Adaptation of Electrical Laboratory Systems through Augmented Reality for Optimization of Engineering Teaching University

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Abstract

This paper introduces an Augmented Reality (AR) application for teaching practices of electrical engineering. In order to improve the autonomy of students and their self-ability we have developed several new practical AR-manuals for being used in the Electric Machines Laboratory. We have used these AR-manuals and the classic ones finding an improvement in learning and motivation of students. The augmented information consists of 3D models, animations and sounds which are superimposed over real objects helping the students in the training of specific tasks. The AR application and the learning environment have been designed based on the principles of interaction between man and machine so the virtual information is presented in an attractive way. Every user provided with a tablet PC or HMD with webcam will be able to visualize on screen the virtual objects added to the real scene. Only one mark has been included in the setting which allows visualization of the virtual information so just one gesture from the user is needed for changing the information. The interactive AR interface has been tested in the laboratory of electrical engineering at a Spanish university.

Categories and Subject Descriptors (according to ACM CCS): H.5.1 [Information interfaces and presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities.

1. Introduction

The implementation and development of communication and information technologies (TICs), in our society and also in the teaching environment is reality already. Actually, they are suffering staggering changes affecting every field of modern society and education is not an exception. These technologies are introduced as a need in the social context where quick changes, rise of knowledge and demands of a high level education constantly updated are becoming a permanent requirement. Before integration of the technological innovations in teaching, the most common method of teaching was the direct communication between teachers and students in the classroom through their attendance; this method is valid and has proven effective but teaching institutions are interested in introducing more productive methods for improving the learning experience and the increase in student's comprehension level.

Computer technologies have provided a strong improvement for these methods. In fact, many universities have adopted virtual learning environments (VLEs) for helping in the teaching process. Pan et al. [PCY*06] have shown that virtual learning applications may provide the tools for allowing users to learn in a quick and entertaining way playing in virtual environments.

During the last few years, TICs have integrated in every teaching level and have been well received by students and teachers alike. We even may consider the students as digital natives because of their technology profile, constantly interacting in their ordinary life with a lot of graphic information supplied by videogames, internet or 3D movies. That's why many universities are seeking new visualization methods for improving the current teaching models and one of the most promising technologies that currently exist is augmented reality (AR). Azuma [AZ97] defines AR as a variation of virtual environments (VR). VR technology completely immerses the user in a synthetic environment which can be interacted with obtaining answers while not seeing the outer real world. However, an augmented reality environment allows the user to see the real world with virtual computer-generated objects superimposed or merged with real surrounding. In terms of technology used, AR may require the following three characteristics: combination of real and virtual, interactivity in real time and 3D registry.

One the most innovative tools for virtual education used in higher education have been the development tools of virtual worlds in education or simulated environments where students can create an avatar and train, learn and manipulate virtual objects inside this virtual environment. The virtual world's experience emulates experience and objects of real life, but AR technology allows coexistence of virtual elements in the real

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world so interaction with objects is real as well [ADE*08] [Cal08].

Augmented Reality can also be used to enhance collaborative tasks. A good example is this work which allows users performing tasks together. In this paper, one of the practices taught in the Electric machines and electric engineering fundamentals is described involving more than 200 students.

In the following section, we analyze previous experiences in the application of augmented reality in higher educational contexts. Then, we describe the key technical elements of the augmented library design to support the augmented implementation, which we have used in our experience. After that, results observed and satisfaction surveys are presented. Finally, conclusions and future work are shown as well.

2. AR education in laboratory practices

During the last few years, in Spanish universities, the number of students has amazingly risen, probably as a side effect due to the country's economic crisis and unemployment issues, but this have not brought together an increase in teaching material and staff. As a result, in engineering degrees, the student/teacher ratio is one of the highest of all universities so this implies a negative influence in attention paid to students and teaching's quality. The problem is especially acute in the practical teaching of these subjects, where the students monitoring and supervision is much more necessary and the learning must be completely personal and manipulative. Therefore, we are aware of the need to seek new ways of teaching in electrical engineering practice, looking for more efficient alternatives, aiming to minimize the problems we face in the actual context.

