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Procedia Engineering 63 (2013) 234 – 242

Procedia Engineering

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The Manufacturing Engineering Society International Conference, MESIC 2013

Virtual environment for the simulation of a horizontal coordinate measuring machine in the teaching of dimensional metrology

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Abstract

This paper presents a new virtual environment aimed to the realization of dimensional metrology practices, in the framework of the Degree in Mechanical Engineering of Technical University of Madrid. The development of this project allows the implementation of an interactive teaching model, focused on the student, which combines master classes and virtual applications, in an environment known as DE–learning (driven e-learning). This teaching tool directs and helps students on an individual way in the dynamic and interactive practice development. In particular, this module simulates the functioning, calibration and measurements using a horizontal coordinate measuring machine (HCMM). The program interface has been developed trying to create an easy-to-use environment for the students, in order to be a first contact with the HCMM and its possible metrological applications.

Selection and peer-review under responsibility of Universidad de Zaragoza, Dpto Ing Diseño y Fabricacion

Keywords: Dimensional Metrology; DE-learning; Horizontal Coordinate Measuring Machine; Engineering Education.

1. Introduction

The growing demands of accuracy and reproducibility of measurements in the field of mechanical engineering, as well as the rapid development of new technologies for their realization, is leading to high demand for adequately trained professionals addressed to this type of activity, Werner et al. (2010).

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Selection and peer-review under responsibility of Universidad de Zaragoza, Dpto Ing Diseño y Fabricacion
doi:10.1016/j.proeng.2013.08.282

The consolidation and expansion of the powers of dimensional metrology and its evolution in modern industrial processes is proportional to the development of new learning methods implemented in the last decades, Werner et al. (2009).

Dimensional metrology is currently part of the academic education of different advanced degree in engineering: mechanical, aeronautical, naval, civil, etc. both as a specific subject and as part of other subjects such as Manufacturing Technology, Manufacturing Engineering or Quality Engineering; in addition some Engineering Faculties offer postgraduate courses and masters in metrology.

In particular, learning the basics of dimensional metrology is one of the objectives of Manufacturing Technology, belonging to the Degree in Mechanical Engineering of the Technical University of Madrid (UPM). Teaching methodology of this course is organized through lectures, problem classes, laboratory, individual work, group work and tutorials. Traditionally laboratory practices have been developed in three blocks, including: dimensional metrology, machining with machine tools and automation of manufacturing processes. These practices are compulsory and must be overcome to pass the course.

Dimensional metrology practices are the students' first contact with one of the main aspects of mechanical production systems. The interactive environment shown in this paper represents a new way of dimensional metrology learning that combines versatility and realism. This project comes from the need to find a new teaching practice, which both suits the new objectives of the Bologna process, including in the White Paper on Education and Training - Teaching and Learning - Towards the Learning Society, European Union (1995), and also allows overcoming the mismatch between the number of equipments and the number of students usually occurring in laboratory practices of engineering faculty - mainly due to the expensive equipment and the increased number of students per group.

The development of this project allows the implementation of an interactive teaching model, centered on the students, combining lectures and virtual applications, in an environment called DE-learning, Gómez et al. (2008 and 2011). Indeed, the elaborated teaching tool directs and step by step helps each student on an individual way in the full development of a practice, in a dynamic and interactive approach through the use of animations, videos and audio contributions, hypertext connections and simulation metrological applications, under the supervision of a teacher-trainer. In particular, this module simulates the operation, calibration and making measurements using a Horizontal Coordinate Measuring Machine (HCMM), DMS680 model. The interface has been developed thinking of creating an easy handling environment for students, in order to serve as a first contact with HCMM and its possible metrological applications.

2. Description of the computing environment

The project is entirely realized with Macromedia software, specifically with Director MX 2004 and Flash MX 2004. These allow the creation of multimedia applications such as high performance animations, and excellent audio and video integration. They also allow the use of scripting languages (Lingo, JavaScript and ActionScript) which help the realization of more complex elements to improve user interaction.

By using Director MX 2004 software (Fig. 1) we can realize a fully interactive virtual environment where students can navigate smoothly through the different contents of the program, view explaining videos, step by step follow the explanations, simulate the calibration and make the selection of results.

