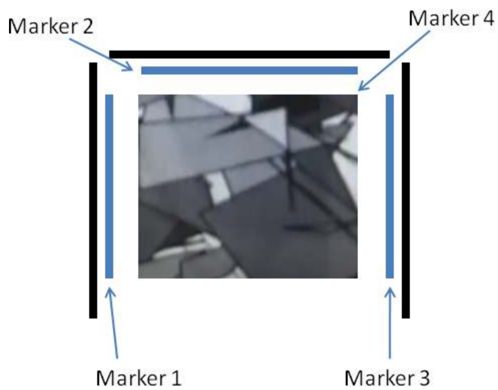

Figure 7: AR immersive cubicle.

3.2 Visualization of geophysical data

During the formation of young researchers in the field of Earth System Physics, they are often faced with studying various land formations and the ability to actually visualize these landforms contributes to their cognitive development.

Figure 7 shows the AR immersive cubicle jointly developed for 3D viewing of geophysical data by Santa's Co (a software development company from Reggio Emilia, Italy), the UU and the ICTP. The semi-immersive AR environment (cubicle) is composed of four markers, while three markers were positioned vertical, the fourth was placed horizontal to provide a 180 + 90 degree seamless exploratory view of the landforms created from data. That is, 180 degree radius in the horizontal direction and 90 in the vertical direction.

Figure 8 and 9 shows horizontal and vertical view of the landforms using a mobile (tablet) device.

The AR cubicle was used at ICTP for the 3D semi-immersive exploration of research data by researchers and also showcased at the 2013 Teachers day event, held at UNESCO headquarters, Paris [2, 3].

3.3 User feedback

Anonymous feedback on the first-time use of the mobile AR visualization tool (first use-case) was obtained from 150 learners from the Obafemi Awolowo University, Nigeria and the Addis Ababa University, Ethiopia. The consenting adult volunteers, who participated without incentives, risks and disadvantages in the international study were informed of the purpose, confidentiality of the study and the intended use of the collected data. Over 90% of the sample population were from various disciplines of natural sciences and engineering. About 74% were undergraduate students and only 19% were female. Although, the mean age was between 21 - 24 years, about 70% of respondents were also first-time users of VR and AR technologies.

Participants selected from a 5-scale Likert responses to closed questions on if the AR tool helped their studies or if they became confused after using th AR tool.

The feedback obtained from show that over 50% of respondents found the visualization provided by the AR tool helped their studies, only 19.33% found the AR tool confusing and in both questions, 20% and 27% of the respondents were not sure. Additional feedback about the mobile AR CAVE like cubicle was obtained during a public event. The invited dignitaries and high school students provided positive comments on the efficacy of the cubicle for tourism and learning.

The results presented in this section are limited to the specific cognitive tasks / scope described in the use-cases and although based on self-assessments by users, they suggest a

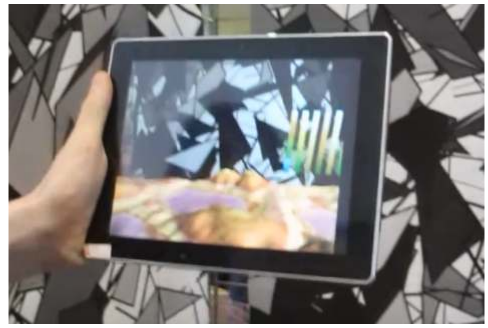

Figure 8: mobile AR horizontal view of immersive cubicle.

Figure 9: mobile AR vertical view of immersive cubicle.

Table 1: Was the AR tool helpful to your study?

Response	%
No	18.12
Don't think so	7.38
Can't say	20.81
Somehow	24.83
Definitely	28.86

Table 2: Did you find the AR tool confusing?

Response	%
No	35.33
Don't think so	18.67
Can't say	26.67
Somehow	14.00
Definitely	5.33

positive contribution to cognitive development.

3.4 Strengths and weaknesses

The visualization of research data could potentially improve and change practices when it is used for navigation through a single large object such as a gigapixel image of deep space; comparison of large numbers of related images, for example brain scans; juxtaposition of a variety of heterogeneous forms of data from different sources, that is, tables, formulas, graphs, photographs and video clips; and for remote collaborative exploration[7].

In both use-cases presented in this paper, mobile AR provides increased interactivity that enabled richer contextually viewing of datasets. The visualization experience is semi-immersive on mobile devices and fully immersive when they are combined with suitable head-mounts. This immersive visualization of datasets enhanced contextual understanding and cognitive development.

