

Solar energy e-learning laboratory - Remote experimentation over the Internet

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Abstract—This paper presents the solar energy e-learning laboratory, developed at the Higher Technical Institute (HTI) within the framework of the Leonardo da Vinci project MARVEL, focuses on the system architecture and its features, and elaborates on the learning platform employed. The laboratory focuses on experiential based learning-arrangements allowing remote and distributed training with the laboratory of solar energy. As a prototype working example the HTI solar energy laboratory comprises a remotely accessible pilot solar energy conversion plant employing the state of the art in software design.

Index Terms—Remote engineering, remote laboratory, remote access, e-learning, solar energy, booking system, TestPoint, Moodle, software architecture.

I. INTRODUCTION

Remote engineering is becoming an important element in engineering education; accordingly there is growing need for new learning media and tools. As a prototype working example we present in this paper the solar energy e-learning laboratory developed at the Higher Technical Institute (HTI) within the framework of the Leonardo da Vinci project MARVEL. MARVEL (Virtual Laboratory in Mechatronics: Access to Remote and Virtual e-Learning) focuses on experiential based learning arrangements allowing remote and distributed working with laboratories, workshops and real working-places in the field of mechatronics to train students in remote engineering [1].

The HTI solar energy e-learning laboratory comprises a pilot solar energy conversion plant which is equipped with all necessary instrumentation and control devices needed for remote access, control, data collection and processing. A major goal of the HTI solar energy e-learning laboratory as well as of the MARVEL project in general is the usage of real worlds in virtual learning environments in order to support work-process-oriented learning with real-life systems. Telematics, remote and mixed reality techniques are used cooperatively within a network that includes colleges, industry partners, and national bodies dealing with certification and standardisation issues.

This paper presents the actual system, which has been developed within the MARVEL project, focuses on the

system architecture and describes some of the forthcoming trends in the training of remote engineering..

Basic System Design

The HTI solar energy e-learning laboratory comprises a pilot solar energy conversion plant which consists of two flat plate solar collectors having a surface area of 3 m² located on the flat roof of the central HTI building, an insulated thermal storage tank located in the solar energy laboratory and other auxiliary equipment and accessories. It is also equipped with all necessary instrumentation, control and communication devices which are needed for remote access, control, and data collection and processing. The schematic diagram of the system is illustrated in figure 1.

The installed hard- and software includes features for controlling external devices, responding to events, processing data, creating report files, and exchanging information with other applications. All relevant weather data as well as operational and output data of the system are registered during an experimental session and are temporarily stored on the controlling PC and are available for downloading for subsequent calculations and/or documentation.

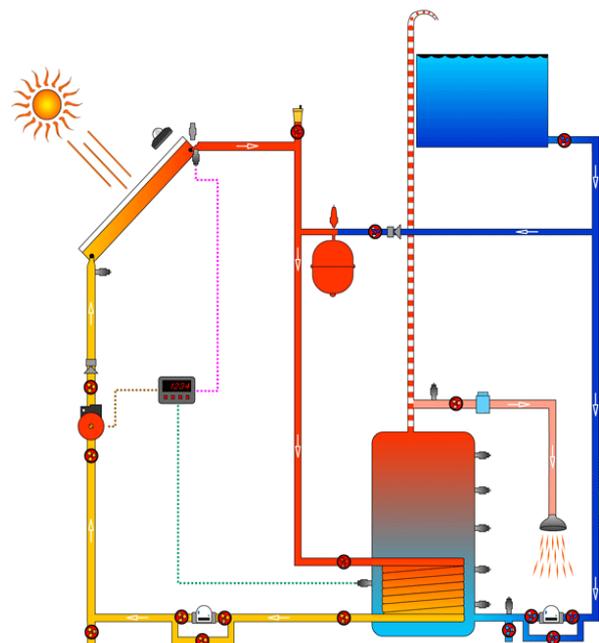


Figure 1: Schematic diagram of MARVEL Solar Pilot System

The aim is to use the Internet as a tool to make the laboratory facilities accessible to engineering students and technicians located outside the HTI premises, including overseas. In this way, the solar energy e-learning lab and its equipment and experimental facility will be available and be shared by many people, thus reducing facility, running, and maintenance costs.

Furthermore, the field of solar energy chosen for this purpose will offer a unique opportunity to students from countries of poor sunshine to have access to real conditions experiments with abundant of solar radiation. The system will enable real-time, remote control, data acquisition and evaluation. It will allow remotely located students to conduct experimental work in an interactive and independent way.

