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AR_Dehaes: An Educational Toolkit Based on Augmented Reality Technology for Learning Engineering Graphics.

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***Abstract*— Augmented reality provides solutions and benefits in many areas of knowledge. In the field of education, we can apply this technology for learning contents and for developing skills in an engaging way. Engineering educators are aware of the need for spatial vision skills in order to project and interpret drawings and plans. We propose an educational kit for use at university-level with contents based on engineering graphics. Preliminary results of a validation study with first year Mechanical Engineering students indicate that this augmented reality training has a positive impact on students' spatial ability and learning for basic engineering graphics contents.**

Augmented Reality, Spatial Abilities, Engineering Graphics.

I . INTRODUCTION

Traditionally, any engineering curriculum at universities has included Engineering Design Graphics subjects in which, during at least one academic year, students receive basic training in systems of representation, sketching, technical drawing and CAD. However, in this context, developments of spatial abilities have not been an explicit learning objective, and their development has been considered an indirect learning outcome.

Many studies lines of research have examined the nature of spatial ability and its impact on graphic education and the challenge of improving the teaching of engineering graphic subjects. Several solutions used traditional instructional methods and technologies to improve spatial ability [1-5]. The technology continues to progress, options for new instructional methods arise that provide potentially effective solutions to the challenge of developing spatial skills in our students.

On the other hand, University teaching in Europe is currently immersed in a major process of change arising from the creation of the European Higher Education Area [6]. The new teaching model entails a methodological change in education, shifting from a teacher centered model to one that places greater importance on the work of the student.

An autonomous learning environment can be frustrating for the student, which is the reason why we propose an application based on an attractive and motivational technology that facilitates the learning of the basic contents of Engineering Graphics and helps to improve students' spatial abilities. Thus augmented reality technology (AR), allows students to take a course in an autonomous and active way.

This active approach is very important, because as Sutton, Heathcote & Bore [7] comment: "*Conventional teaching of technical drawing is partly passive. Students learn from observing instructor-centered demonstrations*". We have created AR-Dehaes, a toolkit that promotes active learning, and encourages discovery through interactivity and object manipulation controlled by the learner. Several researchers [8, 9] report that learners who have active control over novel objects perform better on later tests of object recognition and mental rotation. Further evidence suggests that active exploration and control of novel objects assists the learning of 3D structures, better object recognition and improved spatial ability. The training proposed with AR-Dehaes, is an effective way of improving spatial abilities due to mental visual operations students have to carry out. This set of activities contributes to the development of the spatial factor of the intelligence.

Unlike virtual reality applications, in which the user is immersed in a totally synthetic world, with an augmented reality application, the user interacts with the real, physical world around him or her, but computer-generated virtual objects can also be added. The user has the same visual perception of both virtual and real objects.

The main reason for using an attractive technology is to draw the students' attention so that they will be interested in carrying out a short course of basic contents of Engineering Graphics and improve students' spatial abilities. Our experience says that boring courses have a high withdrawal rate, which we try to avoid by using new technologies like Augmented Reality.

II . AR SOFTWARE DEVELOPMET LIBRARY-HUMANAR.

Although there are several public libraries with AR capabilities, we decided to develop a software library called HUMANAR in order to ensure the integration of Augmented Reality into our applications and to overcome some drawbacks present in some public libraries (ARtoolKit, MRXtoolKit…).

The version of HUMANAR presented here has been specially tuned to ensure a reliable implementation of the augment book described in this paper. This library uses

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computer vision techniques to calculate the real camera viewpoint relative to a real world marker, that it, it calculates the integration of three-dimensional objects codified by the camera and captured by the camera 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. The figure 1 shows the block diagram of HUMANAR library.