The use of AR on commodity ICT devices is cost effective as hardware are readily affordable/available to all and developing corresponding software could be cost-free. Software development is simplified as the application interface was deliberately kept simple to avoid overloading the learner with too much concurrent/contextual information which could harm the cognitive development process[1].

Mitigating two well-known limitations of mobile device involved keeping ambient lighting at normal room levels so learners are not faced with poor visibility on mobile device screens due to strong lighting[13] and addressing the dependency on rechargeable batteries for energy to function required the provision of suitable cables for charging mobile devices as well as factoring in a 20 minutes period for battery charging of user devices prior to activities.

The limited display/screen size allows only a windowed view of dataset(s), with total size (of all datasets) limited by the storage capacity of individual devices. Complex gestures or movements involving two-hands is not yet possible as learners hold the mobile device in one hand and can only perform gestures with the other hand. The current versions of the mobile AR applications have limited support for group-use or visualization.

4. FUTURE WORKS AND CONCLUSIONS

The Artificial Intelligence and Applications Research Group at Ulster University is setting up an Experience Lab, which will include the deployment of cost effective Augmented Reality (AR) cubicles (or CAVEs) at Ulster University and the ICTP. Both groups will investigate creating fully-immersive AR environments using suitable head and chest-mounted mobile devices, this will allow researchers enjoy a 360 immersion exploration of datasets and possible allow the use of both hands for gestural interactions.

Various techniques for dynamically streaming fragmented data to mobile devices will be studied as a way of overcoming limited capacity of mobile devices.

Group work over the internet is also planned for collaborative visualization of research data using mobile AR. Here, two or more researchers in different geographically separate locations can jointly examine and interactively explore research data.

Finally, coordinated data distribution and visualization over local wireless mesh networks would be investigated for group work and visual-experiential presence during videoconferencing meetings.

Apart from the above described activities, we foresee the immersive interactive exploration of various datasets from diverse sources within the "Experience Lab". For example, geospatial datasets of existing locations (or cities) could be used to provide interactive remote exploration and tourism related experience. Other datasets derived from Internet of Things (IoT) or other sensors could be used for the interactive exploration and study of otherwise inaccessible locations including underground caves, coral reefs or other seabeds and even in some mining related activities.

4.1 Conclusion

This paper has examined a cost effective use of mobile Augmented Reality (AR) in the visualization of scientific research data. Two use-cases are presented that show the use of a 3D semi-immersive interactive environment provided by mobile AR including a CAVE like AR cubicle, along with some evidence of contribution to cognitive development. While both use-cases showcased applications in the academic domain, the "Experience Lab" at the Ulster University, Belfast is positioned to research and improve on the application of mobile AR technology for diverse kinds of immersive/experiential academic and non-academic applications including augmented-videoconferencing, augmented-tourism and augmented-mining etc.

5. ACKNOWLEDGMENTS

The authors acknowledge the contributions and support of the School of Computing, Ulster University; the Telecommunications and ICT for Development (T/ICT4D) Laboratory, ICTP and Santa's Co, Regio-Emilia, Italy.

6. REFERENCES

[1] U. Albrechta, C. Nolla, and U. von Jan. Explore and experience: Mobile augmented reality for medical training. In C. U. Lehmann, C. Ammenwert, and C. Nahr, editors, *MEDINFO 2013: Studies in Health Technologis and Informatics vol 192*, pages 382–386, Copehegen, 2013. IMIE & IOS Press.

[2] Annaffismo Innanzitutto [ilsantass]. Santa'S Co. & ICTP at World Teachers Day 2013 - UNESCO - Paris - AR Cave - Part 1. Retrieved from: http://www.youtube.com/watch?v=Gr4_zuMl_qM, October 2013. [Accessed 15 November 2013].

[3] Annaffismo Innanzitutto [ilsantass]. Santa'S Co. & ICTP at World Teachers Day 2013 - UNESCO - Paris - AR Seeduino Board - Part 2. Retrieved from: http://www.youtube.com/watch?v=rxFM__7ZA8c, October 2013. [Accessed 15 November 2013].

