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Web-Based Virtual Testing and Learning in Material Science and Engineering*

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This paper presents a conceptual model for the Web-based virtual testing and learning (WVTL) in applied sciences, especially in the area of materials science and engineering. WVTL is not an existing field but rather an idea, which could be easily handled for educational purposes and staff training as well as for new materials, products and prototypes testing. The paper reports exclusively on the use and services of simulations on the Web and the potential use of WVTL as well as the trends and opportunities in the area.

Keywords: Web-based testing; materials

INTRODUCTION

Web-based virtual testing and learning

WEB-BASED training is a well-known service obtained from the Internet and many applications are currently running on the World Wide Web (WWW). DoITPoMS (Dissemination of IT for the Promotion of Materials Science) [1] created by the Department of Materials Science and Metallurgy at the University of Cambridge is a good sample of such a service. It provides searchable on-line access to an archive of high quality photomicrographs and digital video clips and offers students self-contained learning packages on a wide range of topics in materials science related areas.

Web-based virtual testing and learning (WVTL) is, however, a relatively new concept compared with Web-based training and there are only a few examples available on the Web. Although there are many successfully run simulation software programs on the market for specific applications, such as metal casting technology and bulk/sheet metal forming technology, they are, however, designed for personal use or commercial use of the casting companies and therefore no services are available from them on the WWW. SOLIDCast, FLOWCast and OPTICast are well-known examples of the casting simulation software products of Finite Solutions Inc. [2], and MAVIS-FLOW, MAVIS2000 and GLENIS are the products of ALPHACAST Software Ltd [3]. Software in computer-aided engineering fields widely uses finite element analysis code [4–6]; a well-known one is ANSYS [7], which allows engineers to build computer models of structure, machine components or systems and to study the physical responses of such systems. For bulk/sheet metal forming technology, an exclusive list of software (more than 22 programs) and their developers are cited in a report given by Mynors and his research group [8]. However there are no such services available on the Web for any of this software.

WVTL takes into account a concept of Web-based simulation [9–12], which is a relatively new concept in WWW. WVTL incorporates two elements: one is the use of Web technology and the other is the operation of simulation science. Therefore, it takes an advantage of the Web's ability to hold large and diverse audiences with a knowledge of science but with minimal effort.

In the framework of Web applications, some specific simulation projects (see the next section) have been proposed for a decade in profound areas of applied sciences. Although they did not have a large impact on public use, they did their bit to contribute to the concept of Web-based virtual testing and learning (WVTL) through simulation. The aim of this paper is to bring the issue of the virtual laboratory (VLab) concept into the light

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and explore its wide applicability as a result of recent advances in Web technology.

Simulations on the Web

The proposed work has been considered as an alternative solution for laboratory work in materials science related areas. The following are examples of some of the Web based materials that are currently available.

Etomica: *Etomica* [13] is a Java API (Application Programming Interface) and development environment for construction and implementation of molecular simulations. *Etomica* is one of five Web-based modules for introduction of molecular simulation into the chemical engineering curriculum made by the MMTF (Molecular Modeling Task Force) [14] of CACHE [15]. It was developed by a group of scientist lead by David Kofke at the State University of New York at Buffalo [16]. *Etomica* was formed to promote the use and distribution of molecular modeling tools in the chemical engineering curriculum. *MaterialFracture* is one of the seventh Web-based molecular modules of *Etomica* dealing with microscopic crystal behavior of a solid system with simulations in a 2D-space [17]. It has been proposed that these simulations might be built with API by programming in Java with a text editor, or by using the *Etomica* development environment. *PistonCylinder* and *CrystalViewer* are two other examples of Web-based molecular module simulations prepared by the same group at the State University of New York at Buffalo [18]. All simulations of *Etomica* run on Java applet enabled PC browser windows. Java, introduced by Sun Microsystems is an object-oriented programming language for the Web-based simulation applications [19].

MATTER: There are a few Web sites with materials science related simulations run under the supervision of the *MATTER* project; e.g. *aluMATTER* and *SteelMATTER*. *MATTER* was set up as a non-profit consortium of United Kingdom materials science departments in 1993 to develop and help integrate computer-based learning materials into mainstream teaching [20]. *SteelMATTER* was designed for Web use with introductory information about ferrous metallurgy [21]. This service is mainly for distributing knowledge but it also has some interactive applications (like Jominy hardenability, a ladle stirring experiment, steel production and another ten steel related examples). It has little simulation, but some are interactive and simulate self-learning, similar to *SteelMATTER* in designing the service, which deals solely with aluminum science and technology.

