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DEVELOPMENT OF COURSEWARE MODULES FOR ENGINEERING MECHANICS EDUCATION

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Original scientific paper

This paper discusses a pilot course introduced in mechanical engineering education. Since computers nowadays can provide enormous benefits in the learning process, it is important to study which techniques are the best for a particular subject. In our model the students still attend the lectures and tutorials, but these conventional techniques are enriched by parallel, fully computerized, homework assignments and virtual laboratory testing. For the purpose of homework assignments, a new software called ASDN was developed. ASDN enables automatic generation of individual homework tasks, their distribution via e-mail and automatic collecting and processing of results. For a better understanding of the numerical tasks, the LAB-3D module was developed, which enables a detailed visualization of prerecorded laboratory tests. These tests comprise the whole testing process, from the visualization of the physical test, to the analysis of the measured data and comparison with numerically obtained results.

Keywords: *engineering mechanics, e-teaching/learning, homework*

Razvoj obrazovnih modula za nastavu inženjerske mehanike

Izvorni znanstveni članak

U članku je pilotni primjer kolokvija za poučavanja u strojarstvu. Pošto računala danas omogućuju velike pogodnosti u edukacijskom procesu, važno je analizirati mogućnost njihove primjene u tehnici, stoga smo istražili mogućnost aplikacije računala kod poučavanja. U našem modelu su studenti uključeni kao aktivni subjekt te su vođeni na način da je konvencionalni način poučavanja paralelno nadograđen te u potpunosti vođen računalom i demonstracijom virtualnog laboratorijskog testiranja. Za rješavanje domaćih zadaća je razvijen novi računalski program imenovan ASDN. Program ASDN omogućuje automatsko generiranje individualnih domaćih zadataka, njihovu distribuciju po elektronskoj pošti, te automatsko skupljanje, ocjenjivanje i procesuiranje rezultata. Za bolje razumijevanje računskih zadaća razvijen je LAB-3D modul, koji omogućuje detaljnu vizualizaciju i bilježenje laboratorijskih testova. Ovakav pristup sažima cjelokupan proces testiranja od vizualizacije fizički izvedenog testa, do obrade i analize izmjerenih podataka te njihove usporedbe s računski dobivenim rezultatima.

Ključne riječi: *domaća zadaća, računalsko učenje, strojarstvo*

1 Introduction

Since the beginning of teaching and learning there has always been a permanent quest for improved methods and approaches. There have been remarkable efforts and works done to accomplish this goal in education.

As computers have moved from laboratories to classrooms and homes, many researchers have investigated how useful these can be for educational purposes. The remarkable growth of web and other computer network technologies has added a large number of potential tools to the engineering educator's arsenal [1, 2]. It is anticipated that in the future these technologies will even more change the way instruction will be imparted throughout the educational system.

Nowadays, computer technology is already relatively widespread. One good example is the web-based learning where lessons can be delivered at any place at any time on demand and the students can access the materials as needed. Some of the web-based course modules, presently available on the web, include engineering courses such as Statics [3], Dynamics [4], and Thermodynamics [5, 6]. Another example is the computer assisted simulation that is well recognized for its indispensable usage in understanding real physical behavior of existing systems as well as in modeling or designing new systems. For example, simulation technology has been introduced into undergraduate engineering courses and laboratories by Stern et al [7] in form of teaching modules for complementary computational and experimental fluid mechanics.

As one can infer from the literature, most of the instructor's efforts in today's education systems are directed towards using various computer software as supplementary material to effectively teach the base course material. Enhancing the classical education with these software packages is expected to increase the quality of both teaching and learning. However, such an approach is still on an individual level and for many teachers relatively difficult to implement in practice. Moreover, the level of usage of such virtual teaching methodology in the vocational education training (VET) systems is still in its infancy. It is believed that the proficiency and common use of such systems would improve the quality of education significantly in general education system of all branches, in particular VET.