[4] W. Aung, V. Llic, O. Mertanen, J. Moscinski, and J. Uhomoibhi, editors. *Innovations 2012: World*

Innovations in Enginnering Education and Research. iNEER, Potomac, 2012.
[5] R. Azuma, Y. Baillot, R. Behringer, S. Feiner, S. Julier, and B. MacInTyre. Recent advances in augmented reality. *IEEE Computer Graphics and Applications*, 21(6):34–47, 2001.
[6] C. Basdogan, C.-H. Ho, M. A. Srinivasan, and M. Slater. An experimental study on the role of touch in shared virtual environments. *ACM Trans. Comput.-Hum. Interact.*, 7(4):443–460, Dec. 2000.
[7] M. Beaudouin-Lafon, S. Huot, M. Nancel, W. Mackay, E. Pietriga, R. Primet, J. Wagner, O. Chapuis, C. Pillias, J. Eagan, T. Gjerlufsen, and C. Klokmose. Multisurface interaction in the wild room. *Computer*, 45(4):48–56, April 2012.
[8] M. Billinghurst, H. Kato, and I. Poupyrev. The magicbook - moving seamlessly between reality and virtuality. *IEEE Computer Graphics and Applications*, 21(3):6–8, 2001.
[9] E. Canessa and M. Zennaro. A mobile science index for development. *Internatiional Journal of interactive Mobile Technologies*, 6(1):4–6, 2012.
[10] J. Cecil. The creation of virtual learning environments. In Aung et al. [4], pages 263–273.
[11] M. Davidsson, D. Johansson, and K. Lindwall. Exploring the use of augmented reality to support science education in secondary schools. In *Seventh international conference on Wireless, Mobile and Ubiquitous Technology in Education*, pages 218–220. IEEE Computer Society, 2012.
[12] S. Fiawoo and R. Sowah. Design and development of an android application to process and display summarised corporate data. In *Adaptive Science Technology (ICAST), 2012 IEEE 4th International Conference on*, pages 86–91, Oct 2012.
[13] E. FitzGerald, A. Adams, R. Ferguson, M. Gaved, Y. Mor, and R. Thomas. Augmented reality and mobile learning: the state of the art. In M. Specht, M. Sharples, and J. Multisilta, editors, *11th World Conference on Mobile and Contextual Learning (mLearn 2012)*, pages 62–69, Helsinki, 2012. CEUR.
[14] J. Fox, B. Arena, and J. N. Bailenson. Virtual reality: A survival guide for the social scientist. *Journal of Media Psychology*, 21(3):95–113, 2009.
[15] J. Georgiou, K. Dimitropoulos, and A. Manitsaris. A virtual reality laboratory for distance education in chemistry. 1(11):337 – 344, 2007.
[16] S. J. Henderson and S. Feiner. Evaluating the benefits of augmented reality for task localization in maintenance of an armored personnel carrier turret. In *Proc. IEEE ISMAR-AMH*, pages 135–144. IEEE, 2009.
[17] Y. Huang, Y. Liu, and Y. Wang. Ar-view: An augmented reality device for digital reconstruction of yuangmingyuan. In *Proc. IEEE ISMAR-AMH*, pages 3–7. IEEE, 2009.
[18] J. Kilby, K. Gray, K. Elliott, J. Waycott, F. M. Sanchez, and B. Dave. Designing a mobile augmented reality tool for the locative visualization of biomedical knowledge. In C. Lehmann, C. Ammenwert, and C. Nahr, editors, *MEDINFO 2013: Studies in Health Technologis and Informatics vol 192*, pages 652–656, Copenhagen, 2013. IMIE & IOS Press.
[19] S. L. Kim, H. J. Suk, J. H. Kang, J. M. Jung, T. Laine, and J. Westlin. Using unity 3d to facilitate mobile augmented reality game development. In *Internet of Things (WF-IoT), 2014 IEEE World Forum on*, pages 21–26, March 2014.
[20] F. Liarokapis, N. Mourkoussis, M. White, J. Darcy, M. Sifniotis, P. Petridis, A. Basu, and P. F. Lister. Web3d and augmented reality to support engineering education. *World Transactions on Engineering and Technology Education*, 3(1):11–14, 2004.
[21] S. J. McMillan, M. G. Hoy, J. Kim, and C. McMahan. A multifaceted tool for a complex phenomenon: Coding web-based interactivity as technologies for interaction evolve. *Journal of Computer-Mediated Communication*, 13(4):794–826, 2008.
[22] P. F. D. Moeller, A. Drews, and G. Selke. Micro-magnetic simulations in research-based engineering education. In Aung et al. [4], pages 1–15.
[23] A. Mutholib, T. Gunawan, and M. Kartiwi. Design and implementation of automatic number plate recognition on android platform. In *Computer and Communication Engineering (ICCCE), 2012 International Conference on*, pages 540–543, July 2012.
[24] C. Onime and O. Abiona. 3D mobile augmented reality interface for laboratory experiments. *International Journal of Communications, Network and System Sciences*, 09(04):67–76, 2016.
[25] C. Onime, J. Uhomoibhi, and E. Pietrosemoli. An augmented virtuality based solar energy power calculator in electrical engineering. *International Journal of Engineering Pedagogy*, 5(1):4–7, Jan 2015.
[26] C. Onime, J. Uhomoibhi, and S. Radicella. Mare: Mobile augmented reality based experiments in science, technology and engineering. In M. T. R. Restivo, A. Cardoso, and A. M. Lopez, editors, *Online Experimentation: Emerging Technologies and IoT*. IFSA Publishing, Barcelona, Spain, Dec. 2015.
[27] C. Onime, J. Uhomoibhi, and M. Zennaro. A low cost implementation of an existing hands-on laboratory experiment in electronic engineering. *International Journal of Engineering Pedagogy*, 4(4):1–3, Oct 2014.
[28] C. E. Onime and J. O. Uhomoibhi. Using interactive video for on-line blended learning in engineering education. In *Experiment@ International Conference (exp.at'13), 2013 2nd*, pages 128–132, Sept 2013.
[29] R. O'Toole, R. Playter, T. Krummel, W. Blank, N. Cornelius, W. Roberts, W. Bell, and M. Raibert. Assessing skill and learning in surgeons and medical students using a force feedback surgical simulator. In W. Wells, A. Colchester, and S. Delp, editors, *Medical Image Computing and Computer-Assisted Interventation — MICCAI'98*, volume 1496 of *Lecture Notes in Computer Science*, pages 899–909. Springer Berlin Heidelberg, 1998.
[30] R. Pausch, T. Crea, and M. Conway. A literature survey for virtual environments: Military flight simulator visual systems and simulator sickness. *Presence: Teleoper. Virtual Environ.*, 1(3):344–363, July 1992.
[31] F. Rodigues, F. Sato, L. Botega, and A. Oliveira.

