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Augmented Reality Internet Labs Versus Hands-On and Virtual Labs: A Comparative Study

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***Abstract*—A comparison between three different types of labs, namely augmented reality remote labs, virtual labs and hands-on is carried out. The availability of hands-on labs in engineering and science education that require costly equipment and instruments is restricted for little and limited periods of time for a huge number of students. Solutions to bypass these problems are through the introduction of augmented reality (AR) remote labs and virtual labs. AR remote lab augments the real experiment scene with virtual objects. On the contrary, a virtual lab is a software simulation, which is an imitation of a real experiment represented by a mathematical model. The paper focuses on an empirical study that compares an AR remote lab developed specially for this purpose with its corresponding hand-on and virtual labs.**

Keywords- Remote Lab, Augmented Reality, Usability Testing, Comparative Evaluation, Virtual Lab, Hands-On.

I. INTRODUCTION

This paper is mainly concerned with both the comparison and evaluation of a remote lab based on augmented reality (AR) for the visualization of the client user-interface, against other two types of labs, namely hands-on and virtual labs. Remote labs are dedicated for disparate types of scientific and engineering experiments. After having designed and implemented a prototype of an AR remote lab, a comparative evaluation was carried out, aimed at checking and proofing the appropriateness of augmented reality for its usage in representing client user-interfaces in remote labs. It is undeniable that labs present an essential part in engineering education because they provide practical knowledge for students. Hands-on labs are available for little and limited periods of time for a huge number of students. The number restriction of lab experiments refers to costly equipment and instruments required for this type of labs. An approach to bypass the mentioned problems is by employing virtual and remote labs that assist students in developing their practical skills. However, applying this type of labs leads to the fact that students suffer from the weakness of reality representation of experiment equipment [1]. Augmented reality is defined as the combination of real environment with virtual computerized objects such as text, 2D images, or 3D models, and/or enhancement to sound, graphics or other human senses. Both the visualization of the application presented through a user-interface to the user or the appearance of user in this ultimate system samples as she/he is working in a single real environment [1]. Milgram et al. [2] explain a taxonomy that identifies the relation of real and virtual environments. The real world and the virtual environment are at the two opposite ends of this continuum with the middle region called mixed reality (MR), which is a region in which real world and virtual world objects are presented together within a single display.

A developed system will be briefly introduced that improves performing experimental lab through Internet using augmented reality technique. Building this system is of great significance, as a prototype is necessary to evaluate carrying out experiments through conventional and AR remote labs. To achieve the previously mentioned objective, the applications of AR technologies in other fields were studied. Understanding the ideas and the techniques behind such applications might be helpful for contributing of newer ideas to our remote AR lab. Furthermore, in order to categorize our approach in the remote labs' landscape, it is significant to be familiar with other kind of remote labs as well as e-learning located behind these techniques. The AR user-interface of the developed remote lab, which will be fed with picture data of the physical experiment on the server side, represents one of the major concerns of this research. The student interacts with the remote system through the interaction devices: mouse, keyboard and monitor. At the begin of an experiment session, she/he has to establish a connection to the remote located AR lab, offering a real view of experiment's circuit by adding an overlapping image or text on the delivered Webcam picture of kit. Once the connection is established, the student can begin to manipulate the experiment.

Although this paper discusses some technical issues of the implemented AR lab, we will mainly focus on the evaluation of the AR remote lab whose visualization uses a form of mixed virtual and real (video-captured) lab elements that can not only be simple elements such as resistors, capacitors, inductors, electromechanical modules, but also more

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complicated units such as oscilloscopes, DDMs, function generators as well. This evaluation compares our AR remote lab with other two lab approaches: hands-on and virtual labs in order to find out how much effective augmented reality Internet labs assist students in understanding and reinforcing their theoretical concepts.

