A Virtual and Augmented Reality course based on inexpensive interaction devices and displays

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Abstract

In the last years a plethora of affordable displays, sensors, and interaction devices has reached the market, fostering the application of Virtual and Augmented Reality to many new situations. Yet, creating such applications requires a good understanding of the field and specific technical skills typically not provided by current Computer Science and Engineering education. This paper presents a graduate level course offered to MSc Programs in Computer and Electrical Engineering which introduces the main concepts, techniques and tools in Virtual and Augmented Reality. The aim is to provide students with enough background to understand, design, implement and test this type of applications. The course organization, the main issues addressed and bibliography, the sensors, interaction devices and displays used, and a sample of the practical assignments are briefly described. Major issues are discussed and conclusions are drawn.

1. Introduction

Virtual Reality (VR) and Augmented Reality (AR) have currently a broad range of applications in entertainment, industry, medicine or marketing, among others, and never before has the technology been so affordable. As a consequence, a rapid growth of VR and AR use in many more situations is to be expected. Yet, developing such applications requires an understanding of the field and specific technical skills typically not provided by current Computer Science and Engineering education, even if VR as well as AR courses may be considered natural complements of Computer Graphics education [Z06].

This paper describes the main aspects of an elective, graduate level course on Virtual and Augmented Reality offered twice at the University of Aveiro (at the first semesters of 2013-14 and 2014-15) simultaneously to MSc Electrical and Computer Engineering students. While presenting the topics addressed and the main bibliography, the emphasis is on the computer laboratory equipment and the practical activities and assignments.

The rest of the paper is organized as follows: section 2 addresses related work concerning VR in education and education in VR; section 3 briefly presents the course organization, topics addressed, and main bibliography; section 4 describes the hardware and software used for demos as well as practical assignments, and shows examples of successful students assignments; issues, conclusions and ideas to improve future editions of the course are presented in the last section.

2. Related work

Virtual Reality has been shown to have the potential to enhance education [DB09] [D09], and inexpensive sensors, displays and interaction devices have been used in education and training in various ways. Several authors describe how they have been taking advantage of current affordable VR technology to improve the education of computer science and engineering students at their own institutions [AAW11] [C08] [CRCB*09] [HA14] [SP13], in what circumstances VR should be used in education and training in general [P09], and how to use it to create knowledge and solve complex problems in a group framework [MUH10]. On the other hand, Augmented Reality is also considered as offering promising perspectives for science education [DB09]. A study involving Computer Science, Information Systems, and Design students [SP13] suggests that the participants were motivated and interested in developing AR systems, mainly for entertainment, using desktop and Android platforms; nevertheless, the complexity of programming languages and system architectures were viewed as challenging.

While Virtual and Augmented Reality being considered as promising tools in education is an interesting motivation to use them with students, we focus on how to include these technologies in the *curriculum* of the Computer and Electrical Engineering programs we offer; yet, we found not as many papers on this subject. Actually, this may reflect a relative scarcity of specific courses, and possible reasons might be the little room available for additional topics in current *curricula*, as well as a lack of faculty expertise and adequate equipment [C08].

G. Burdea, the coauthor of one of the first textbooks meant to support a VR course, made an informal worldwide survey (updated in 2008[1]) and concluded that as of 2004 the vast majority of universities offered no such courses and suggested that the cost of adequate laboratories might be an important reason [B04]. Yet, according to this author, even then that should no longer have been the case as VR technology had evolved dramatically in the previous years entailing an increase in performance and a decrease in prices. *A fortiori*, at present this should not preclude offering courses in the field as a variety of low cost sensors, interaction devices and displays has reached the market, and a laboratory to adequately support VR/AR courses may have a cost affordable to most universities.

Meanwhile, several authors have described the VR/AR courses they lecture and offer advice on how to organize such courses, albeit having different approaches. We briefly mention the ones that have been more useful to design our own course.

Stansfield [S05] presents an elective course offered to Computer Science students having already some Computer Graphics background. The course is aimed at providing an introduction to Virtual Reality, as well as an opportunity to incorporate capstone elements that allow undergraduate students to apply many computing skills they have acquired in other courses. The course includes a lecture-based component and a hands-on experimental component. The latter component is an on-going, semester-long team project, based on an open software platform developed at Sandia National Laboratories, as well as on a software platform developed in-house. According to the author, demos of some of the more traditional display devices (such as a CAVE) are valuable. During their project teams build a complete VR system having access to specific Virtual Reality H/W, as head-mounted displays and trackers.

