Augmented Reality Technology for Education

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1. Introduction

Nowadays, our educational institutions are frustratingly outmoded in terms of teaching students. The entire process of giving lectures, taking notes, reading facts from books, and taking final exams is a throwback to institutions of learning dating back to the Renaissance. Remarkably, very little has changed today: with notable exceptions, the vast majority of university professors continue to bore students with ineffective, non-interactive approaches to education that result in little more than the professor's notes becoming the students' notes without passing through the minds of either. True learning is experiential. Humans learn best by doing, not by reading or listening to lectures. The more senses are involved (sound, sight, touch, emotions, etc.), the more powerful the learning experience. That's why today's best teachers are those pioneering individuals who take the effort to engage their students in meaningful activities that reach students at multiple levels.

In this sense, augmented reality appears as an emerging technology that promises to make "educational immersion" available to practically everyone. Augmented Reality (AR) is a technology that permits to overlay computer graphics onto the real world. Unlike immersive Virtual Reality, AR interfaces allow users to see the real world at the same time as virtual imagery attached to real locations and objects. In an AR interface, the user views the world through a handheld or head mounted display (HMD) that is either see-through or overlays graphics on video of the surrounding environment. AR interfaces enhance the real world experience, unlike other computer interfaces that draw users away from the real world and onto the screen.

Through the use of advanced technology an empty space is turned into a very rich educational experience. AR interface is a visualization technology that can take advantage of the limitations offered by other visual means of communication for learning. Traditional methods of learning spatially-related content by viewing 2D diagrams create a sort of cognitive filter. This filter exists even when working with 3D objects on a computer screen because the manipulation of the objects in space is made through mouse clicks.

2. Augmented Reality

Augmented Reality (AR) is a recent technology that is similar to the Virtual reality (VR) paradigm. As is the case for virtual reality, several formal definitions and classifications for augmented reality exist (Milgram & Kishino, 1994). Some define AR as a special case of VR; others argue that AR is a more general concept and see VR as a special case of AR. AR combines 3-dimensional (3D) computer-generated objects and text superimposed onto real images and video all in real time. An interesting definition of AR has been described by Azuma (Azuma, 1997), as a variation of Virtual Reality. VR technology completely immerses a user inside a synthetic environment. While immersed, the user cannot see the surrounding real world. In contrast, AR allows the user to see the real world, with virtual objects superimposed upon or composited with the real world. Therefore, AR supplements reality, rather than completely replacing it. With AR applications it is possible to show to the user a common space where virtual and real object coexists in a seamless way. From a technological point of view AR applications must fulfil the following three requirements (Azuma, 1995): Combination of real and virtual worlds, real time interaction and accurate 3D registration of virtual and real objects.

Augmented reality applications can be used under several setups including monitor based systems, see-through and video-see-through head mounted displays (HMD) and projection based spatial augmented reality.

AR is a technique fields that have found applications in several areas like surgery (Shuhaiber, 2004), production and maintenance (Caudell & Mizell, 1992), edutainment (Beckhaus et al, 2003) and collaborative design (Navab, 2004).

2.1 Augmented reality and education

Since 1990 several VR systems dedicated for educational use have been described (Bell & Fogler, 1995), (Byrme, 1996), (Loftin qt al, 1993), (Winn, 1997). A good summary of educational applications can be found in (Mantovani, 2001).

ScienceSpace (Dede, 1996) is a collection of immersive virtual worlds for investigating kinematics, electrostatics and molecular structures respectively.

For Biology teaching the Project NICE NICE (Narrative-based, Immersive, Collaborative Environment) (Rousos et al, 1997) used a CAVE immersive system in which children can plant flowers, move clouds to water them or move the sun to make them grow master.

In the area of mathematics education CyberMath (Taxén & Naeve, 2001) presents an avatar-based shared virtual environment for improving mathematics education.

Virtual Reality Roving Vehicles (Rose, 1995) is designed as an outreach VR to children in schools. In (Rose & Billinghurst, 1995) they describe a 3D world for learning Japanese.

Finally, one of the most interesting project in our opinion is Construct3D that describes an AR system for geometry education (Kaufmann & Schmalstieg, 2003). From a technical point

of view, the system is based on the Studierstube (Schmalstieg, 2002) system that presents several capabilities for AR collaborative interaction.