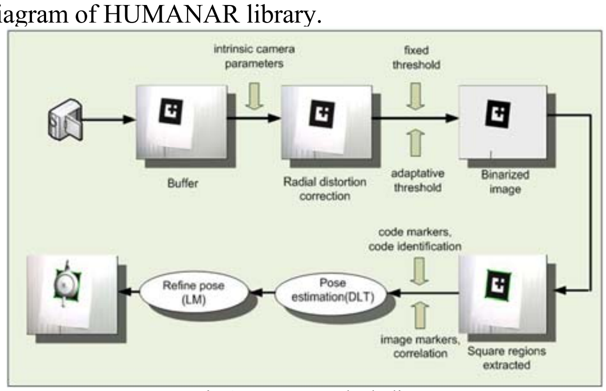


Fig 1. Humanar Block diagram

A. *Marker detection*

HUMANAR library supports two different types of markers: Template-based markers and ID-based markers 4x4 code words (Fig. 2). For a brief description of different types of markers at the Augmented Reality environments, see [10].

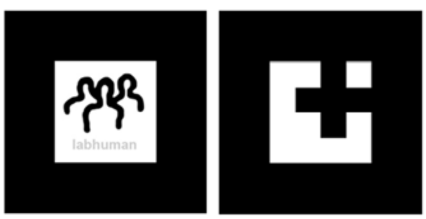


Fig 2. Kind of markers supported by Humanar.

The recognition of the marks by the programme is done in several steps:

In the first step, the camera picks up the image of the fiduciary marker and the programme turns the image of the marker into binary code, that is, it converts the image into pixels that have certain characteristics that make it recognisable, and it can do this in different ways:

- Using a fixed threshold.
- Using an adaptive threshold.

Using a fixed threshold is recommended under ideal circumstances, where the lighting and camera parameters are constant. In this case this technique performs adequately. However, if the lighting conditions are different in each frame, using an adaptive threshold can be a better option. HUMANAR threshold determination is based on Pintaric´s technique [11]. Basically this algorithm operates on a per marker basis and evaluates the mean pixel luminance over a thresholding region of interest.

The second step is marker contour detection where 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.

In the next step, the pattern is normalised by using a perspective transformation to square landmarks thus getting square landmarks. The transformation is applied to a square region of interest (see Fig. 3) and the interior part of the marker is extracted. Finally it is necessary to identify the interior of the pattern.

Fig .3 Example of pattern normalization.

For 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 that fixes the marker orientation.

For 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 [10]. For an MSE measure, small values indicate similarity. This approach is not luminance invariant, however. A better approach is the normalised 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).

B. *Camera calibration*

To calculate the real camera viewpoint relative to a real world marker is determining the intrinsic camera matrix $\boldsymbol{K}$ and a vector $\boldsymbol{\gamma}$ with the distortion parameters (intrinsic parameters).

$$K = \begin{bmatrix} f_x & \sigma & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix} \qquad \gamma = \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \beta_1 \\ \beta_2 \end{bmatrix}$$

Where f_x, f_y are respective the focal length in the $\boldsymbol{x}$ and $\boldsymbol{y}$ direction, (c_x, c_y) is the camera's optical centre, α_1, α_2 the radial distortion parameters, β_1, β_2 the tangential distortion parameters and finally σ is the camera's skew between X and Y axes.

For the calibration step the Zhang´s method is used [12]. The input of this algorithm is the correspondence between

2D image points and 3D scene points over a number of images. The output is the intrinsic camera matrix as well as the radial distortion coefficients.

C. Calculation of marker position and orientation.

The camera pose can also be estimated if the internal parameters of the camera are known. The relation between a 3D plane and its image projection can be represented by a homogenous 3 x 3 matrix, called a homographic matrix. Let us assume that Z = 0, because the marker is in a plane. If we know several points on a plane that we call the reference plane, we look for its corresponding image on the image plane (homographic plane). This is what is known as projective transformation on the plane (fig. 4). The homographic matrix is used to determine the transformation of the points in space to points on the image plane.

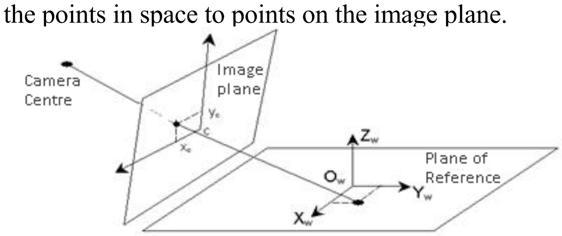


Fig 4 Image plane and plane of reference.