Zara [Z06] describes a course mainly based on VRML for students having already a background in Computer Graphics (CG). He contends that VR education fosters a better understanding of real-time 3D graphics and the tradeoffs between image quality and rendering speed. Students' assignments evolve from simple 3D scenes to complex, interactive virtual environments. Most students attending this course rated its usefulness high and its difficulty as medium; however, a strong negative correlation between the perceived difficulty and the students' CG background was observed, suggesting that a VR course may be viewed as a natural extension to CG education, as the author claims.

Cliburn [C06] integrates Virtual Reality concepts at the end of the introductory Computer Graphics course, and his students develop simple VR applications as a final practical assignment based on an in-house toolkit for multi-monitor graphics programming. According to the author, these projects were "immersive, interactive, and certainly imaginative, satisfying Burdea and Coiffet's three I's of virtual reality … contained a virtual world, immersion, sensory feedback, and interactivity, fulfilling Sherman and Craig's definition as well".

[1] http://vrtechnology.org/resources/public/survey.html (on-line December, 2014)

Häfner et al. [HHO13] describe how they teach a practical course in Virtual Reality for graduate and undergraduate students in diverse engineering fields (namely, mechanics, mechatronics and electrical engineering, computer sciences, physics and engineering management) combining lectures, demos, and practical classes. The course is based on state-of-the-art hardware and software, yet it also gives students the possibility to work with low-cost equipment. The authors started by using 3DVIA Virtools[2] as software platform, having as main advantages the documentation and a visual programming paradigm; however, there was no large users community, manual configuration of VR hardware was complex, and the costs for licenses were high. Eventually, they developed their own VR engine. The course is focused on fostering learning about VR by simulating interdisciplinary industrial projects and students' projects are developed by multidisciplinary teams. According to the authors, the most important factors for the course success are a careful design of the students' projects; a group configuration and task assignment according to the students' background; using an open source, well documented, and actively used software platform; and (last but not least) updating lectures and labs to keep the students motivated.

Our course was designed to be adapted to the context of our department educational offer and taking into account the experience presented by these authors. It was designed to be attended by last year Computer Engineering and Electrical Engineering graduation students, which implies starting by an introduction to Computer Graphics to ensure a minimum understanding by the latter. Students were given the possibility to propose their own projects (e.g., related to their MSc dissertation). The course was also planned to make use of recent and affordable VR equipment, as well as open-source simple software (no complex and difficult to setup frameworks), the goal being not just modelling but actually understanding the whole process necessary to create a virtual environment.

3. Course organization, topics, and bibliography

The course is organized in 14 three-hour weekly sessions, each session typically comprising a lecture, a demo, a paper presentation by a student or group of students, and a lab class. In this section we briefly describe the topics addressed in the lectures and lab classes, as well as the main bibliography.

Slides and further material concerning the practical assignments may be found at the course web page: http://sweet.ua.pt/bss/disciplinas/RVA/RVA-home.htm.

Topics addressed

As the course is offered to last year students of the Computer Engineering MSc (EC) and the Electrical Engineering MSc (EE), who have different backgrounds and programming skills, some homogenization is needed, namely concerning Computer Graphics fundamentals and graphics programming libraries, which are new to EE students and may work as a recapitulation for EC students providing an opportunity to better understand basic concepts.

[2] http://www.3dvia.com/products/3dvia-virtools/ (on-line December, 2014)

The main topics addressed in the lectures are:

- Introduction to VR and AR, historical perspective, overview of the main issues, applications and challenges;
- Rendering the virtual world;
- Physical modelling of the virtual world;
- Frameworks;
- Input and output devices;
- Camera models and calibration;
- User-centred design; interaction in VR/AR;
- Human factors; guidelines for VR/AR applications.

The computer laboratory classes are divided in two main blocks. The sessions in the first half-semester focus on 3D creation, visualization and interaction with virtual worlds using VTK as the main graphics engine. The remaining laboratory sessions deal with Augmented Reality: first an introduction to camera calibration, a central problem in AR, is done using OpenCV and teaching students the basics of camera calibration using a chessboard pattern. Then the ARToolkit is introduced to provide contact with an AR application. In the last session, the ARToolkit is adapted to run with VTK: with such an update students can develop AR applications without the need to learn an additional graphics engine.