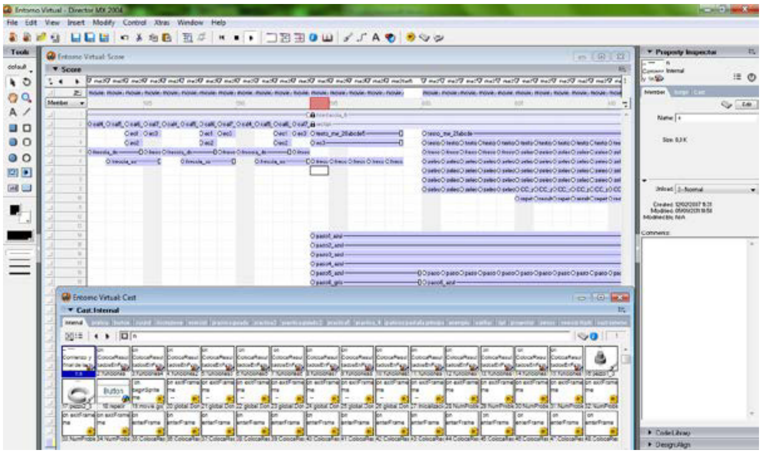

Fig. 1. MACROMEDIA DIRECTOR 2004 software structure.

Director MX 2004 is a program which allows the creation of simple scripts through language Lingo (C variant) in order to obtain easier commands for the navigation along the entire contents of the project. The student displays a panel with various options that let them choose at any time the content they want to access to. So, for example, if a student forgets a concept or reaches a dead end while performing a simulation, he can go back and find the solution in the theory sections. This way of displaying information is the most advantageous to the student, as it is possible to customize both the examples to perform and the way to address them. This user interactive mode is already taking place in many different environments such as web pages, where the content is not read vertically but the required information is selected. This system offers the advantage of showing the required information at all times. For example, throughout the tutorial there are a number of accessible information icons to deepen a particular point, without interrupting the development of the practice being performed (Fig. 2).

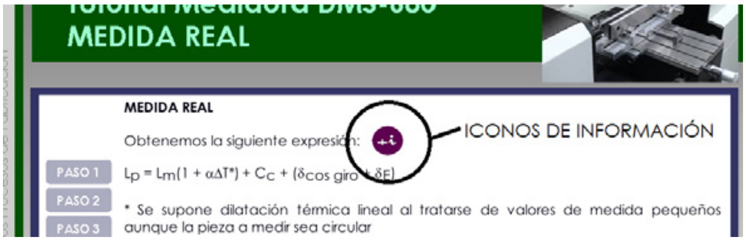

Fig. 2. Detail of information icons.

Other complementary software for the realization of the virtual environment are: Macromedia Flash 8.0, Adobe Photoshop 7.0 and Autodesk Inventor (Fig. 3).

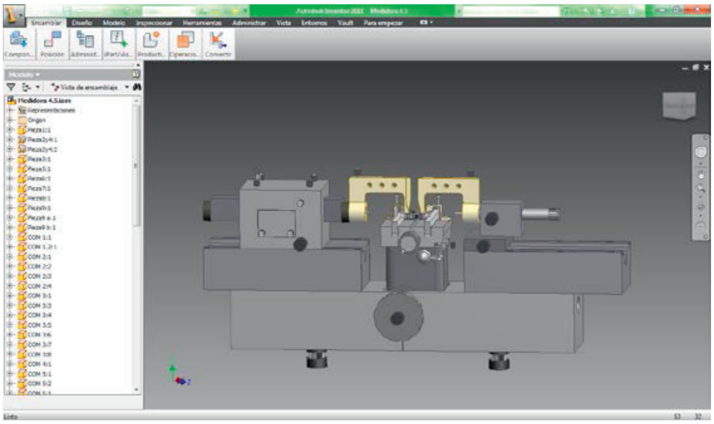

Fig. 3. 3D model of an assembly for rings gauge measurement (Autodesk Inventor Software).

3. Description of the virtual environment

The virtual environment is divided into five main sections accessible through the main screen (Fig. 4):

- Introduction: including basic information on the HCMM and its working.
- Example of measurement: showing a solved example incorporating the basics concepts.
- Calibration of the machine: this section allows HCMM calibration step by step, encouraging user interaction with the environment.
- Making real measurements: an external (cylindrical plug limit gauge) and an internal (ring gauge) measurement is implemented
- Web reference: this section includes a list of references where we can get more information about the practice.
- Help: this section provides the user a basic help.