The expression of the homographic matrix H assigns its corresponding point on the image plane to a point on the reference plane. The homographic matrix H is defined as:

$$\begin{bmatrix} x_c \\ y_c \\ w \end{bmatrix} = \mathbf{H} \begin{bmatrix} X_w \\ Y_w \\ W \end{bmatrix} \Longrightarrow \begin{bmatrix} WX_w \\ WY_w \\ W \end{bmatrix} = \begin{bmatrix} \mathrm{a} & \mathrm{b} & \mathrm{c} \\ \mathrm{d} & \mathrm{e} & \mathrm{f} \\ \mathrm{g} & h & 1 \end{bmatrix} \begin{bmatrix} x_c \\ y_c \\ 1 \end{bmatrix} \quad (1)$$

Where:

- H is a matrix that describes the homography.
- The system of co-ordinates of scene $X = (X_w, Y_w, W)^T$,con $Z_w = 0$.
- The system of co-ordinates of image $x = (x_c, y_c, w)^T$.

A point P in the real world will have its corresponding point 2D (p) in the image under the perspective Q = K [R / T]:

$$\widehat{p} = Q\widehat{P} = K(R^1R^2R^3t)\begin{bmatrix} X \\ Y \\ 0 \\ 1 \end{bmatrix} = K(R^1R^2t)\begin{bmatrix} X \\ Y \\ 1 \end{bmatrix} = H\begin{bmatrix} X \\ Y \\ 1 \end{bmatrix} \quad (2)$$

Where R^1, R^2 and R^3 respectively are the first, second and third column of the rotation matrix *R*. Conversely, once *H* and *K* are known, the camera pose can be recovered. The matrix *H* can be estimated from four correspondences $P_i \leftrightarrow p_i$ using a Direct Linear Transformation (DLT) algorithm.

The matrix H can be determined for four points:

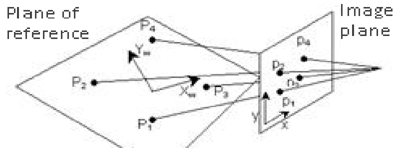


Fig 5 Points in real world and its corresponding points 2D.

$$\begin{bmatrix} x_1 & y_1 & 1 & 0 & 0 & 0 & -X_1x_1 & -X_1y_1 \\ 0 & 0 & 0 & x_1 & y_1 & 1 & -Y_1x_1 & -Y_1y_1 \\ x_2 & y_2 & 1 & 0 & 0 & 0 & -X_2x_2 & -X_2y_2 \\ 0 & 0 & 0 & x_2 & y_2 & 1 & -Y_2x_2 & -Y_2y_2 \\ x_3 & y_3 & 1 & 0 & 0 & 0 & -X_3x_3 & -X_3y_3 \\ 0 & 0 & 0 & x_3 & y_3 & 1 & -Y_3x_3 & -Y_3y_3 \\ x_4 & y_4 & 1 & 0 & 0 & 0 & -X_4x_4 & -X_4y_4 \\ 0 & 0 & 0 & x_4 & y_4 & 1 & -Y_4x_4 & -Y_4y_4 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \\ d \\ e \\ f \\ g \\ h \end{bmatrix} = \begin{bmatrix} X_1 \\ Y_1 \\ X_2 \\ Y_2 \\ X_3 \\ Y_3 \\ X_4 \\ Y_4 \end{bmatrix}$$

Since $H^t_w = K(R^1\ R^2\ t\ )$, the translation vector *t* and the first two columns of the rotation matrix *R* of the camera pose can be retrieved from the product $K^{-1}H^t_w$. The last column R^3 is given by the cross-product $R^1 x\ R^2$ since the columns of R must be orthonormal.

D. Augmentation of virtual objects.

The graphical engine used for the augmentation of virtual object at the scene is Brainstorm eStudio [13]. This is an advanced, multiplatform, real time 3D graphics presentation tool. In order to include Augmented Reality functionality in Brainstorm eStudio, a plug-in has been developed in C++. This plug-in incorporates detection and tracking options from the HUMANAR library.

III . RESULT

The content of didactic toolkit – AR-DEHAES—based on augmented reality technology has been the subject of a validation study and indicates that this first version of toolkit AR_Dehaes is an effective tool for developing spatial abilities and to learn content of engineering graphics in students.