VTK was chosen as the main graphics engine, despite some limitations when compared with other engines such as OGRE, OpenSceneGraph or the more recent Unity, due to its flexibility and large range of application in visualization. However, VTK does present some limitations, namely regarding multiple texturing, creating difficulties when students try to generate more complex 3D worlds.

Main bibliography

One of the difficulties in offering a VR/AR course is the bibliography. While there are some books which are very useful to help define a course structure and support the history, principles and guidelines that should be addressed, VR/AR science and technology is rapidly evolving and every year new trends and devices appear, thus a constant update is needed. To stay current, we have been relying on conference and journal papers, as well as vendors' sites for the technical characteristics of new hardware.

The following books were used as main bibliography:

Grigore Burdea, and Philippe Coiffet, *Virtual Reality Technology*, 2nd ed., Wiley-Interscience, 2003.

Doug Bowman, Ernst Kruijff, Joseph LaViola Jr. and Ivan Poupyrev, *3D User Interfaces, Theory and Practice*, Addison Wesley, 2005.

Alan Craig, William Sherman, Jeffrey Will, *Developing Virtual Reality Applications, Foundations of Effective Design*, Morgan Kaufmann, 2009.

Alan Craig, *Understanding Augmented Reality, Concepts and Applications*, Morgan Kaufmann, 2013.

Mario Gutiérrez, Frederic Vexo, Daniel Thalmann, *Stepping into Virtual Reality*, Springer, 2008.

John Vince, *Introduction to Virtual Reality*, Springer, 2004.

Borko Furht (ed.), *Handbook of Augmented Reality*, Springer, 2011.

William Schroeder et al., *The VTK User's Guide 11th Edition*, Kitware inc., 2010.

Gary Bradsky, Adrian Kaehler, *Learning OpenCV*, O'Reilly, 2008.

The books by Burdea & Coiffet, and Bowman et al. have been used to structure the course and are recommended as the main bibliographic references for the topics addressed in the lectures. The book by Craig et al. approaches Virtual Reality mainly from the point of view of the design and implementation of applications and includes interesting in-depth application case studies. The book by Craig presents fundamental concepts in the design of applications, mainly addressing AR as a medium and is recommended as an introduction to Augmented Reality. The books by Gutiérrez et al., and Vince are suggested as introductory references to Virtual Reality, since they provide an easy to read motivating overview of the field. The books by Schroeder et al. and by Bradsky & Kaehler have been used as references for specific topics and examples used in laboratory classes. The handbook edited by Furht addresses technologies and applications and its chapter 1 is recommended as a brief outline of Augmented Reality issues, applications, and challenges.

The proceedings of the IEEE Virtual Reality (IEEEVR) conference, the IEEE Symposium on 3D User Interfaces (IEEE3DUI) and the International Symposium on Mixed and Augmented Reality (ISMAR) have been providing most of the papers for student presentations. These presentations guarantee that students have access to cutting edge research work, since they have to select and propose the papers they are interested in reading and presenting to the class.

4. Hardware, software and practical assignments

The course has a hands-on approach and thus it must be supported by a suitable laboratory and a set of assignments meant to help students acquire the understanding and the specific technical skills needed to create VR/AR applications. In the following, hardware and software used, as well as some of the more successful assignments developed by students are briefly presented.

Hardware and software

The laboratory classes, demos and assignments were based on a set of (mostly inexpensive) sensors, displays and interaction devices we have been acquiring over the past years:

- Oculus Rift, version 1 and 2 (http://www.oculus.com/)
- VR2000 Head-Mounted Display (HMD)
- Intersense Inertia 3 Orientation sensor
- Wiimote
- InertiaCube BT (www.intersense.com/pages/18/60/)
- Razer Hydra (http://sixense.com/razerhydra)
- Leap Motion (https://www.leapmotion.com/)
- Google Cardboard (https://cardboard.withgoogle.com/)

- Kinect version 1 and 2 (http://www.microsoft.com/en-us/kinectforwindows/)

The laboratory set-up cost, including the latest version of each device, is about 3.500 €. However, it is interesting to note that most of the budget was used to buy the less recent equipment (VR2000, Intersense). The latest devices – Kinect, Cardboard, Oculus Rift, Razer Hydra, and Leap Motion – all together cost less than 1.000 €, a budget we deem very reasonable to set up a laboratory allowing the development of a wide range of motivating and instructive applications.