3. The Hum-AR library

The Hum-AR (HuAR) is a C and C++ language software library that lets programmers easily develop Augmented Reality applications. Augmented Reality (AR) is the overlay of virtual computer graphics images on the real world, and has many potential applications in industrial and academic research.

3.1 Introduction
Hum-AR uses computer vision techniques to calculate the real camera viewpoint relative to a real world marker. This method can be divided in four parts:

1. Camera calibration.
2. Marker detection.
3. Calculation of marker position and orientation (pose estimation).
4. Augmentation of virtual object.

Hum-AR supports two different types of markers:
-   Template-based markers
-   ID-based markers 4x4 code words.
-   For a brief description of different markers types at the augmented reality environments, see (Fiala, 2004).
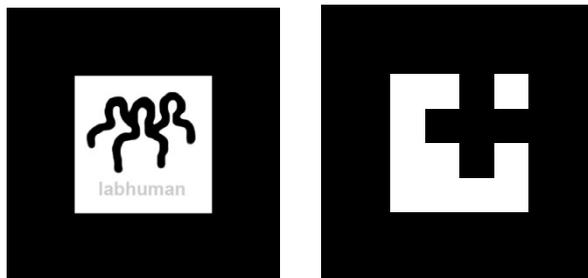

Fig. 1. Example of different types of markers supported by our library. Left: Template-based markers. Right: ID-based markers.

3.2 Camera Calibration
The first step for calculating the real camera viewpoint relative to a real world marker is a camera calibration for determining the camera's intrinsic parameters (camera's centre, focal length and distortion parameters).

For this purpose it is only necessary different captures of planar checkerboard patterns. For calibration step the library implements the Zhang's method (Zhang, 2000). The input of this algorithm is the   correspondence between 2D image points and 3D scene points over a

number of images and outputs the intrinsic camera matrix as well as the radial distortion coefficients and the scene points of the correspondence have to be in the same plane and to obtain a good result, this plane should be different for every calibration image.

3.3 Markers Detection
For marker detection is necessary to binarize the grab camera frame. It can be made in different ways:

 1) Using a fixed threshold.
 2) Using an adaptive threshold.

Using a fixed threshold is recommended under ideal circumstances, where the lighting and camera parameters are constant, the technique perform adequately for most tasks. But at the most cases the lighting conditions are different in each frame. In this case can using a method for automatic threshold value. The method used is based on Pintaric´s technique (Pintaric, 2003). Basically this algorithm operates on a per-marker basis and evaluates the mean pixel luminance over a thresholding region-of-interest. For a more detailed description see (More, 1978).

The next step is a marker contour detection. So the connected components must be extracted. Later the perimeter of each contiguous region of black pixels is traced to produce a chain representing an object border. A set of line segments are then fit to these points, so that all border pixels are within some minimum distance of a line segment. If the resulting polygon is sufficiently large and has exactly four sides, it is considered a candidate marker and passed on to the identification process. For stability reasons is necessary to refine the four landmarks localizations. This method iterates to find the sub-pixel accurate location of a corner, or "radial saddle point". It is based on the observation that any vector from q to p is orthogonal to the image gradient. The core idea of this method is based on the observation that every vector from the center q to a point p located within a neighborhood of q is orthogonal to the image gradient at p subject to image and measurement noise.

Following the pattern is normalized, it means, that we make perspective transformation of a square landmarks to unit square landmarks. The perspective transformation is applied to square ROI (See Figure 2) and the interior of the marker is extracted. At the next step is necessary to identify the interior of pattern. We use a different approach for a marker type. If use an ID-based marker, it must be designed in such a way that can be easily detected and be unique enough to be easily identified from others markers. Each marker must also provide some kind of hexadecimal code. This hexadecimal code fixed the marker orientation.

Fig. 2. Example of pattern normalization.

At Template-based markers a candidate image is compared to the known images in each of the four possible orientations. A variety of methods are possible for comparing images. The mean squared error (MSE) is a common measure of image similarity, particularly when measuring image degradation. For an MSE measure, small values indicate similarity. This approach is not luminance invariant, however. A better approach is the normalized correlation coefficient; at this approach the mean and standard deviations for the image and pattern are computed.