The university classrooms have been updated with infrastructures allowing use of the teaching technologies most suitable, internet, computers, electronic blackboard, projectors, video conference systems, etc...Any of these technologies would allow integration of augmented reality inside the classrooms, in fact, research has shown that learning does occur in virtual environments [Har06] and one of the earliest works in this area, applying AR to an educational context, is the "Classroom of the Future" [Coo01], which conceptualises how it could be possible to enhance interaction between instructor and students to interact through various interactive scenarios in a collaborative environment. As authors of this work, we consider interesting adapting the practice labs into an AR working setting where markers should be included in machines, workbenches or control panels where students can visualize through a Tablet PC or a mobile device the instructions or training needed for using or manipulating the equipment in front of him. These settings allow that several students may train simultaneously even without the teacher attendance needed.

The augmented reality experience only requires adding a webcam to a Tablet PC, iPad or any mobile device and the proper software. Using the screen to visualize the augmented scene is a cost-effective and eye-catching alternative in the educational context. The basic scheme of an augmented reality system consists in a camera which captures snapshots of the real world connecting to a computer that makes necessary calculations for merging virtual objects into the real scene. The result is an image shown to the user through a graphic interface (Fig. 1).

The aim of AR in the laboratory is creating an environment where real life is enhanced by virtual elements in real time. The purpose of AR is enhancing the information we naturally receive through our five senses, by addition of superimposed or constructed virtual elements for bringing additional information which may not be possibly seen by natural means. One of its most important characteristics is the way in which it creates an interactive environment between the computer system and its user. Today AR environments create interactive systems that aren't simply a face-to-screen exchange any longer, but an interaction with the whole environment as well. (Fig. 2)

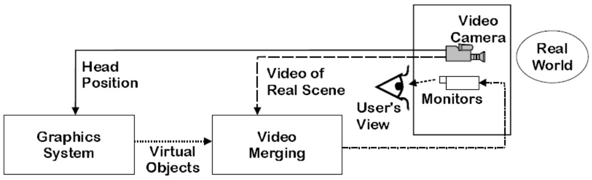


Figure 1: *Basic scheme of an augmented reality system [Val98]*

Short characteristics of an AR environment:
- Combines real and virtual environments
- Is real-time interactive
- Is registered in four dimensions (three dimensional space and time)
- Virtual objects can be static or manipulated
- There is interactivity between the object and the real world
- The abstract concepts can be made visible, enhancing the ability to understand

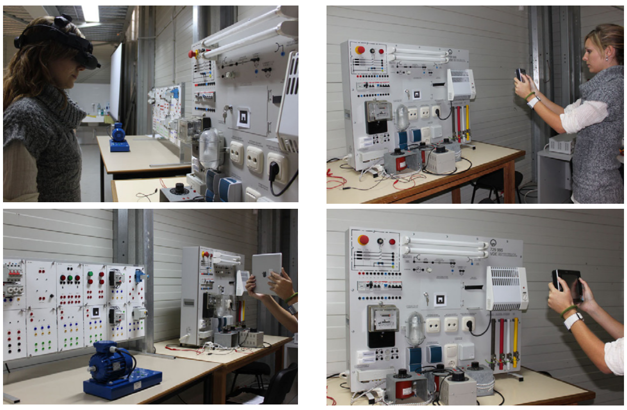


Figure 2: *Augmented Reality environments (HMD, PC and mobile devices)*

3. Augmented reality application on education

According to The New Media Consortium's 2011 Horizon Report [JSWLH11] augmented reality is becoming a technical trend in higher education and is just two to three years away from making technology blend virtual and real. It's expected to reach mainstream use in education through augmented reality textbooks (augmented book).

It's nearly impossible to forecast what technology will bring next year but is possible to predict the outlook in ten years. We believe that one of most relevant changes in our society will be augmented reality which is a technology that is actually being developed in several fields[1],[2] and applied to medicine, architecture, marketing, advertising, military, archaeology, leisure, etc.

The versatility offered by AR technology has allowed the development of applications on several areas of knowledge in education like mathematics, mechanic, physics, and town planning among many others. In higher education there are very few applied teaching applications but here are the only ones known to date:

- *Interactive Media System Group*: Researchers from the Institute of Software Technology and Interactive System (Vienna University of Technology) are the pioneers in development of the augmented reality applications for education (http://www.ims.tuwien.ac.at). The Construct3D app, as described in [KS03], is an application designed for teaching mathematics and geometry in higher education. The apps allow creation of geometric scenes so both teacher and student can interact while explaining. It can be used in three different ways:
    - Autonomous mode where students can see and interact with objects built by themselves
    - Collaborative mode visible for every user.
    - Teacher mode allowing him to choose the viewing mode between some students or all of them.