In general, most students in engineering sciences have difficulties in their study if they are not mastering well enough the fundamental concepts and basic principles. This situation is not so rare in the classical lecture-mode of teaching. In order to address this deficiency in the teaching/learning process a new innovative education model was developed. Another reason for developing a new model was that MOODLE [8], used by the university as a common teaching/learning support platform, could not meat well the needs of our teachers of mechanics. In particular, homework assignments in mechanics can become relatively sophisticated, meaning that their solution cannot be obtained by a few simple formulas. Instead, relatively complex solution algorithms may be needed to solve the problem. MOODLE does not offer a reasonable way to achieve this.

In our model the student's obligation is to attend the lectures and after that to solve the corresponding homework assignment. For that purpose new software called ASDN was developed. ASDN enables automatic generation of individual assignments, their distribution via e-mail and automatic collecting and processing of results. For a better understanding of the numerical tasks involved in homework, a LAB-3D module was developed. This module enables web access to accompanying prerecorded laboratory experiments, in order to get a good visualization of the physical process under consideration.

The proposed courseware differs from most of the existing courses by the following topics:

- lectures are enriched by easy on-demand generation and distribution of individual homework assignments which may require relatively complex solution algorithms (e.g. finite element solution of a truss structure);
- homework assignments are enriched by on-demand prerecorded laboratory tests, giving the students a better 'feel' for the topic by visualization and interactive virtual experiments, related to the physical process under consideration.

2 Education model

In our innovative education model the teaching and learning process is supported by two systems: ASDN and LAB-3D. ASDN is devoted to homework assignments generation, distribution, and results processing. LAB-3D is devoted to accompanying virtual laboratory testing enriched by numerical results obtained by commercial software.

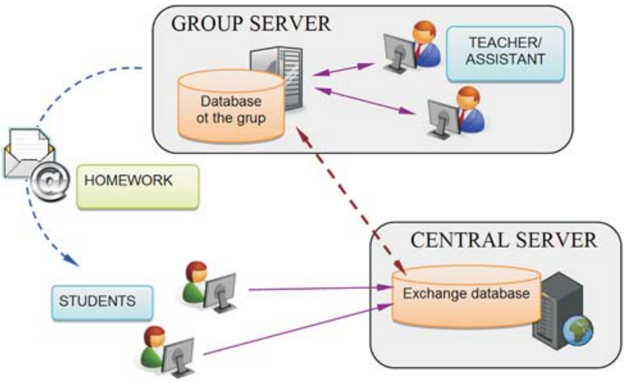


Figure 1 Functional scheme of the ASDN system

2.1 ASDN system

The functional scheme of the ASDN system is shown in Fig. 1 [9]. In brief, it can be described as follows: the teacher makes a request to send to a particular group of students a particular type of homework assignments. The system generates various homework assignments with different input data and dispatches them via e-mail. The student opens its individual assignment and solves it. The central server processes the results which are communicated to the computer of the teacher.

In order to support such functionality, the system consists of the following applications, coded in C#:

- *ASDNManager* – this is the teacher's application for adding new homework assignments, distributing them and collecting the results;
- *ASDNUporabnik* – is the student's application for opening the homework assignment and returning the results;
- Other applications (*HMWWebServer, HMWExchange-Server*, *HMWBaseServer*, and *HMWSolverLibrary*) – are all other applications that manage all the other (communication, data exchange, storage, …) work that is hidden from both the teacher and the student).