Two other simulations available through the Internet from the International Iron and Steel Institute and *MATTER* are 'Materials Selection for Car Door' and 'Secondary Steelmaking Simulation' at a site called 'Internet Learning of Steel Applications & Processes' [22]. In the 'Materials Selection for Car Door' simulation, the user defines the parameters by selecting or entering the appropriate data for selecting the materials and fabrication technologies for the door outer panel for a typical family car. The aim of the user is to define the best material and design factors that will give overall weight reduction (hence fuel economy/emissions), cost, stiffness, safety, durability, recycleability and performance. In the second simulation (Secondary Steelmaking), the user plays the role of a plant metallurgist in charge of secondary steelmaking operations. The user is expected to take charge of a ladle of molten steel from the Basic Oxygen Furnace, and attempt to deliver it to the appropriate caster at a specified time, composition, temperature and inclusion content (cleanness). The user should also aim to complete the simulation at minimum processing cost.

VRML by NIST: National Institute of Standards and Testing (NIST) is an agency of the United States Commerce Department's Technology Administration. Works could be found on the visual representation and simulation of construction and building related models, activities, and processes at the Website run by NIST [23]. The Virtual Reality Modeling Language (VRML) is used for the visual representation of those functions. Although it is not a virtual testing laboratory it has user-Controlled VRML Simulations of an Excavator, Tower Crane, and Dump truck National present good examples of Web-based virtual training and learning in practical matters.

REACTOR: *REACTOR* is the laboratory simulation for general chemistry run by Late Nite Labs laboratory simulation site [24]. *REACTOR* laboratory simulator site offers an algorithm-driven simulation package for college level courses. With *REACTOR* Web-based simulations, the users can carry out hands-on experiments freely on any computer with access to the Web.

Visual Quantum Mechanics is another Web-based simulation used for teaching of high school and college students via the Internet [25]. This project has been developed by the Physics Education Research Group in the Department of Physics at Kansas State University and it is funded by the National Science Foundation (U.S.). To run the simulations at the *Visual Quantum Mechanics* Web site, a shock ware plug-in is required. *Energy Band Creator* (34k), *Quantum Tunneling* (20k) and *Wave Function Sketcher* (57k) are some of the interactive physics simulations available at the site.

Model ChemLab is chemistry lab simulation software mainly created for an educational purpose and can be used on a personal computer at home or, by obtaining a multi-user license, in classrooms [26]. *Model ChemLab* (run by Model Science Software initiated at McMaster University in Canada) allows the user to perform interactive chemistry labs simulations. The Pro-version of the program holds a 'Lab Wizard' tool, which allows educators to create their own lab simulations. The developer of *Model ChemLab* is studying ways to integrate their software applications with the WWW. Currently they have no service available on the Web.

The concept of Web-based modeling and simulation were discussed after a series of successful international conferences that have been held in United States since 1998. The first International Conference on Web-Based Modeling and Simulation, which was sponsored by the Society for Computer Simulation, was held in San Diego, California on 11–14 January 1998 [27]. After 1998, successive conferences in this area were held in different locations in the USA. There is, however, no record of such an event in the area of Web-based Virtual Testing.

OBJECTIVES OF THE WVTL-VLAB

Application of Web-based virtual testing and learning (WVTL)—Virtual Laboratory (VLab) — will not only give the user the ability to explore knowledge, but it will also allow them to test and deal with the concepts of materials properties. To do this WVTL-VLab allows the user to observe the results after running tests with 'input parameters' and getting 'output parameters' that allow them to examine cause and effect. WVTL-VLab is to concentrate on more widely used areas, such as areas where running costs are high or there is a time limit. Therefore, its objectives and benefits would be summarized as follows:

- to overcome the limitations in real laboratory testing conditions by allowing flexibility of testing on any parameter that may not be visible in real life conditions (such as factors of heat and speed);
- to determine and predict the material's mechanical performance in a virtual environment;
- to develop quick and effective decision-making;
- to allow an ease of design of new materials, products, prototypes, and testing of the models;
- to create an easily handled educational tool for universities and for staff training for industry.