The author proposes giving an augmented class where students are provided with HMD and can interact with virtual objects and do exercises following the teacher's advice. Using this tool the student can learn how to manipulate 3 dimensional geometric objects in the space provided and also carry out geometric and mathematical operations.

The Same authors developed an educational tool for explaining physical experiments [KM08]. The concepts are explained through animations and the student has the possibility to interact with virtual objects which can be learnt through practise.

- In engineering education, Martín-Gutiérrez has developed a training that improves the spatial skills of students [MSC*10]. The Application is based on performing graphic engineering exercises using augmented reality, and through this, it's obtained an improvement in the spatial capacity of the students helping them to understand the contents of geometric graphics.
- In medical education, for those seeking training for the future such as anaesthetists, there is an AR simulation proposed using operating theater's material [QLFF09].

In higher education, some AR experiences have been performed already but haven't generated any didactic material for continued use; we can just mention a collaborative learning study in land and town planning fields [CW08]. The experience concluded showing that AR technology may improve the design of tasks performed by students. Another interesting basic app on the AR field is developed by Gillet, Sanner, Stoffler, Goodsell, & Olson [GSS*04].

[1] http://www.wikitude.org/en

[2] http://studerstube.icg.tu-graz.ac.at/handheld_ar

4. AR system. Software Library

Although there are several public libraries with AR capabilities, we have work with researches of Labhuman institute (www.labhuman.com) to create a software library called HUMANAR in order to ensure integration of Augmented Reality into our applications and overcome some drawbacks present in some public libraries. HUMANAR uses computer vision techniques for calculating the real camera viewpoint relative to a real world marker, which calculates integration of three-dimensional objects codified by the camera and captured by itself in real time. When the marker enters the scene picked up by the camera, the fusion of the real world with the virtual object is shown on the screen. This requires the application to relate the two worlds (real and virtual) in a single system of co-ordinates. The key technical issues for the development of the AR book have been: Marker detection, Camera calibration, Calculation of marker position and orientation, Augmentation of virtual object.

HUMANAR library supports two different types of markers (Fig. 3).

- Template-based markers.
- ID-based markers 4_4 code words.

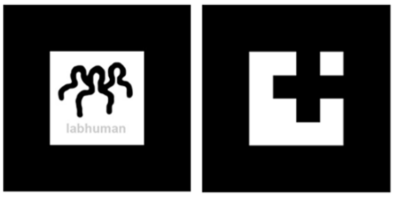


Figure 3: *Kind of markers supported by HUMANAR.*

For a brief description of different types of markers in the augmented reality environments, see [Fia04]. Figure 4 shows the block diagram of HUMANAR library. More details about this library can be consulting in Martin-Gutierrez [MSC*10]. The graphics engine used to display three-dimensional models was GAME STUDIO V-8.

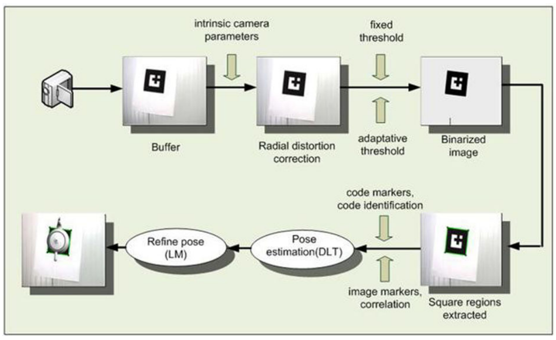


Figure 4: *HUMANAR Block diagram*

5. Practice's description.

The Electrical Machine Laboratory has four independent job positions, ranging from protection Systems to analysis, construction and operation of different types of electrical machines: electrical protection (Masterlab-5000, by 3E-Equipos Electrónicos Educativos, S.L.), construction and study of electric machines (TPS 2.5, by Leybold Didactic GmbH), performance and operating characteristics of electric machines (by Lucas-Nülle GmbH) and industrial electric equipment – training in electric machines' automatic control (Masterlab-3000, by 3E-Equipos Electrónicos Educativos, S.L.).