The AR-Dehaes toolkit is composed by a software application, an explanatory video, a notebook and an augmented book (Figure 6).

- The software application contains one hundred exercises with three dimensional virtual models. These models will be visualized on the computer screen when fiducial markers are received by the webcam.
- The explanatory video has duration of six minutes. It explains the theoretical contents of orthographic views and freehand sketching.
- The notebook contains one hundred exercises that have to be solved by the students.
- The augmented book that provides fiducial markers of virtual three dimensional objects. The students can turn, move or bring the notebook to the webcam. They will then be able to see different perspectives of the virtual model and complementary information for exercise resolution.

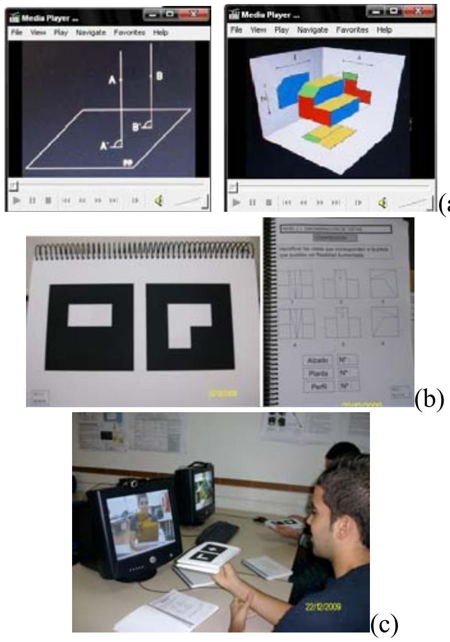


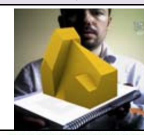
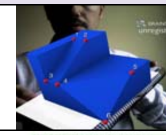
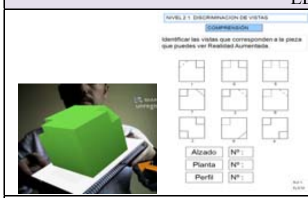
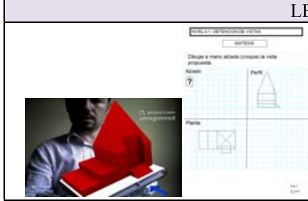
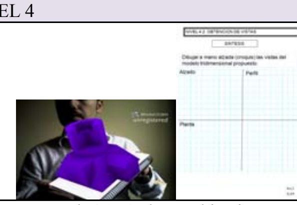
Fig 6. (a) Screen explanatory video, (b) Notebook and Augmented Book, (c) Students using AR_Dehaes.

The training is organized into five sessions with a total duration of nine hours (four sessions of two hours and a final session that lasted one hour). Students can visualize the three-dimensional model in augmented reality (augmented book) and they can check if their freehand sketches correspond to the three-dimensional virtual models which they are viewing.

- *Level 1*. The students have to identify surfaces and vertexes on both orthographic and axonometric views of a three-dimensional virtual object, which is created on the augmented book.
- *Level 2*. The students have to identify orthographic views of the virtual three dimensional models from the exercise book.
- *Level 3* is devoted to the identification of the spatial relationship between objects. This is carried out by means of "recount" exercises, where students are asked to identify how many object are in touch with one selected. Also there are exercises about the selection of the minimum number of views to completely define an object.
- *Level 4* has a greater difficulty than the previous levels. There are exercises where the students have to sketch a missing orthographic view, knowing two orthographic views of a model, using the virtual model as the only input, they have to sketch all the orthographic views.
- *Level 5* exercises are the most difficult ones for students, because they require a greater level of spatial ability. Students are provided with three orthographic views of each object, and they have to build in their minds the corresponding three-dimensional model and then draw a freehand perspective of it. Students have one hour to complete six exercises, without any virtual model help. This level of the course is used for evaluating the advance of students.

When they have carried out the proposed isometric drawings, they can be verified.