Usually, in academic contexts, paying for the software licenses to develop VR and AR applications is problematic and thus the course laboratory classes and programming assignments are based on free, open-source software, namely VTK, OpenCV, and the ARToolkit, available freely for non-commercial use, the main disadvantage of this approach being the relatively reduced documentation available and the lack of support for more complex or recent devices [B04], which make the final assignments more challenging.

Examples of successful assignments

Along the course, students (organized in groups of two) have to carry out two assignments. The first assignment is related to Computer Graphics and virtual world creation and modelling. The goal of the second assignment is to motivate the use of the available input/output devices in order to create engaging VR/AR applications, with a focus on the user interaction with the virtual environment. Whenever possible, students are encouraged to regard the second assignment as an extension of the work done in the scope of the first one. A different list of possible assignments is provided each semester; however, students may propose their own work, for instance related to their MSc dissertation subject.

In the first assignment students are supposed to consolidate the issues addressed in the first laboratory sessions. Given their diverse background, students may have different knowledge and skills; for instance, Computer Engineering students have already attended a Visual Computing course based on OpenGL and OpenCV. The use of VTK allows introducing a different library and revisiting the main CG topics necessary to handle a virtual world. Thus, the first assignment reintroduces the main CG concepts while guiding the use of VTK. After attending those laboratory sessions and submitting the first assignment, students should be familiar with: 3D transformations, camera and lighting control, object and illumination properties, rendering options, and textures. Some time is also dedicated to interaction in 3D, through the use of callbacks and widgets. Manipulation of polygonal meshes and cutting/clipping operations are also addressed. Students are also introduced to other kinds of 3D data representations (e.g., unstructured grids, 3D volumetric grids).

The second assignment is less guided and implies selecting the interaction techniques to be used, as well as the most adequate devices, and then analysing and integrating the devices to enhance the interaction with the virtual environment.

Here follows a list of some of the assignment proposals:

- Configuration of a virtual museum/environment.
- 3D environment for music creation
- Visualization of 3D Skull data
- Visualization of atmospheric data
- 3D visualization of boreholes and 2D images of seismic data
- Visualization of sound reflections in a room
- Simple modelling of university campus buildings using basic shapes and texture
- 3D sculpting environment/carving software
- Modelling of shapes from point clouds
- Study and exploration of a possible engine to be used in VR/AR
- 3D immersive scenario /game/ visit
- Using of Oculus Rift with VTK
- Interaction with objects in virtual environments
- Using natural markers to create an AR demo to publicize our department
- VR application to allow cutting a data set manipulating a real plane
- Interactive floor

Some of the more successful assignments developed in the past two years are presented in the following.

Application for quick 3D modelling of simple rooms from 2D floor plans

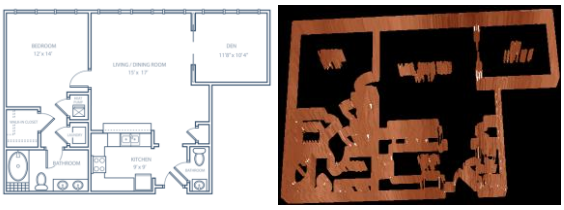

Figure 1: Original 2D floor plan and extruded 3D model

The objective of this assignment was to produce an application for quick 3D modelling from 2D floor plans. The work involved some simple image processing, namely an Edge Detector that was implemented in VTK. The results of the edge detection were extruded in order to create a 3D representation with a given height. The application also allowed refining the edge detection results by changing the Canny edge detector thresholds in real time. Finally, some texture was applied to the final 3D extruded model, as seen in Figure 1 with a 2D house plan as input.

Interactive 3D environment for music creation and playing

This assignment involved the development of a 3D world with several 3D widgets that can be used for music creation/modulation. The created environment allowed the activation of several instruments and corresponding soundtracks while interacting with 3D widgets. Several 3D models of music instruments freely available in the Internet in different formats (coming from Sketch-up, Blender or 3DS max) were integrated. Also several frames with posters from artists were located on the walls (see Figure 2). Users could freely select instruments to reproduce some sounds. Alternatively, the selection of a frame would trigger the animation of a flying CD towards a radio and the following

streaming of a music from the selected artist. The 3D world and interaction were based on VTK, and FMOD was used for sound streaming.

Figure 2: Guitar and radio in the VE environment. Clicking on a frame triggers the flying CD animation.