Students from collaborating partner institutions will have remote access to the system. A booking tool, shown in figure 2, is available to control the access time for the equipment by the instructors. A number of laboratory experiments and learning tasks have already been developed including familiarisation exercises as well as system performance investigations and e-maintenance tasks [2, 3]. All exercises and learning tasks are supported by web-based learning materials in the form of 'virtual books' [4].

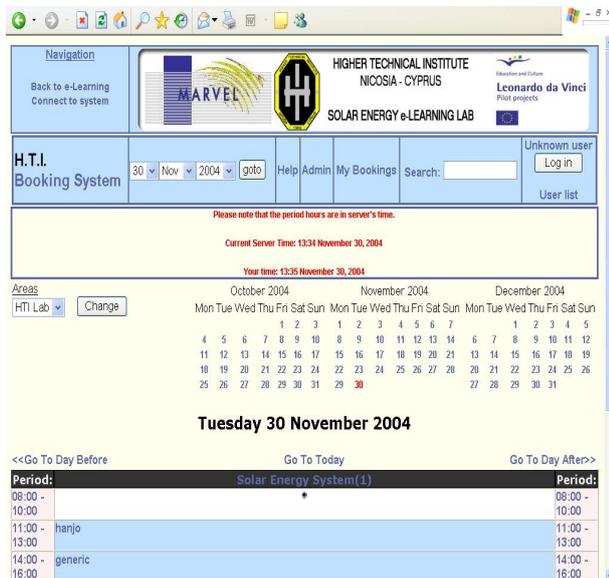


Figure 2: The HTI Solar System booking system which allows for time slot reservations

II. SOFTWARE ARCHITECTURE

A. Overview

The architecture of the system is a layered or tiered architecture. It consists of four different layers with each layer providing its services to the next layer by using the services of the layer below it. In the next sections a description for each of the consisting

components is given. Figure 3 outlines the different layers with a short description of the responsibilities for each one of them.

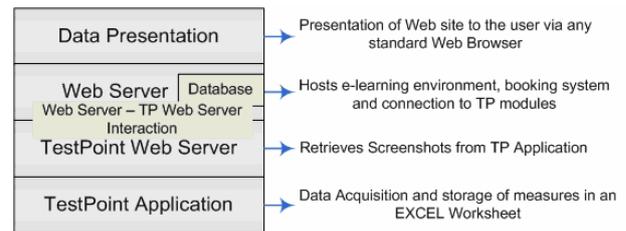


Figure 3. The software architecture of the solar system

For the implementation of this architecture two different computers were used. Figure 4 shows this architecture in a graphical way with the four layers separated by dotted lines.

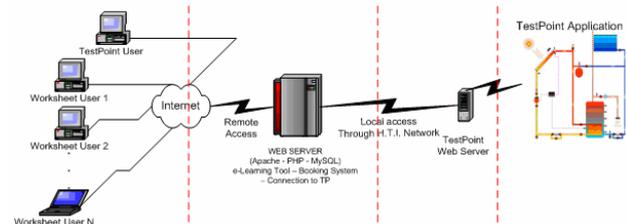


Figure 4. Schematic representation of the system distinguishing the four layers

B. Layer's Description

Data Presentation: A user may visit the laboratory website anytime from anyplace in the world. The only requirements are a computer connected to the internet and any of the standard web browsers. By typing the address of the HTI solar energy e-learning laboratory (<http://e-lab.hti.ac.cy>), the user can visit the initial page of the website. It is possible for visitors with little interest in solar energy to read and study on the subject with no requirements or registration or testing. So, not all of the pages require login. As in matter of fact, one can see most of the pages without the need of creating an account. Login, and thus creating an account, is only needed when the user decides to take the so called pre-lab test. The available activities in the web site are presented in Figure 5.

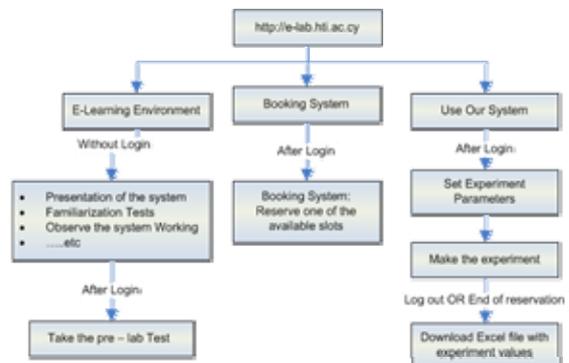


Figure 5: Activities in the Solar Energy e-Lab

Web Server and Database: The initial idea was to use the very popular LAMP (Linux – Apache [5] – MySQL [6] – PHP [7]) platform for the implementation of our system. This idea was strengthened by the fact that moodle, the e-learning environment used, was written in PHP using MySQL as the supporting database. So the team decided to use this platform with the difference of using MS Windows XP rather than Linux. Apache is considered to be one of the best web servers and the fact that PHP and MySQL are now precompiled in the kernel of this server, made its use imperative. On the Web server all the needed files for Moodle are installed, i.e. the booking and the module used to connect to the system.