Students at these practices are low-level students (university degree's first course) without background in this kind of electrical material.

In this paper, AR techniques have been applied for the workshop called "Electrical Machine Teaching Models". The students use different types of electric machines: AC and direct current (DC) generators with permanent magnets and single-phase motors (both synchronous and asynchronous). To this end, students have the basic components of a motor (coils, rotor, wide pole pieces, etc) and they need to assemble the different kinds of machines on a panel frame. "Classic manuals" include a flat diagram of the mounting plan (see figure 5).

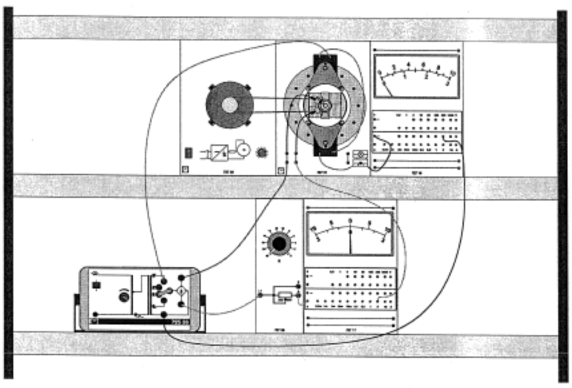


Figure 5: *Traditional Script Practices*

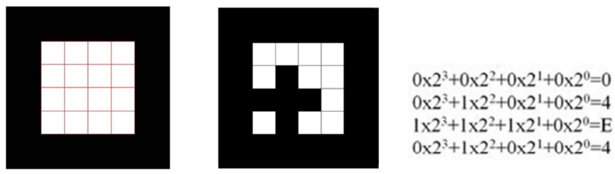
As you can see, if you do not have adequate practise, the interpretation of such schemes requires the help, explanations and direct supervision of the teacher. The traditional practices model is not efficient, since a single teacher has to guide and teach 15 students, conducting simultaneously five different practices. As a result, direct care time spent by the teacher for each student is greatly reduced. And there is also the danger of this type of practice, where students must manipulate actual pieces of an engine and high working voltages.

We have tried with "collaborative methods" where some students receive prior training being able to monitor the work of their own colleagues later [GFPdP11]. This method has given good results and has increased the student's lab productivity. However, its application increases greatly the teacher's workload as he must duplicate their work in the laboratory: first for training tutors and then monitoring and assisting the work done with the rest of the students. By using AR manuals, the student-tutor is not needed and we can optimize the lab time available. Moreover, the electric machine practices are optimal for the implementation of AR techniques: we need to view and manipulate 3D parts, being essential both a suitable placement of each piece as the proper development order at each step it is essential for complying accurately with all the assembly and safety instructions.

6. Augmented Reality app for training on electric machine models

6.1. Mark's design

We have an easy application for creating the fiducial marks that can also be interpreted by the augmented reality software developed by the LabHuman Institute. It's a Word document where there is an image we can manipulate. The image is a black frame containing a white surface divided in 4 rows and 4 columns meaning that we have 16 squares where colours can be changed. If we convert these squares to black we may design our own marks (see figure 6).



(6a) *(6b)*

Figure. 6a and 6b. *Fiducial markers design*

Each one of the 16 cells is a 1-bit binary number so each form in one of the 4 rows belongs to a 4-bit binary number. Besides, every column has a different value (three for the column far left and zero for the column on the far right). Having in mind we are dealing with a binary code and its base being 2, the columns will have the values 2^3, 2^2, 2^1, and 2^0 (column values from left to right).

According to the colour, and having in mind the binary base of each cell, it's considered sketching with value 1 the black colour on cell and with value 0 the white colour on cell. If we take the previous image (Fig 6a) the 16 squares are white so for each one of the four rows, the combination would be 0x2^3 + 0x2^2 + 0x2^1 +0x2^0. The result of each row is equivalent to a hexadecimal base digit (combinations of ones and zeroes in a 4-bit group are 2^4=16). So, for each one of these marks, four hexadecimals digits are obtained, that will be read by the software from the upper row until the lowest one in the mark.