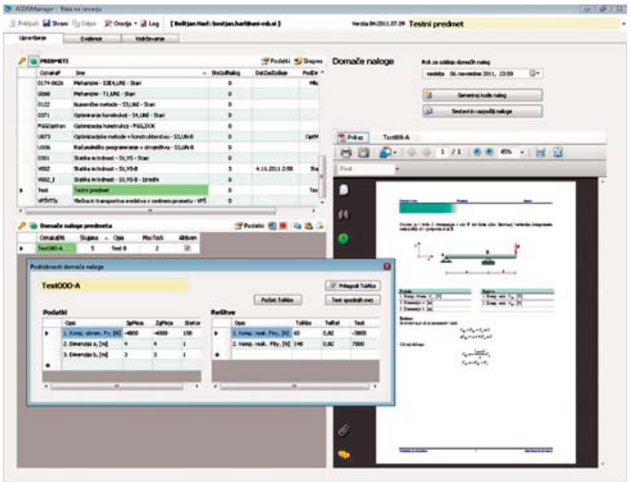


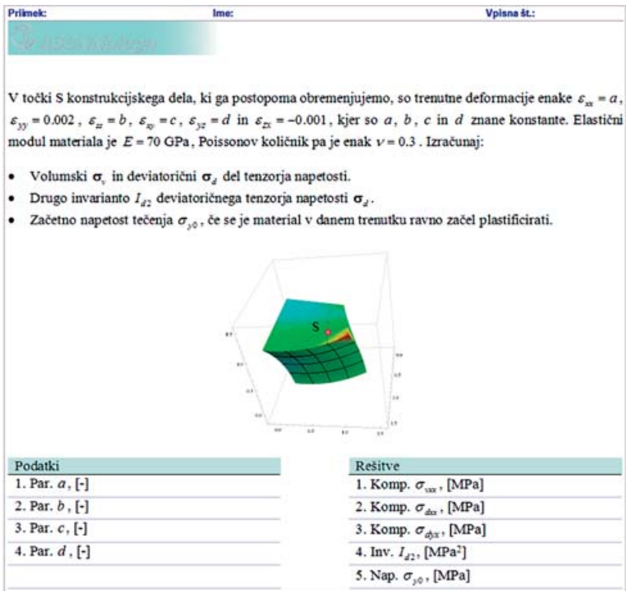
Figure 2 The main window of the *ASDNManager* application

The most important goal of the ASDN system was the possibility to generate/dispatch complex and individual homework assignments by a minimum work of the teacher. Actually, once a particular homework assignment is in the ASDN library, the whole process is done by a few mouse clicks within the *ASDNManager* application, Fig. 2.

However, there is no workaround to the process of preparing a homework assignment and put it into the ASDN library. The homework assignment preparation consists basically of two steps:

- preparation of the PDF file of the assignment and
- coding of the solution algorithm.

The first step (preparation of the text and drawings) can be done by using any appropriate tool. In our case we typically prepare the document by using MS Office and an appropriate template to ensure a consistent look of the assignments, Fig. 3. Once the document is finished, it is simply saved as a PDF file. The input data in the assignment document is given in the parametric (not numeric) form, Fig. 4. The actual numerical values are provided to the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V točki S konstrukcijskega dela, ki ga postopoma obremenjujemo, so trenutne deformacije enake $\varepsilon_{xx} = a$, $\varepsilon_{yy} = 0.002$, $\varepsilon_{zz} = b$, $\varepsilon_{xy} = c$, $\varepsilon_{yz} = d$ in $\varepsilon_{zx} = -0.001$, kjer so a, b, c in d znane konstante. Elastični modul materiala je $E = 70$ GPa, Poissonov količnik pa je enak $\nu = 0.3$. Izračunaj:

- Volumski $\boldsymbol{\sigma}_v$ in deviatorični $\boldsymbol{\sigma}_d$ del tenzorja napetosti.
- Drugo invarianto I_{d2} deviatoričnega tenzorja napetosti $\boldsymbol{\sigma}_d$.
- Začetno napetost tečenja σ_{y0}, če se je material v danem trenutku ravno začel plastificirati.