The MySQL database is also installed on the same machine with all the needed tables to support the installed modules. What is not stored on this server are the screenshots of the system during its normal operation. When the user is connected (or requests to see the system working as an observer) an HTTP request through PHP to the machine hosting the TestPoint Web server is sent asking for the picture of the system with the values at that specific time.

Web Server and TestPoint Web Server Intermediate Level: The interaction of the web server with the TP web server requires actions from both ends. Once the user logs on to the system, he/she has to set the parameters of the experiment. These parameters are written to a text file and the text file is copied to the machine where TestPoint [8] is installed.

TestPoint Web Server: TestPoint's Web Server is a part of the Internet Toolkit, an add-on module to commercially available TestPoint. Its job is to supply screenshots of a part or the whole of a defined TestPoint application that is currently been running. In web server's settings one may define the working port that is going to be used by the client when requesting these screenshots. No further configuration is needed from the laboratory since its task is very simple and straightforward.

TestPoint Application: Once the application is started and initialized and in order to begin measuring, it is looking for an initialization file. When the system detects this file, it reads the configuration parameters, it takes any actions required (e.g. refreshing water) and it starts measuring the values from the various installed instruments. Every 30 seconds these values are also written to an excel file. When the user wishes to logout (or when the reservation slot reaches its end) the configuration file is deleted and the system stops working. The excel file is then copied to the web server, and at the logout screen, and the user is given the option of downloading the file with the stored data, figure 6. If the user closes the browser window without logging off first and to avoid having the system running continuously a batch job on the computer running the TestPoint was added as a safety measure. This batch job runs five minutes after the ending time of each of the reservation

slots and takes all needed actions ensuring that the system is properly stopped and initializes the various parameters for the next user.

	Collector Temperatures (°C)		Water Temperatures (°C)		Storage Tank Temperatures (°C)			Ambient Temp (°C)	Solar Radiation (W/m²)	Collector Flow Rate (l/s)
	Outlet	Inlet	Hot Water out	Fresh water in	Bottom	Mid-point	Top			
4	60.7	58.5	40.8	20.6	37.9	52.8	56.8	13.3	1122.0	0.11
5	60.7	58.5	40.2	20.0	34.4	51.7	47.1	14.5	1119.6	0.11
6	61.3	58.5	40.8	20.6	35.5	52.8	47.1	13.3	1122.0	0.11
7	60.7	58.5	41.9	20.6	37.9	53.4	56.8	13.3	1129.2	0.12
8	61.3	58.5	39.6	19.4	33.8	51.1	48.8	13.3	1134.0	0.11
9	61.3	58.5	40.8	20.0	36.1	52.8	55.7	13.9	1134.0	0.11
10	61.3	58.5	41.4	20.6	37.3	55.4	51.7	13.9	1134.0	0.11
11	61.3	58.5	41.4	20.0	35.5	52.8	47.7	14.5	1119.6	0.11
12	61.3	58.5	41.9	20.6	39.4	53.4	52.3	13.9	1134.0	0.11
13	61.8	59.0	40.8	20.6	36.1	53.4	56.2	13.9	1143.6	0.11
14	61.8	59.0	41.9	20.6	37.9	53.4	48.3	13.9	1153.2	0.11
15	61.8	59.0	40.8	19.4	34.9	52.8	54.5	14.5	1153.2	0.11
16	61.3	59.0	41.4	20.6	39.0	54.0	55.1	13.9	1158.0	0.11
17	61.8	59.6	41.4	19.4	34.9	52.8	47.7	14.5	1153.2	0.11
18	61.8	59.0	40.8	20.0	36.1	52.3	56.2	13.9	1156.6	0.11
19	61.8	59.0	40.8	20.6	35.5	52.8	56.2	13.9	1156.6	0.11
20	62.4	59.0	40.8	20.0	36.7	53.4	57.5	13.9	1162.8	0.11
21	62.4	59.6	41.4	20.6	37.3	53.4	48.8	13.9	1165.2	0.11
22	62.4	59.6	40.8	19.4	34.3	52.8	52.8	13.9	1170.0	0.11

Figure 6. The downloadable EXCEL file with previously recorded data

C. Challenges and solution

There is one issue that concerns every one that offers services through internet, and that is security. So one of the primary concerns right from the start of the system design was security of both the main web server and the TestPoint Web server. The web server is under the HTI domain so the security mechanisms for the whole institute are inherited by the computer hosting the web server. So there was a need for additional security to the machine of hosting TestPoint and its web server. This computer is also under the HTI domain but restrictions from within the institute had to be applied. So with the creation of a Virtual Local Area Network (VLAN), restrictions to this machine were applied allowing the computer hosting the web server to only send requests.