3D visualization software for the robot soccer team CAMBADA

One of the students of the 2013/2014 edition was a member of the robotic soccer team of the University of Aveiro – CAMBADA (Cooperative Autonomous Mobile roBots with Advanced Distributed Architecture). He wished to create 3D visualization software that might be integrated within the current team console to replace the 2D view being used. The first assignement focused on the visualization (Figure 3). Besides displaying the field and robots, it might be used later during games to display additional information for debugging (such as heat maps with the results of algorithms running on the agents).

The work was further developed in the second assignment to allow an Augmented Reality module based on the ARToolkit and VTK. With this module the user can interact with the world by pointing a camera to a marker (see Figure 4) and test interactively the algorithms running on the robotic agents. The optical centre of the camera can be used as a pointer for data input (e.g., the 2D location of another robot).

Figure 3: 3D robotic soccer console with a 3D visualization of the field.

Figure 4: AR interaction with the CAMBADA console interface.

Virtual interaction with a real environment

This project was aimed at evaluating the possibility of using a Kinect, an HMD (VR2000), and an orientation sensor to detect the position of a user in a real environment and allow him/her to move in a 3D enhanced replica or the environment. As an example, a section of a corridor of our department was modelled using Sketch-up and texture mapped with real photographs (see Figure 5).

In addition to modelling, the students developed a communications module of communication the Kinect. In the final demo, a user can move freely in the modelled section of the corridor, while seeing the 3D replica of the corridor in the HMD. The camera orientation was mapped using an InertiaCube BT orientation sensor, and the head position was given by the skeleton tracking algorithm of the Kinect. A future evolution of this work, with several Kinects (to enlarge tracking space) might be used to allow moving in a real environment while exploring an enhanced version of the room (for example a virtual enhanced museum, mapping the geometry of a real room).

Figure 5: 3D model of a section of our department.

Augmented promotional material of our department

This proposal adapted AR examples based on the ARToolkit to allow an AR visualization of buildings using a natural marker, namely the flyer of our department (see Figure 6). In a first stage, the students modified the ARToolkit to allow mapping of VTK models (instead of OpenGL) using several models developed in the first assignments. The second part of the work involved image

processing to replace the AR marker by a natural marker (the image of a flyer). Some experiments were done using OpenCV for camera calibration and marker detection (using SURF); however the achieved refresh rates were slow for real use.

Figure 6: IEETA building on a natural marker.

Study of AR tools for mobile platforms and examples

A student proposed to evaluate and test AR tools available for mobile platforms. In addition to a general analysis of available tools, some examples were developed using AndAR and Metaio. Figure 7 presents a game developed using Metaio. The user selected a surface where the physics of the game would take place. The user could then control a character with his/her finger to avoid meteorites that roll on the surface at different speeds.

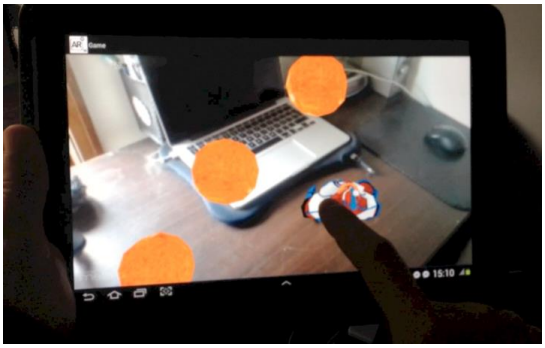

Figure 7: Meteorite avoiding game on an Android tablet using Metaio

Exploration of Google Cardboard

In this project, students were challenged to explore the capabilities of the Google Cardboard and its SDK, creating an application using a mobile phone and Google Cardboard.

Figure 8: Google Cardboard (https:// cardboard.withgoogle.com)

Students started by exploring the SDK, however using it would involve low-level OpenGL programming that was outside the scope of the course. They came up with an alternative: using three.js (http://threejs.org/). This option made easier the use of WebGL (since three.js is a high level library built over WebGL), and solved many compatibility and installation issues, since three.js runs on a browser. As final demo, students developed a simple 3D environment with texture and illumination. In the environment textured cubes with artists album covers are displayed (see Figure 9: Google Cardboard demo environment.). The gyroscope is used to detect head orientation and play music according to the album the user is looking at.

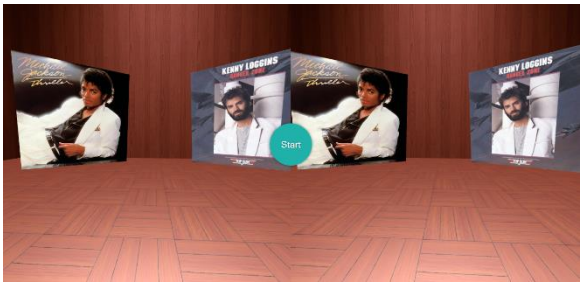

Figure 9: Google Cardboard demo environment.