Fig. 4. Main screen of the virtual environment.

In the first "Introduction" section a physical description of the machine and each of its parts is performed. This section is a tutorial for students who wish to start the HCMM use (Fig. 5).

a b

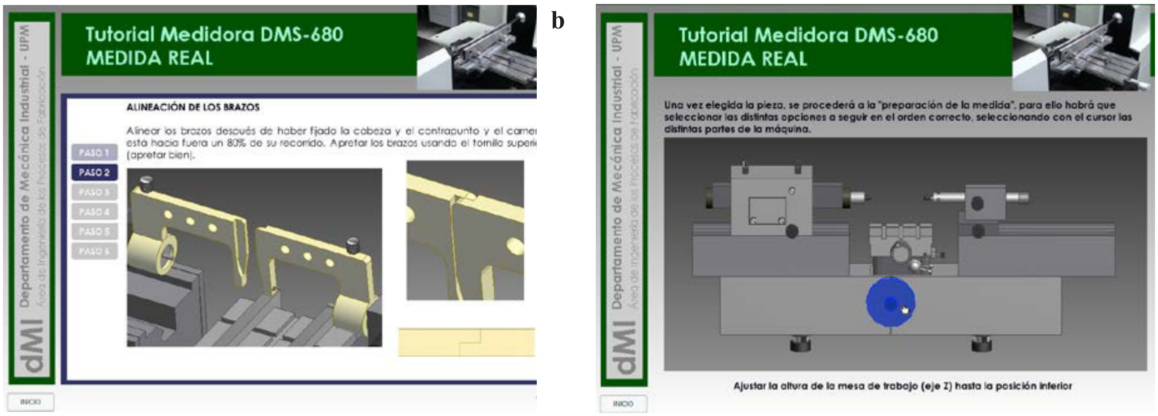

Fig. 5. (a) Description of a HCMM part; (b) Illustration where the student must select the actions in the correct order.

Once the student has acquired the fundamental physical and metrological concepts to understand the operation of the described machine (exploring the sections "Introduction" and "Example of measurement") and supported by a fundamental metrological knowledge bases (acquired in the theoretical lessons), the environment allows the student to perform the calibration of HCMM using gauge blocks. This calibration is performed first on a point and then on a measurement interval, realistically simulating the calibration of the machine. In the section "Calibration", the tutorial becomes fully interactive, because students need to perform calculations to make the right decisions and continued progress in the program. Student can choose a calibration interval and select 3 points of the same to make the calibration (Fig. 6). The results will be extrapolated to the full range.

Fig. 6. Example of calibration on a point.

Once the student has understood the HCMM calibration and measurement procedure, there is the estimation of an actual measurement with two examples, one external measurement (cylindrical plug limit gauge) and another measure of the internal one (ring gauge) (Fig. 7). Next, the program provides an environment where to choose the following operations to make a real measurement process of the one of two shown pieces.

Fig. 7. Description of the possible measurements (cylindrical plug limit gauge or ring gauge).

Each time we access to the measurement implementation, new measurement results and different temperature conditions will be obtained, so that each student performing the tutorial should address the proposed calculations to arrive at the right solution, which can be different from his/her classmates. Using the obtained measurement result after conducting 10 times the measurement on the ring gauge (Fig. 8 (a)) and using the data related to the mean temperature and the variation with respect to 20 °C, it is possible to proceed to estimate the actual measurement with its associate uncertainty (Fig. 8 (b)). To do so, students need to consider the uncertainties linked to the machine, obtained in the previous section "Calibration".