Another point of interest is the various alternatives tested in an effort to set the experimental parameters and start or stop the system. In the previous sections the final solution was described yet at least two more of those efforts worth mentioning. The first approach was to set the parameters by sending HTTP requests and then start and stop the system in some way, according to user actions. This solution was abandoned because of some limitations of TestPoint's Web Server. The second effort included the creation of two standalone applications using C# taking advantage of Microsoft's Remoting Technology [9], a protocol that accompanies .NET platform for programs that need to send or receive data through any network. The module installed on the Web Server would send requests and the module installed on the TestPoint Web Server would serve them. This solution also failed. At that time the experimental parameters were changing while the file was opened by the TestPoint Application. In this case, the C# application was unable to open an already opened file (especially while it was open by a different application). What the program does now is that it reads the file and then

immediately closes it, making thus possible the run of the system.

III. LEARNING PLATFORM

The selected e-learning platform at the web server is Moodle, which is a course management system provided freely as Open Source software (under the GNU Public Licence). Moodle [10] will run on any computer that can run PHP, and can support many types of database, particularly MySQL. This choice allows for flexibility in the learning tools and provides various learning environments to suit the requirements of the various courses [11]. In this particular case Moodle is used as a demonstration, a quiz and an experimental tool. The Moodle capabilities were enhanced so that the running of the actual experimental set-up is only allowed after the successful completion of the preliminary exercises. With this platform, the user can work independently, or work as a team with people from the same class or even from a different school far away talking to each other on the special tool provided at the platform.

IV. LEARNING SCENARIOS - EXPERIMENTAL WORK

The learning scenario comprises a series of exercises of different degree of difficulty and complexity. For each exercise, the student undergoes an online assessment and is allowed to proceed to a real experiment only if he/she is successful to the pre-lab test. It also comprises an indexed glossary which includes a good number of terms and definitions related to the solar energy laboratory. Following is a brief description of the four categories of learning exercises:

A. *Familiarisation with the HTI Pilot Solar Energy Plant*

Two introductory exercises were prepared for the prospective user. Their objective is to familiarize the student with the HTI solar energy e-learning lab and make him/her conversant with the components of the pilot solar energy conversion plant. Upon completion of these exercises the student should be able to name each component in the plant and identify the various components needed to construct a solar plant.

B. *Component functions*

Two more advanced exercises for the interested student were also prepared. The objective of these exercises is to familiarize the student with the system layout, make him conversant with the function of each component and the system operation. At the end of these exercises the student should understand the function and operation of each piece of equipment in the system and appreciate its role in the system as well as introduce him into the hydraulics and flow circuits of the plant.

C. *Live Online Experiment, data collection, storage tank stratification, Investigation of collector instantaneous efficiency*

This will take the student into the real world of experimentation with a number of capabilities. The student will get acquainted with the remote control of the system (getting into the system through the internet, switching ON and OFF the system) and exercise in taking the readings of the various measuring devices, such as temperatures, flow rates and solar radiation. The student will take sets of readings for various conditions and different scenarios. One of the scenarios will be to elaborate on the stratification of temperatures in the vertical type storage tank and get a first-hand experience of the variation of temperatures across the tank at different operational conditions, explain the stratification effect and comment on the results.

Another experiment is to investigate the instantaneous efficiency of the collector or determine the rate of thermal energy removed from the storage tank to the consumption. For this purpose, the student will record a number of readings (incident solar radiation, water flow rates, temperatures, etc.) and using certain thermodynamic equations [12] he/she will determine the performance characteristics of the collector and compare them with those given by the manufacturer.

The test will be conducted at various conditions and with different scenarios such as for example: with or without consumption of service hot water, at different temperature differentials, etc. Should the student have more time available, he/she could use the data recorded in the Excel file downloaded at the logout or any time during the experiment, to plot a graph for the collector efficiency. A screenshot of the system diagram labelled with the real readings is shown in figure 7. The image is refreshing in 5 minute intervals allowing the students adequate time to observe all the readings and encourage a discussion on the displayed results. For example, a discussion could be initiated on the subject of temperature stratification in the storage tank: how do the temperatures at various levels differ, why the temperature at the top of the storage tank is higher, etc.