WVTL-VLab does not only mean to distribute and apply the animated and simulated documentation; it also means to open up a new perspective to the users with a practical background.The benefits of using any VLab would differ, depending on the sector being used. The ultimate aim is to build 'The Ultimate Contemporary Virtual Laboratory', which would serve as a real laboratory but have the advantage of having all the possible projected benefits.

METHOD OF ACHIEVING PROPOSED WORK

WVTL-VLab was initially thought to overcome the problems associated with the real laboratory tests carried out for mechanical performance and properties of materials using different test parameters, such as the factors of heat and speed, in real laboratory conditions. The main problems encountered with real labs are health matters and technical issues, such as a time limit for testing all the parameters, or uneconomic tests performed with many test parameters. Therefore, an attempt was made to create a laboratory in a virtual world but with all the benefits of real laboratory conditions. This project is now at the development stage and will be executed once the theoretical work is completed.

Creating a model of WVTL

First, instead of building many specific virtual test laboratories, a model structure will be constructed such as that proposed previously by Yang [28] and his research group in 2004 for seismic ground work. Since a framework is to be built for the WVTL model for creating a specific VLab, the system design will consider four main parts as shown in Fig. 1. The first is the Data Collection System (DCS), which merges raw data from real laboratory tests, data upload, end user inputs and data mining. The system will gather raw data through information from that specific testing with all parameters. Data mining deals with the extraction of the useful knowledge from the sets of linear or discrete data. Data mining is defined as 'the nontrivial extraction of implicit, previously unknown, and potentially useful information from data' [29]. The system will allow the operator to upload their data following a simple flow model in a given format to the main supercomputer. A Web-based friendly graphical user interface (GUI) will be used for input and output modes. A GUI is also going to be an interface for users who can set up and modify the VLab input files, run the model and obtain immediate responses to questions of interest with great ease. In order to build a knowledge based WVTL model for VLab a vast amount of data will be collected and stored at the DCS unit as a database.

The Data Input Interface Management System (DIIMS) transfers raw data to the Database Management System (DMS), where they are qualified before the next stage, the Data Processing Unit, which incorporates with Intelligent Data Analysis (IDA) systems (Fig. 1). The transformation of data into an information mode is the work of the IDA unit. Here, the use of knowledge will be very important, especially where there is a lack of data or uncertainty is high. This is one of the main objectives of this work and why real laboratory test results are collected and stored by the DCS and used by WVTL. The model system will continuously be tested using a set of well-developed and pre-tested examples using data collected from real laboratory tests. Artificial intelligence and current mathematical models for simulations will be used in the IDA system. All these will help to build a WVTL model template for VLab. For

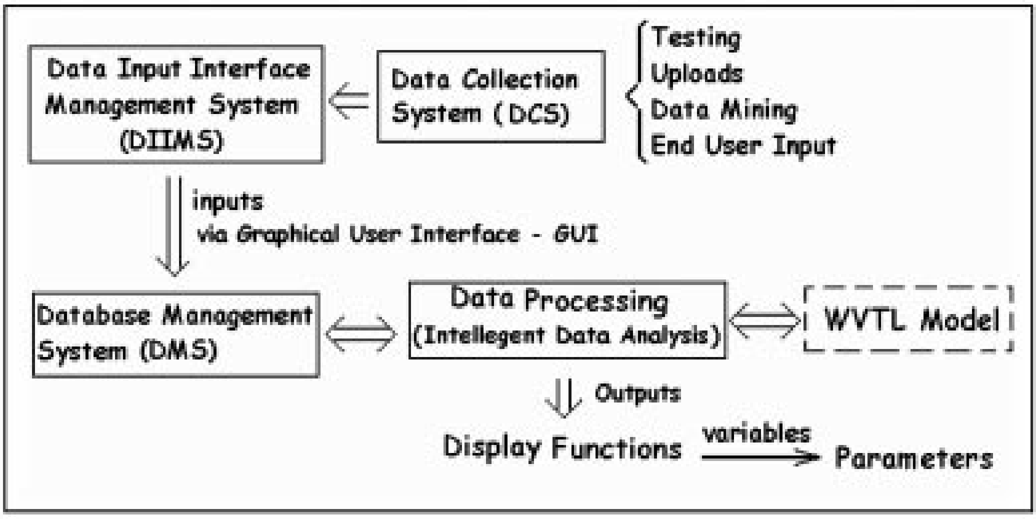

Fig. 1. A flowchart showing the main parts of the WVTL model for VLab.

display functions, Common Gateway Interface (CGI) scripts and Java-based simulation environments could be the ideal tools to use with the World Wide Web (WWW) for VLab.