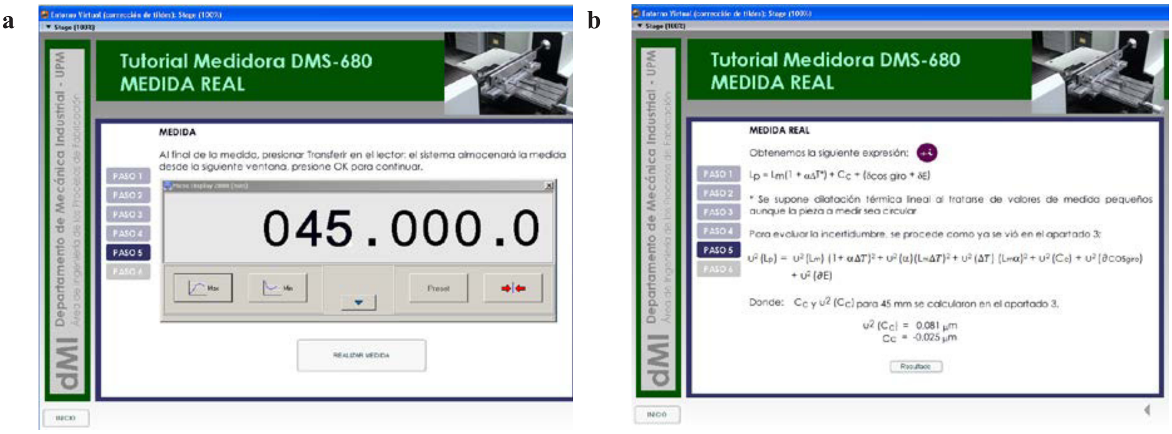

Fig. 8. (a) Example of a measurement; (b) Example of estimating the actual measurement with its associate uncertainty.

Once performed all calculations, the student will compare the obtained results with a set of options displayed on the screen (Fig. 9). If the calculated result is correct, the student will access to the last screen displaying a table with the results summary. If not, the student must check his calculations to find the right solution.

a b

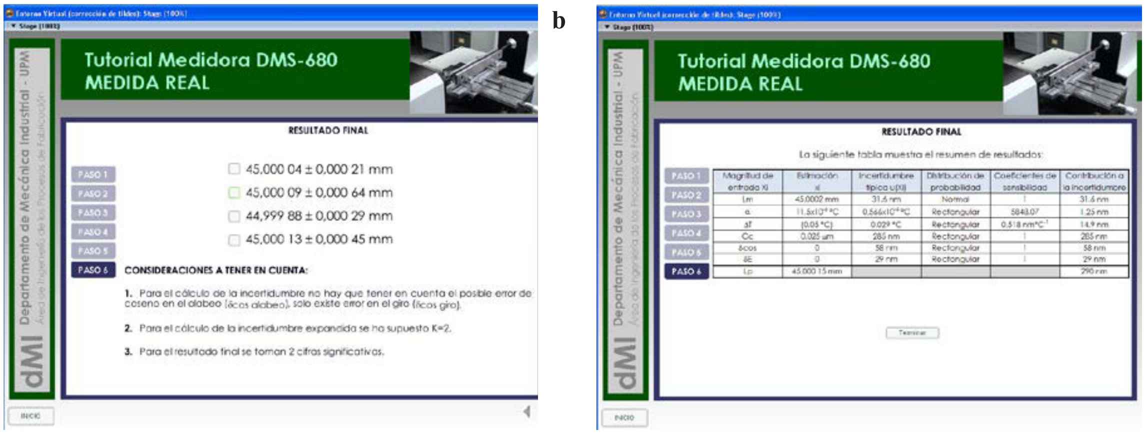

Fig. 9. (a) Example of measurement results; (b) Display of results.

4. Evaluation of developed virtual environment

In order to perform a first check of the application efficiency and effectiveness, we made a study on the students' satisfaction. In the academic year 2012-2013 within the subject “Manufacturing Technology” belonging to the actual five Degrees of the University School of Technical Industrial Engineering of the UPM, students voluntarily decided to conduct a dimensional metrology “pilot” practice, using the developed virtual environment. Earlier, the same students had performed a conventional practice of dimensional metrology called “Practice 1”.

A 25-question survey, 15 on the virtual environment and 10 on conventional practice, was conducted. The satisfaction degree for each question went from 1 (very negative) to 10 (excellent). From a total of 500 students enrolled in the course, 86 students participated in practice “pilot”. Because of the low turnout, the results can not be generalized, but this preliminary study allows a comparison between the two methodologies (traditional and DE-learning) from the students' point of view and highlight any possible improvement for the next course. After analyzing the opinion survey results (Table 1), teachers must be aware of how students perceive the methodology, in order to change the weak aspects.

The data in Table 1 show a very good perception by students of the pilot groups, expressing satisfaction with a mean of 7.69 points out of 10 (question No 15 of the survey) and standard deviation of 1.42 and allocate more than 6 points to all the other aspects of teaching activity, represented in each question. As for the developed application, the students globally evaluated it with a mean score of 7.92, satisfactory result.