Integration framework of augmented reality and tangible interfaces for enhancing the user interaction. In *Virtual and Augmented Reality (SVR), 2012 14th Symposium on*, pages 100–107, May 2012.

[32] D. Schmalstieg and D. Wagner. Experiences with handwith augmented reality. In *6th IEEE and ACM International Symposium on Mixed and Augmented Reality*, pages 1–13, Japan, 2007.

[33] B. Schwald and B. de Laval. An augmented reality system for training and assistance to maintenance in the industrial context. In *Proc. Int. Conf. Comput. Graphics, Visualiz. Comput. Vision*, pages 425–432. IEEE Computer Society, 2003.

[34] B. Sobota, S. Korecko, and F. Hrozek. Mobile mixed reality. In *Emerging eLearning Technologies and Applications (ICETA), 2013 IEEE 11th International Conference on*, pages 355–358, Oct 2013.

[35] K. Squire and E. Klopfer. Augmented reality simulations on handheld computers. *Journal of Learning Sciences*, 16(3):371–413, 2007.

[36] H. Tan and A. Pentland. Tactual displays for wearable computing. *Personal Technologies*, 1:225–230, 1997.

[37] J. van Erp, F. Lotte, and M. Tangermann. Brain-computer interfaces: Beyond medical applications. *Computer*, 45(4):26–34, April 2012.

[38] A. Voors. 4nec2 antenna modeler and optimizer. Available from: http://www.qsl.net/4nec2/, October 2012. [Accessed 8 January 2014].

[39] M. White, N. Mourkoussis, J. Darcy, P. Petridis, F. Liarokapis, P. Lister, K. Walczak, K. Wojciechowski, W. Cellary, J. Chmielewski, M. Stawniak, W. Wiza, M. Patel, J. Stevenson, J. Manley, F. Giorgini, P. Sayd, and F. Gaspard. Arco - an architecture for digitization, management and presentation of virtual exhibitions. In *Computer Graphics International*, pages 622–625, Crete, 2004. IEEE.

[40] C. Xiao and Z. Lifeng. Implementation of mobile augmented reality based on vuforia and rawajali. In *Software Engineering and Service Science (ICSESS), 2014 5th IEEE International Conference on*, pages 912–915, June 2014.

[41] P. Zahorik. Assessing auditory distance perception using virtual acoustics. *Journal of the Acoustical Society of America*, 111:1832–1846, 2002.

[42] M. Zennaro and C. Fonda. *Radio Laboratory Handbook*. ICTP - The Abdus Salam International Centre for Theoretical Physics. Available from http://wireless.ictp.it/handbook/Handbook.pdf, 2004.