How WVTL-VLab works

After constructing a model using the WVTL template, any specific virtual laboratory (VLab) can be assembled at any time once there is sufficient data on that topic, e.g. building a VLab for tensile testing of metals. This lab might then be called a Web-based virtual testing and learning-virtual laboratory for the tensile testing of metals (Vlab-TTM). A sample virtual laboratory for tensile testing of metals is given in Fig. 2 showing parts of the lab's main structure.

Numerous tensile tests are carried out every year for metallurgical applications in different industries or for educational purposes in teaching the mechanical properties of metals. It is very likely that some of those tests are identical in using same material and testing conditions, since tests are carried out according to the international standards. The reproducibility of tensile testing with metallic materials with known specifications, i.e., chemical composition, their production route, microstructural features, size, shape and surface parameters, is the reason why metals are preferred for use in structural applications. A Vlab-TTM with highly reproducible real lab data usage could be useful for reference purposes as well as for designing new materials with known specifications before they are manufactured and tested.

Any client or user of the lab on the Web can, using a browser, dynamically build input files (parameters necessary for testing) using HTML (HyperText Markup Language) forms generated by a CGI program located on the server site. Before beginning the VLab, the user will also be prompted by a simple interface to choose a material and testing parameters from a predefined list from a material store. Testing parameters could be material type, its geometry, temperature, cross-head speed, etc. The server, using a HTTP (HyperText Transfer Protocol) tool, will then be able to generate the required files, based on user's choice. The output value could be in the form of a graph of stress–strain data and visual inspection of

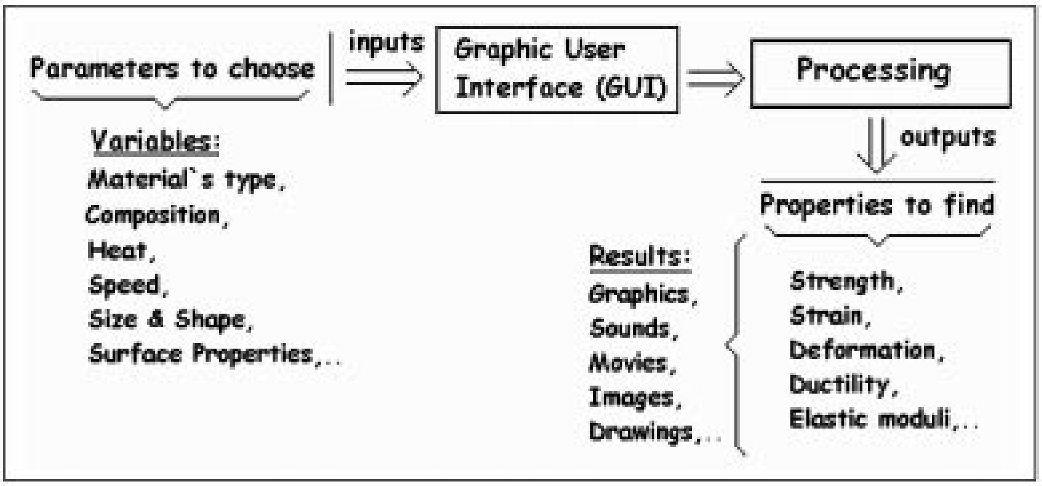

Fig. 2. A structure of WVTL: VLab for tensile testing of metals.