Our augmented reality software identifies the marker through a decimal association and that's why this hexadecimal code of 4 digits should be transferred to decimal notation. For personalizing the application that we are going to create, we modify a file from the program's source code. In this file, we associate the decimal code belonging to a mark with a 3D model file in any of these formats: FBX, MDL, VRML, OBJ.

The figure 6b shows a marker with a value equal to 04E4, which is associated to the augmented reality code as marker 1252 which is the equivalent value in decimal base to the hexadecimal value 04E4 value. The source code contains information about the marker, the virtual object which codifies and the location parameters of the virtual information respecting the marker. Below source code to a file.

```
[PARAMETERS]
scale = 1.088
path_config_camera = camerap
language = es

#mark code must be in decimal
#only 1 mark code
#several models and relative offsets

mark0 = 1252
size0 = 50
totalModels = 3

model0_0 = models\\rotor_3_polos.mdl
scale0_0 = 2
offset_x0_0 = 10
offset_y0_0 = 10
offset_z0_0 = 0
offset_pan0_0 = 45
offset_tilt0_0 = 0
offset_roll0_0 = 0

model0_1 = models\\bobina_1000_vueltas.mdl
scale0_1 = 1
offset_x0_1 = 0
offset_y0_1 = 0
offset_z0_1 = 20
offset_pan0_1 = 0
offset_tilt0_1 = 0
offset_roll0_1 = 0

model0_2 = models\\iman.mdl
scale0_2 = 500
[…..]
```

6.2. Virtual information

The 3D Studio software has been used to create the models and 3D animations which we want to incorporate to the real scene (figure 7). The information has been saved in MDL format as this format is compatible with the graphic engine of the GAME STUDIO A8 software, which is the one over which our augmented reality graphic viewer will work.

Figure 7. *Some 3D models of pieces for training with electric machines.*

6.3. AR application for electricity laboratory practices

Each practice consists in the manipulation of electric machines located in a workplace so each one of them has been provided with a fiducial marker (see figure 7).

The application is programmed so the sequence where different 3D models are shown superimposed over the real machine can be followed through the instructions and explanations in the practice's manual. For visualizing each sequence the user will press a key from the laptop.

Figure 8. *Augmented objects in real scene.*

7. Teaching Experiences. Preliminary validation study

In order to analyse the impact of the educational augmented reality app on students, a group of first year electrical engineering students (20 participants), has been randomly chosen for performing the practices using this application. Ten of them used the Tablet PC for visualizing the virtual objects meanwhile the other ten students used a head mounted display (HMD).

They were asked to perform the following operations over the electric machines being assisted by the instructions provided through the AR app. Next day they are also given an appointment for performing the operations again but now without using the AR application aiming to check the learning acquired. The students were able to work on their own, without any need of instruction or assistance from the teacher who didn't even need to interact with them, observing that operations are being carried out properly. In the following table, results show the students that were able to complete the exercise in the two sessions proposed.

Table 1: N*umber of students completing the tasks*

	Day 1 Using the AR app	Day 2 Without the AR app
Using a Tablet PC	9	8
Using a HMD	10	10

A satisfaction survey shows that all students expressed a highly positive attitude to the augmented reality technology and the augmented contents. They considered the AR app used is well presented and well structured. The overall appreciation of the training was excellent and most students considered it very useful, very interesting and they were satisfied with the technology and methodology. All students considered that AR system is pleasant to use.

8. Future work

We have actually expanded the 4 electric machines setting in the electricity laboratory so in the following months we will include this learning methodology in the curriculum of those subjects involved aiming to perform a big scale study including over 200 students. We can extend this practice methodology to the mechanic's laboratory for providing it with machines that are not economically accessible by our department.

9. Conclusions

The rise of students which opt for studying engineering degrees make the practice's laboratories overcrowded worsening the teaching quality and reducing teacher's dedication to every student. Besides, learning and teaching procedures need to evolve for taking into account the high technological profile that most students show. In some cases, outdated teaching creates barriers for some students that are used to interact with modern technological gadgets and computers.

AR applications allow that in certain teaching/learning contexts they may be performed by the student on his own saving the teacher's time for repeating explanations. The students tend to show some sympathy and kindness to this technology so they are motivated to use it meaning that a well-planned AR application will allow them to perform learning processes.

We believe that augmented reality is a cost-effective technology for providing students with more attractive contents than paper.

Acknowledgements

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