Podatki	Rešitve
1. Par. a, [-]	1. Komp. σ_{vxx}, [MPa]
2. Par. b, [-]	2. Komp. σ_{dxx}, [MPa]
3. Par. c, [-]	3. Komp. σ_{dyx}, [MPa]
4. Par. d, [-]	4. Inv. I_{d2}, [MPa^2]
	5. Nap. σ_{y0}, [MPa]

Figure 3 Example of the ASDN assignment

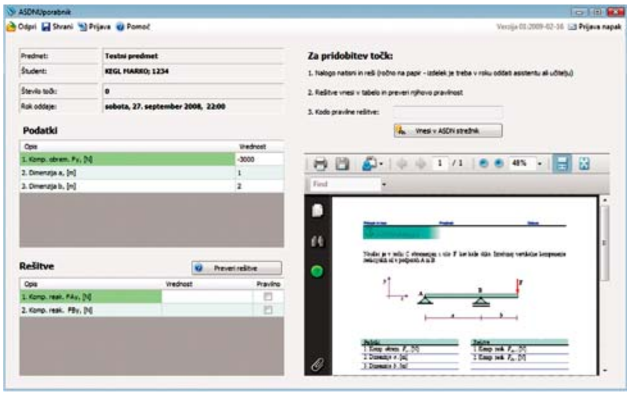

Figure 4 The main window of the *ASDNUporabnik* application

student separately by the application *ASDNUporabnik* which also opens the document and prepares it for viewing and printing.

The second step – coding of the solution algorithm – is somewhat more sophisticated since we assume that the assignments and consequently the solution algorithms will be relatively complex. For that purpose the solution algorithms are coded in C# and added to the dynamic link library *HMWSolverLibrary*. Of course, this coding in C# can be done manually, but this is not a very efficient way. For that purpose we use the AceGen [10] package, which runs within *Mathematica*. AceGen enables derivation of formulas by using a high-level language. The derived formulas can then be exported in several computer languages – C# is one among them. The process can therefore be outlined as:

Problem →*AceGen* →*Final formulas*
→*C# code*
→*HMWSolverLibrary*

Once the solver routine in C# is obtained, it is simply added to the *HMWSolverLibrary*. The final step, required to be done by the teacher, is the determination of the lower and upper limits for the input data of the assignments. These limits are necessary for the system to generate random but valid input data for an individual assignment.

In real circumstances the teacher typically generates several similar, but different, homework assignments, intended to illustrate a particular topic from mechanics. When the assignments are sent out, for each individual student the system randomly selects one assignment from the available pool of similar assignments and randomly generates the corresponding input data.

2.2 LAB-3D system

To provoke learners' interest in engineering mechanics as well as to enhance their understanding of the topics, the theoretical work is enriched by 3D video clips, supported by theoretical background. For example, video laboratory experimental environment has been developed for tensile material tests. Such tests are presented in a form of video clips along with the real material behavior simulation and animation by the use of commercial finite element program ABAQUS (www.simulia.com). For this purpose three CCD cameras have been located in the laboratory: the 1st with global view, the 2nd providing a detail view of specimens, and the 3rd with the view of the screen where the testing results are displayed. The video clips from all three cameras are integrated by software in order to enable switching between different views (i.r. cameras) by a mouse click.

Let us look at the tensile test representing a simple example for testing in a laboratory. A tension test consists of slowly pulling a sample of material in tension until it breaks. The test specimen used may have either a circular or a rectangular cross section, and its ends are usually enlarged to provide extra area for gripping and to avoid having the sample break where it is being gripped, as is shown in Figs. 5 and 6.

Figure 5 A screenshot of laboratory environment supported by three CCD cameras at the moment of extension adjustment

Figure 6 A screenshot of laboratory environment supported by three CCD cameras at the moment of specimen failure

In this user friendly virtual experiment environment it is easy the follow the testing procedure simply by watching the three types of real video recordings of the specific test. It also gives the full theoretical explanation of the testing procedure as is shown in Fig. 7.