If the coefficient for one image is maximal for the image set and exceeds a fixed threshold (0.5), the image is accepted. This approach has got several disadvantages over the ID-based markers, the main is inter-marker confusion (false-positives and positives-false).

3.4 Markers Pose Estimation

HuAR use the Levenberg-Marquardt (Azuma, 1995) algorithm for pose estimation. The Levenberg-Marquardt algorithm (or LMA) provides a numerical solution to the problem of minimizing a function, generally nonlinear, over a space of parameters of the function. These minimization problems arise especially in least squares curve fitting and nonlinear programming.

3.5 Technical advantages of Hum-AR

HuAR presents several advantages over other AR libraries like for example ARToolkit. Among other it can be cited:

1. Different marker types (ARTollkit markers and ID-based markers).
2. Variable border width can be changed to use more area of the marker for pattern instead of the black border. This increases detection of very small markers. ID-based markers only support two types of border size (simple or double). In Template-based markers the border can have any size.
3. Variable pattern size at the Template-based markers, (e.g : 16x16, 32x32, 64x64,…)
4. Adaptive threshold for avoid illumination variations at the scene.
5. Oclussion of black border at the Template-based markers (Figure 3 (a)).
6. Graphical interface for camera calibration and pattern creation.
7. Less jitter than ARToolkit.
8. Support to infrared marker detection (Figure 3 (b)).
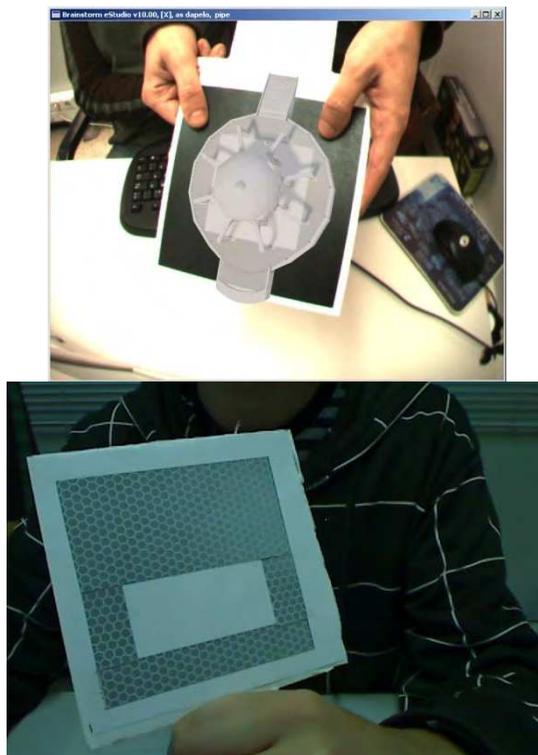
Fig. 3. (a) Left: Example of oclussion. (b) Right: ID-based markers with retro-reflective paper for supported infrared marker detection

4. Applications of Hum-AR

All three applications described below are developed over Brainstorm eStudio, an advanced, multiplatform real time 3D graphics presentation tool. In order to include augmented reality functionality in Brainstorm eStudio, a plugin has been developed in C++. This plugin incorporates detection and tracking options from our OTR library.

4.1 "Magic window" skeleton

This application simulates a system where a user can see his/her own skeleton through a "magic window". This system uses as main interface a handled palette, which is made with lightweight cardboard. This palette has two little parts at the bottom in order to stay perpendicular to the floor by itself. Moreover, two marks have been printed over it, one on each side.

First, the system has to be calibrated in order to know user height, and thus assign the correct height to the skeleton model on display. So, the user must put the first mark at his feet, and then a green rectangle appears over it. At that moment, someone else should press "c" key, which begins the calibration process, the screen shows the word "Calibrating" blinking for five seconds, and then the system register user's feet position. After this step,

the screen shows the user a message urging him to put the palette on his head, thus the system registers his head position, and so gets his height.

Once the system is calibrated, someone else picks up the palette and flips it in order to move it in front of the user's body. Thus the palette becomes on a "magic window" which allows the user see his own skeleton, as it's shown in the figure.