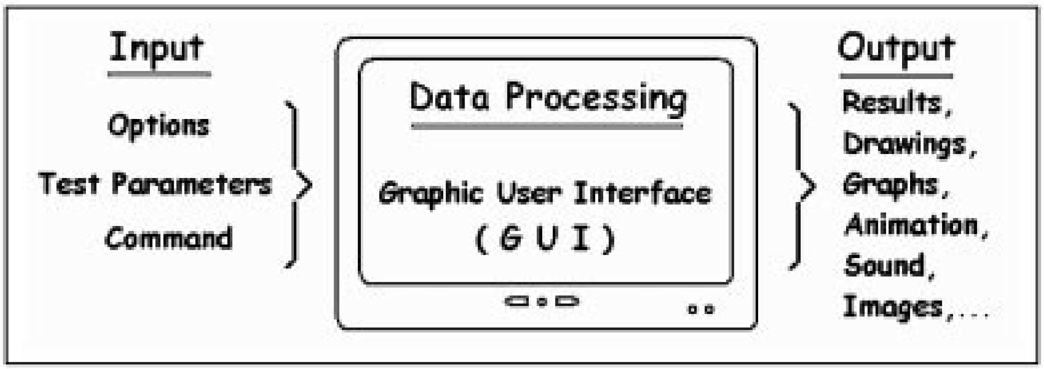

Fig. 3. Basic representation of user and system interaction.

fracture surfaces. The user can change any initial test parameters each time they re-run the test to see the effect of that particular parameter on the output result (Fig. 3). Each VLab may also include self-assessment questions and interactions with an optional performance report after each test is completed. All systems might be installed locally by a course instructor and the user's progress on the VLab might be diverted to the instructor for their evaluation. This is especially useful when WVTL-VLab is to be used for distance learning. A contributor list, glossary entries and further reading section with references could be an accessory to each VLab. The contributor of any data supplied and used on any specific VLab will then be acknowledged by displaying the contributor's name and details in a 'contributor list' section of Vlab, which will give the level of their contribution.

VLab is to be specifically constructed for a particular application, such as that described previously, but it could be expanded to include all sorts of materials testing, such as hardness, a Charpy impact test, three-points bending and so on. The difficulties are going to be with the consistency of the input data that come from different sources and the reliability of the output values. The accuracy of the output value depends strongly on the input values. The obstacles will be in the collection and precision of real laboratory testing data and interpreting them in a standardized form so that a useful and meaningful relationship could be built. Therefore, the quality and the quantity of the tests are important for reliable test results. In order to overcome these problems, systems will be designed in such a way as to continuously crosscheck the data from different sources. These data will be compared with that from real tests, which will be carried out from time to time to maintain the reliability of the system.

PROJECTED IMPACTS OF WVTL

- The WVTL-VLab might be used individually for instructing or training the user through self-learning on the Web.
- WVTL through VLab will allow the use of a learning chain in classical training and teaching. It is also thought to be a useful tool for instructors to be able to allow an individual to work in a science lab in their own time. For industrial application, VLab would also be useful, since testing of different parameters could be carried out in such a way that could be called upon and used by staff for self-training when necessary.
- WVTL-VLab could also be useful in overcoming the problem of distance learning in practical science. WVTL-VLab will be an ideal tool for pre-lab work, demonstrations and labs that otherwise could not be performed due to time constraints or health risks.
- The VLab in a selected area is going to be interactive, asynchronous, readily available and cost-effective.
- A specific VLab is to serve as a sharing environment for learning, assessing and knowledge sharing.
- At the same time, WVTL-VLab helps individual learning and it might encourage high-order thinking skills as one benefit.
- This sort of brainstorming on the Web will contribute to building an ultimate virtual laboratory where new materials could be designed and their properties tested solely in a virtual world before carrying out real laboratory work or production.

CONCLUSION

This paper examines the WVTL-VLab conceptually in the light of currently running virtual labs on the Web. A theoretical model structure was proposed and a sample laboratory was incorporated into the model to evaluate the validity of the system.

This paper examines some of the virtual Web-based tools for laboratory applications and introduces a novel idea i.e., WVTL-VLab. VLab is not an alternative or a version of any currently used similarly named product available on the market or on the Web, but it is an aid to a real lab. Once in service, the VLab would be able to yield numerous advantages and benefits for members of the public through the Web.

In higher education, VLab would help students to use their creative thinking by giving them opportunities to exercise different parameters. Using VLab in education also will benefit users with problem solving abilities by helping them to exercise different parameters that are not possible or feasible to use in real laboratory conditions. In this sense the virtual educational tools that are currently used are very limited.

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