Short theoretical explanation of the testing procedure is also given as follows:

"A tension test consists of slowly pulling a sample of material in tension until it breaks. The test specimen used may have either a circular or a rectangular cross section, and its ends are usually enlarged to provide extra area for gripping and to avoid having the sample break where it is being gripped".

Additional explanation of stress-strain behavior is given by the application of the ARAMIS testing system (www.gom.com). This test was done separately with two

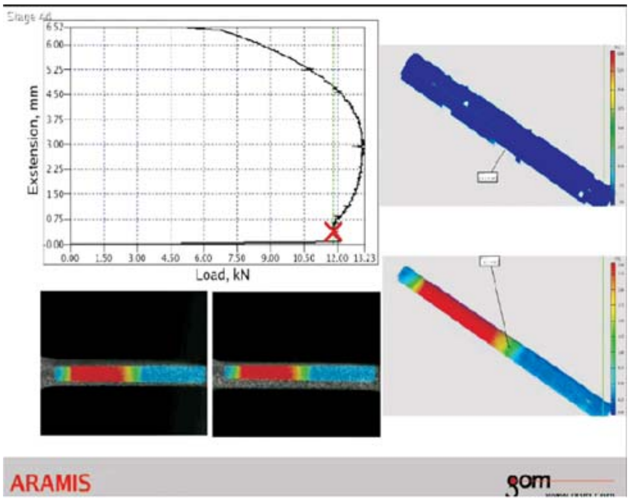

Figure 7 Tensile test performed by the *ARAMIS system*

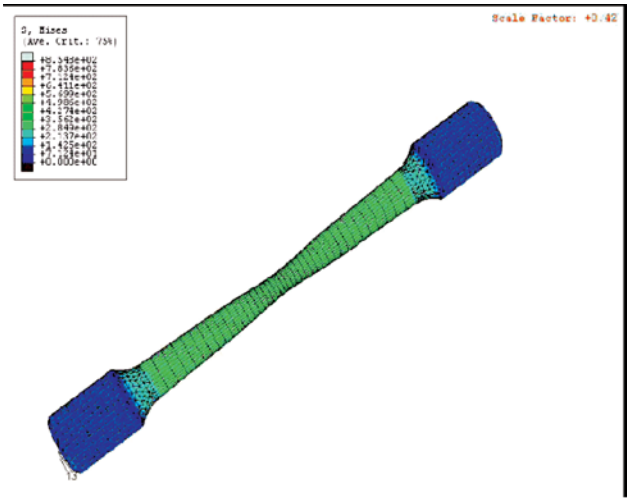

Figure 8 Theoretical explanation of the testing procedure

CCD cameras. The whole test was recorded and saved as an additional video clip file, as is shown in Fig. 8.

Additional explanation of stress-strain behavior is provided by simulation by a commercially available software ABAQUS, Fig. 8.

Along with the videos and theoretical explanations, animations of the specific tests offer a better insight into the theoretical aspects as well as the testing procedure. At the end of the testing, the initial data (initial diameter, initial span distance) and recorded experimental results are provided in an MS Excel file with corresponding instructions and data. Therefore, the student is able to analyze experimental data and calculate the tensile properties related to the performed test in the same way as he would be present in the laboratory during the testing.

3 Conclusions

In this study, a pilot course in mechanical engineering education is introduced. The pilot course focuses on regular and moderately complex homework assignments that are generated, distributed and analyzed fully automatically, requiring a minimal amount of work of the teacher. The only serious work that has to be done is the code development for the solution algorithms. However, once there are enough assignments in the library, the whole procedure can be run by only a few mouse clicks.

Along with the system for homework assignments, another system was developed that enables virtual experimental work in the laboratory. This system comprises video materials for all interesting phases of the experimental work, short explanations, analysis and for comparison numerical analysis done by using commercial engineering programs. The results of virtual tests are stored in separate files and delivered to the student. In that way the student may further analyze this data and compare his results to the results obtained by commercial programs.

In future, ASDN system will be prepared in the English language for Erasmus students.

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