Oculus Rift Lens distortion

In this assignment students were asked to study the Oculus Rift lens distortion and image generation rules in order to create a “plug in” for Oculus Rift rendering of VTK projects. The idea was to make possible the use of Oculus with any other assignment developed within the course. Students had to investigate the Oculus Rift SDK and the lens distortion. Their work allowed to define two virtual cameras in VTK providing off-line rendering. The distance between the cameras is set accordingly to the Oculus parameters that are read through the SDK. The two images are then distorted using the lens distortion equation from the devices. Finally both images are merged into a single image that can be visualized in the Oculus Rift (

Figure 10). The main limitation of the work was the low refresh rate (around 4 Hz) since all the computation and image lens distortion were computed in the CPU.

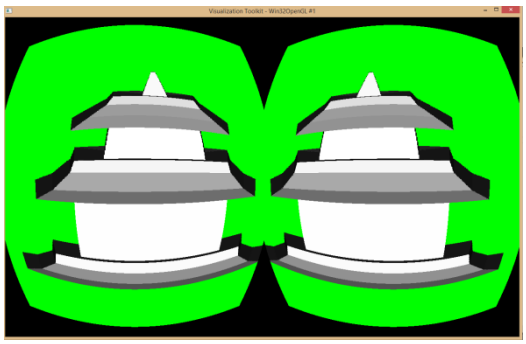

Figure 10: Rendering of a simple model using VTK and considering Oculus Rift distortion

5. Discussion and Conclusions

The Virtual and Augmented Reality elective course was offered twice, in a competitive course offering scenario, and it worked with its maximum student capacity (15 students). At the end of the first edition (in January 2014) we applied a questionnaire to gather some feedback from the students. The general feedback was positive; most students enjoyed the course and found the topics and assignments interesting and relevant. The main complaints were related to the amount of workload associated with each one of the courses they attended during the semester, resulting in a few students devoting significantly less time to the assignments than expected. This was clearly visible in some assignments, as students did not commit the time that was planned. The grades were coherent between both assignments, with two groups (4 students) clearly below average.

In the first edition of the course, a lecture was allocated to present demos of all the available hardware. Some students suggested spreading these presentations/demos along the entire semester. In the second edition this presentation was spread among several sessions, with a short presentation of a different device, between the lecture and the laboratory session; however, we still have mixed feelings about the best way to present the equipment so that all the students have enough contact with it, both to understand the potential and limitations of each type, and to be able to select the one they should use in their assignments.

One of the major problems we felt was the difficulty to find a VR platform flexible enough to easily integrate all the VR devices available, and thus most assignments used drivers from the vendors. A system based on VRJuggler and OpenSceneGraph was developed [SDS14] as a possible platform for the course, nonetheless its installation complexity and the lack of support for recent hardware prevented us from using it in the course. We are considering the use of more recent tools, such as Unity 3D [JKAH14] for future editions, yet further analysis is necessary since this solution also presents several drawbacks given that Unity 3D is a commercial platform and might reduce flexibility for use in some projects (e.g., involving data visualization), which has been a clear benefit of VTK. On the other hand, such a tool might ease virtual world creation, resulting in more realistic and complete assignments that might also be more rewarding for the students.

While deciding what software platform to use and the creation of challenging, motivating, and feasible assignments are currently major issues in the design of a Virtual and Augmented Reality course implying trade-offs, we believe that the real challenges are directly related to the nature of this course: the careful balance between design principles and technological information, as well as the need of a constant update.

Acknowledgments

We thank all the students that attended the Virtual and Augmented Reality course and gave us their feedback concerning all aspects of the course. We thank in particular the students that developed the assignments presented as examples of what has been done using the interaction and display hardware. We are also grateful to Sérgio Eliseu and Mário Vairinhos, for making a demo of the Meta Glasses and to Hugo Nogueira for lending the Leap Motion sensor.

This work was partially funded by FEDER through the Operational Program Competitiveness Factors – COMPETE – by National Funds through Foundation for Science and Technology – FCT (references FCOMP-01-0124-FEDER-022682 and PEst-C/EEI/UI0127/2011), and by the Program "Partilha e Divulgação de Experiências em Inovação Didática no Ensino Superior Português" (84/ID/2014).

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