D. *“Passive” participation to the experiment - watch the system working (no interaction)*

In case the system is busy, because a user is online performing an experiment, another user may get into the e-lab as an observer, without any booking and without needing to conduct the pre-lab test! The system will open a new window and he/she will be able to have a view of the system in operation and get the readings but he/she will not be allowed to intervene into the operation of system or to control the system. He/she can, however, record the readings and use them for calculations if he/she wishes so. There is no limitation to the number of “passive” participants.

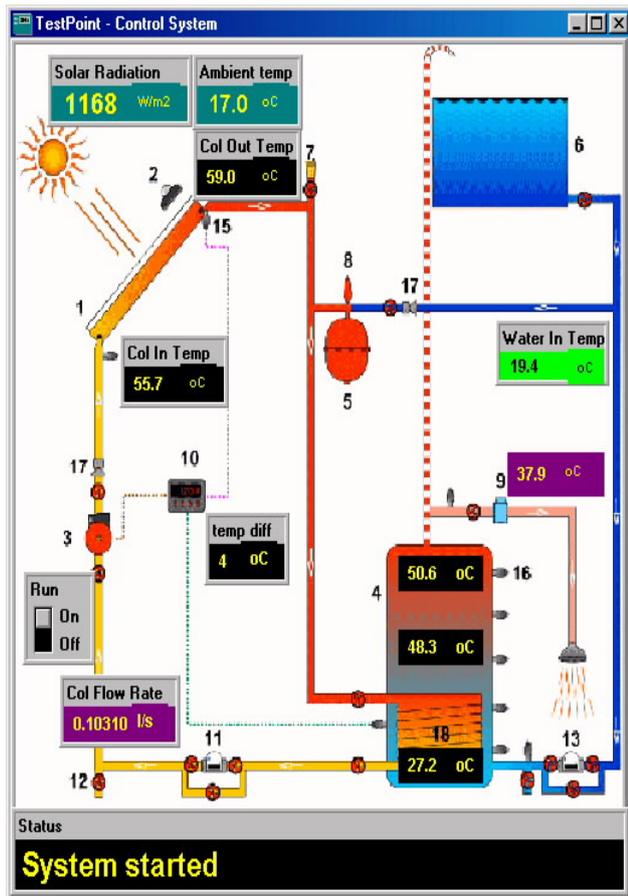


Figure 7. Live online experiment – System real readings

CONCLUSION

An important innovation within the approach of the HTI solar energy e-learning lab is that the concepts and examples for real working and learning are developed and accessed virtually through remote processes. Accordingly the system goes beyond 'traditional' remote laboratories, because it provides distributed work places for remote engineering in technical and vocational training.

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REFERENCES

- [1] Müller, D., Ferreira, J. M., "MARVEL: A mixed-reality learning environment for vocational training in mechatronics", *Proceedings of the Technology Enhanced Learning International Conference*, (TEL'03), Milan, Italy, November 2003.
- [2] Michaelides I., Eleftheriou P., and Müller D. "A remotely accessible solar energy laboratory - A distributed learning experience". *Proceedings 1st International Conference on Remote Engineering and Virtual Instrumentation (REV2004)*, Villach, Austria, 28-29 September 2004, ISBN 3-89958-090-7, (2004).
- [3] Michaelides I., Eleftheriou P. "The HTI e-learning platform – A remotely accessible solar energy laboratory". *HTI Review*, No 33, 33-36, (2004).
- [4] The HTI solar energy e-learning laboratory website: <http://e-lab.hti.ac.cy>
- [5] The Apache HTTP Server Project: a secure, efficient and extensible server, <http://httpd.apache.org/>
- [6] The world's most popular open source database, <http://www.mysql.com/>
- [7] PHP: A widely-used general-purpose scripting language that is especially suited for Web development, <http://www.php.net/>
- [8] TestPoint - Keithley Solutions for Data acquisition. http://www.test-point.com/gen_tp.html
- [9] .NET Remoting: A programming model and runtime support for making interactions between objects living in different processes and machines transparent, <http://msdn.microsoft.com/library/default.asp?url=/library/en-us/dndotnet/html/introremoting.asp>
- [10] Matt Riordan, Moodle – An electronic classroom, Teacher Manual, <http://moodle.org/>
- [11] Moodle – A free, Open Source Course Management System for Online Learning, <http://moodle.org/>
- [12] Duffie J. A. and Beckman W. A. "Solar Engineering of Thermal Processes". John Wiley, New York, 1991, pp. 301-307.

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