This first application's version forces the user to keep still when someone is moving the "magic window" in front of him. Later versions will allow some kind of movement.
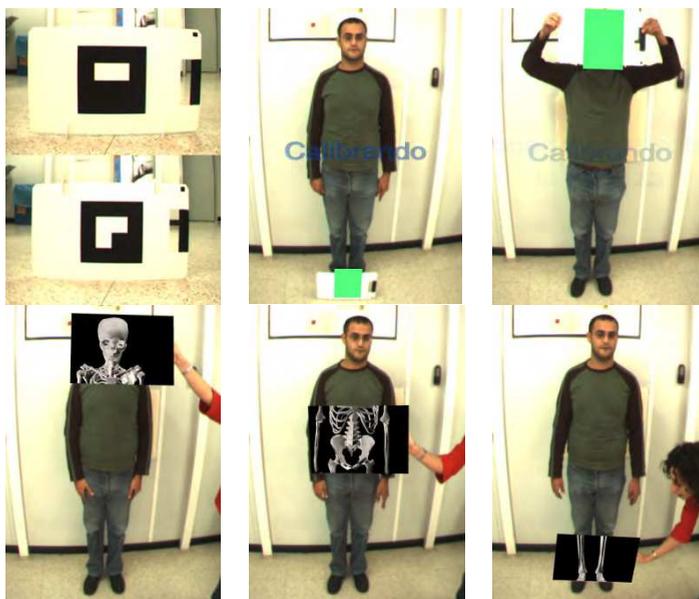
Fig. 4. The magic skeleton application

4.2 Water cycle "magic cube"

This application shows the water cycle on a very simple way, from the clouds to the sea.

In this case, a "magic cube" has been used in order to guide the user by the different phases that water crosses.

Four of the six "magic cube" practicable faces have been used in this application, placing a small mark on a quadrant of every used face. The "magic cube" can be seen in the figure, and it can observe the small mark size.

The user just has to show the cube to the camera, observe the screen and interact as the system orders him. So, the first thing to do is to show the system the init mark. After that, a virtual object appears over the cube, it represents a small island with a little mountain. At the same time a boiling water sound can be heard and a kind of smoke (water vapour) starts to go out of the sea. Gradually a cloud is formed over the sea until the boiling water sound ceases and the water vapour stops to escape from the sea. Then, the system shows two red arrows indicating the user how he has to open the "magic cube" out to pass to the next water cycle stage.

Next, the system shows a new scene, where the user hears a blowing air sound and the clouds approach to the mountain and it starts to rain. After that, the system again indicates the user how to open the cube out and the next stage is reached, where the clouds disappear completely and the rain ceases.

Finally, the user is guided to the last scene, where he hears a flowing water river sound and the river produces flashes, completing the water cycle.
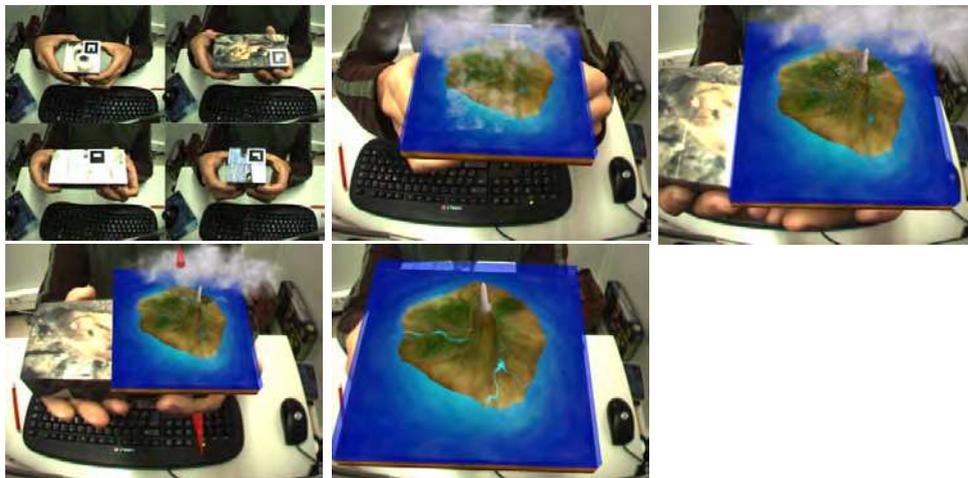

Fig. 5. The water cycle application

4.3 Cube

This application shows all cube's geometric properties on a very graphical way.