Comparing the results of the “pilot” one with the conventional practice, it is possible to notice (Table 1) that students valued autonomy level, clarity of practical examples and the assessment tests favorably. In contrast, students' lowest score was for the interaction between themselves, compared to conventional practice.

These elements reveal how the new employed teaching methodology through the use of the virtual environment, allows greater satisfaction and interest in the taught subject by students who have experienced it.

Table 1. Student satisfaction survey of the “pilot” group.

Indicate from 1 (very negative) to 10 (excellent) the degree of satisfaction with reference to the software developed.

Item	Question	Responses No.	Mean	Std. Deviation
1	Ease of navigation	86	8,65	1,41
2	Clarity of contents	86	8,04	1,29
3	Structure of the contents	86	8,19	1,03
4	Training capacity	86	7,43	1,70
5	Flexibility	86	7,28	1,41

Indicate from 1 (very negative) to 10 (excellent) the degree of satisfaction with reference to the teaching methodology.				
Item	Question	Responses No.	Mean	Std. Deviation
6	Level of autonomy in the study.	86	8,26	1,43
7	Completion time of the practice.	86	7,80	1,55
8	Interaction with other students.	86	6,47	2,81
9	Practical examples clarity.	86	7,93	1,80
10	Self-assessment tests	86	7,43	1,86
Indicate from 1 (very negative) to 10 (excellent) the degree of satisfaction with reference to the developed activity.				
Item	Question	Responses No.	Mean	Std. Deviation
11	My starting level has improved, with respect to the powers provided in the course syllabus.	86	7,00	1,45
12	I found the information, provided on the developed subject, accessible and useful.	86	7,93	1,44
13	The activity thereby developed encourages my participation in it.	86	7,31	2,16
14	My interest in the topic has been addressed in this activity, has grown.	86	6,97	1,70
15	Overall, I am satisfied with the developed activity.	86	7,69	1,42
With regard to the dimensional metrology “Practice 1”, indicate from 1 (very negative) to 10 (excellent) the degree of satisfaction.				
Item	Question	Responses No.	Mean	Std. Deviation
16	Level of autonomy in the study.	84	7,13	1,61
17	Completion time of the practice.	84	6,82	1,78
18	Interaction with other students.	84	7,27	2,27
19	Practical examples clarity.	84	7,50	1,89
20	Assessment tasks practice.	84	6,98	2,05
With regard to the dimensional metrology “Practice 1”, indicate from 1 (very negative) to 10 (excellent) the degree of satisfaction.				
Item	Question	Responses No.	Mean	Std. Deviation
21	My starting level has improved, with respect to the powers provided in the course syllabus.	84	7,15	1,53
22	I found the information, provided on the developed subject, accessible and useful.	84	7,14	1,61
23	Practice in the way which has been developed in the lesson has been encouraging my participation in it.	84	7,06	1,90
24	My interest in the topic has been addressed in practice has grown.	84	6,87	1,51
25	Overall, I am satisfied with the developed practice.	84	7,31	1,69

5. Conclusions

The essence of the project consists in creating a new teaching tool allowing a student to face a real metrology problem. Both the calibration module and the internal and external measurements exercises guide and direct the student “step by step” to take the correct metrological decisions with sufficient variability to make the results comparable to those obtained in a real laboratory reproducibility conditions.

When the student, who did not have a deep contact with the measuring machine DMS680, gets a clear idea of how to perform the proposed exercises with the real machine - thanks to the examples shown in the program and following the theoretical explanations - the main objective of the virtual environment is met. If the project had only an informative nature, like a laboratory manual, we would not be sure that the students understand the tasks to follow to take the entire measurement. Therefore the simulation is particularly important, as the student sees the difficulties that can be found before proceeding in the laboratory. Obviously there is an important limitation since, although it would be the best, we cannot include all applications offered by the machine because of its complexity. However, the program allows simulating the most general applications, such as conducting of longitudinal measurements for both gauge blocks and for measuring specimens.

The application of ring gauges for internal measurements and cylindrical plug limit gauge for external ones are also two types of generic measurements for the standard use of the machine, but we must not forget that each type of measurement requires a specific measurement procedure. Therefore, although it cannot include some interesting examples such as threads measurement, the students get an overview of the various methods of measurement available on the HCMM.

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