TABLE I. LEVELS AND TRAINING TASKS

<table>
<tr><td colspan="6">LEVEL 1</td></tr>
<tr><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td colspan="2">Task 1.1.Identification of surfaces. Orthographic views.</td><td colspan="2">Task 1.2.Identification of surfaces. Axonometric projection.</td><td colspan="2">Task 1.3.Identification of vertexes.</td></tr>
<tr><td colspan="6">LEVEL 2</td></tr>
<tr><td colspan="3"></td><td colspan="3"></td></tr>
<tr><td colspan="3">Task 2.1.Identification of orthographic views.</td><td colspan="3">Task 2.2.Identification of wrong orthographic views.</td></tr>
<tr><td colspan="6">LEVEL 3</td></tr>
<tr><td colspan="3"></td><td colspan="3"></td></tr>
<tr><td colspan="3">Task 3.1. Recount</td><td colspan="3">Task 3.2. Selection of the minimum number of orthographic views to define an object.</td></tr>
<tr><td colspan="6">LEVEL 4</td></tr>
<tr><td colspan="3"></td><td colspan="3"></td></tr>
<tr><td colspan="3">Task 4.1. "Missing view" exercises.</td><td colspan="3">Task 4.2. Orthographic views sketching.</td></tr>
<tr><td colspan="6">LEVEL 5</td></tr>
<tr><td colspan="6"></td></tr>
<tr><td colspan="6">Task 5.1. Perspective sketching.</td></tr>
</table>

A. *Preliminary Study of Validation.*

In order to analyse the impact of the educational content on students, a group of first year mechanical engineering students (24 participants), has been selected and they did the proposed course with AR-Dehaes for the first week of the academic year. Also we consider a control group made up of 25 students (1st year) in agricultural engineering that undergo no kind of spatial skills training. The levels of their spatial ability were measured before and after the course (table 1) with MRT (spatial relations) and DAT-5:SR (spatial visualization) tests [14,15].

TABLE II. MEAN VALUES PRE/POST TEST AND GAIN SCORES

	Pre- test		Post- Test		Gain MRT	Gain DAT 5:SR
	MRT	DAT 5:SR	MRT	DAT 5:SR		
Experimental Group n = 24	19.67 (7.91)	29.17 (7.29)	27.71 (7.83)	38,46 (7.05)	8.04 (5.31)	9.29 (4.08)
Control Group n=25	17.44 (9.82)	28.40 (10.17)	22.08 (9.94)	33.52 (11.77)	4.64 (4.36)	5.12 (7.13)

When we compare the mean values obtained in the pre and post tests using the *t-Student paired series test,* the experimental group scores show t=3.531 for the MRT, p-value=0.0009 and DAT-5:SR t=4.49, p-value=0.00004. In the MRT test, the control group obtained t=1.88, p-value=0.066 and in the DAT-5:SR t=1.718, p-value=0.092. There is a statistically significant increase in the improvement of spatial ability if we compare the results of the experimental group with the control group that did not undergo this training. The p-values are well below the 1% of statistical significance, which indicates that the students have a probability of over 99% of improving their levels of spatial ability by training as proposed with Augmented Reality.

An examination of the contents of engineering graphic at the end of the training course shows an average score for the experimental group of 5.7 points out of a maximum possible of 6 points.

A satisfaction Survey shows that all students expressed a highly positive attitude to the material and contents. They considered the material well presented and well structured. The overall appreciation of the formation was excellent – good and most students considered it very useful, very interesting and they were satisfied with the technology and methodoly. All students considered that AR-Dehaes system was pleasant to use.

IV . CONCLUSION

Learning and teaching procedures have to evolve to take into account the high technological profile that most of students show. In some cases, outdated teaching methods create a barrier for some students that are accustomed to interact with modern technological gadgets and computers. In the context of courses related to technical drawing and design, this represents a serious handicap to engage them in tasks based on classic pen and pencil exercises. Augmented reality is a cost-effective technology to provide students with attractive contents with respect to paper books, giving new life to classical paper and pencil exercises.

ACKNOWLEDGMENT

The Spanish Ministry of Education, through the "Program for Studies and Analysis" (Project "Evaluation and development of competencies associated to the spatial ability in the new engineering undergraduate courses" ref. EA2009-0025) partially supported this work.

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