In this case, user uses a palette shaped cube. Six different marks are placed at each cube face, but they all operate as if they were a single mark, allowing the user to see the virtual object, in this case a virtual cube, from all possible vision angles.

In this system user must interact with the keyboard in order to see all the different options implemented. Thus, when the user presses "d" key a virtual cube appears opening their faces out, and moving from the centre to the top left corner of the screen.

On the other hand, when the user presses "b" key, the system illuminates the closest virtual cube face to the camera, it also illuminates the same face in the opened cube, and plays a sound at the same time.

User can see cube vertexes in both figures by pressing "t" key. Moreover, he also can see all cube diagonals by pressing "g" key. He even can view both cubes without faces, only edges, by pressing the "a" button. Finally user can access to an information board by pressing the "i" key. This board contains information about: Volume, area, edges, vertexes and diagonals.
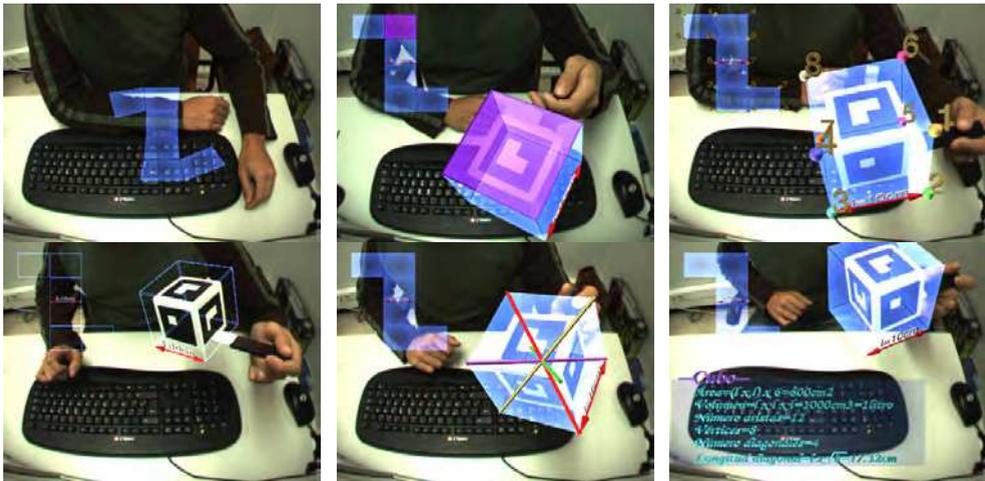
Fig. 6. The cube application

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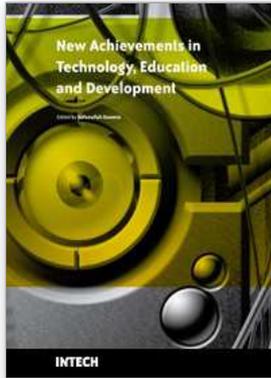
New Achievements in Technology Education and Development
Edited by Safeeullah Soomro

Since many decades Education Science and Technology has an achieved tremendous recognition and has been applied to variety of disciplines, mainly Curriculum development, methodology to develop e-learning systems and education management. Many efforts have been taken to improve knowledge of students, researchers, educationists in the field of computer science and engineering. Still many problems to increase their knowledge on daily basis so this book provides newly innovations and ideas in the field of computer science and engineering to face the new challenges of current and future centuries. Basically this book open platform for creative discussion for future and current technologies to adapt new challenges in education sector at different levels which are essential to understand for the students, researchers, academic personals and industry related people to enhance their capabilities to capture new ideas and provides valuable contribution to an international community.

How to reference
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Mariano Alcaniz, Manuel Contero, David C. Perez-Lopez and Mario Ortega (2010). Augmented Reality Technology for Education, New Achievements in Technology Education and Development, Safeeullah Soomro (Ed.), ISBN: 978-953-307-066-7, InTech, Available from: http://www.intechopen.com/books/new-achievements-in-technology-education-and-development/augmented-reality-technology-for-education

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