II. HANDS-ON, VIRTUAL LABS AND REMOTE LABS

The main purpose of engineering education is to prepare engineers who can deal with equipment and instruments. Since engineering is an applied science, its courses are containing the biggest part of lab studies. Therefore, labs are essential in scientific education. Recently, the environments of labs have been changed by e-learning technologies, which have opened many doors in education. Students learn more efficiently if they have the chance to carry out experiments because they allow students to compare theories with experiments, collaborate with each other, and give them chance to follow their interests. Unfortunately, many engineering courses do not contain lab component because of great expense and space considerations. Different technologies offer new ways of many educational objectives that changed the lab education land [3]. By using text, pictures and illustrations, and multimedia, we can build simulations of complex processes of biological and medical sciences, agriculture, engineering and educational practice, which are not easily accessible in real time and settings. Simulations allow a student not only to see what is complex, but he can learn from hands on experience as well [5]. In a hands-on lab, a real experiment is locally realized. Two characteristics differentiate hands-on from the other two labs [4]. On the one hand, the real equipment that is used in the lab is physically locally connected, and on the other, the students and the equipment must locally present in the same land of lab.

In the last decades, the usage of virtual labs or simulation lab has increased rapidly in engineering education. Virtual labs enable the student to access the engineering applications easily at anytime and from any computer. Examples of these engineering applications are simulations, demonstrations, and exercises. A virtual lab is a software simulation, which is an imitation of a real experiment represented by a mathematical model. In other words, virtual labs imitate the hand-on lab; that is, instead of performing the experiment on actual equipment, the tests and possibly even the data are simulated on a computer [6]. Unfortunately, this weakens students' reference to reality, and thus, they can't later deal with these components and instruments in real work. Where a simulation commonly replaces the real system, virtual labs typically resort to simulation software such as MATLAB or LabVIEW or specific applications.

Remote labs benefit from contemporary e-leaning and Internet technologies. Now, many academic institutions provide a variety of remote labs experimentations designated as Web-based labs or online labs; these labs support remotely controlled physical experiments [7]. Remote lab may be defined as a lab accessed via a communication network in order to execute a lab experiment, whose usage involves real devices and equipment. The lab server communicates between the user and the physical experiment in the lab [8]. This type of lab is suitable to distance learning courses where students do not need to be locally present on campus. The instruments of an experiment that is controlled through personal computer, is the core of the remote lab. These instruments can be remotely configured by software that makes it easily to share of expensive instruments and equipment. A remote lab must be provided with an interface to send commands and receive feedback from the lab equipment. There are a number of methods that provide remote access to the lab equipment. The general method is the use of a Web browser such as Internet Explorer and Firefox. User access is regulated by schedule and limited time.

III. SOME HARDWARE/SOFTWARE ASPECTS OF THE DEVELOPED AR REMOTE LAB

In order to compare a remote lab using augmented reality with hands-on and virtual labs, it was necessary to specify, design and implement a new one. The experiment used is already available as hands-on. The corresponding virtual lab consisting of a simulation experiment can be created with any simulation software such as MATLAB or LabVIEW or specific applications that is known as problem solving environment (PSE). This approach employs programming code to simulate the result of engineering or scientific problems using quite sophisticated numerical analysis, programming, and graphical tools. Best known of these PSEs is MATLAB, Pspice etc. An augmented reality remote lab is a system composed of hardware and software components that involve the ability to access physical labs through Internet. Individual students utilize a communication network to perform a lab experiment, and interact with a Webpage to access the lab from their homes independent from time and place. In following, we will briefly describe the AR remote lab developed in this research to study how much AR is appropriate to visualize remote labs, describing its distributed system architecture. The main circuit is displayed on student's computer screen with all required components and instruments for enabling him to operate on his experiment interactively. The circuit is consisting of ten red light emitter diodes that are connected in series with each other; these LEDs are located at the terminals of each component and instrument to be wired. The LEDs circuit is necessary in order to assist the HSL filter, which is implemented in forms of a software program, to determine the positions of node's components and instruments on the captured video photo of the AR remote lab's kit.

For allowing effective human-computer interaction, user-centered socio-technical systems must consist not only of pure technical software and hardware components, but demand well designed graphics promoted through taking various ergonomic aspects into account [9]. The user-interface plays a central role for obtaining a harmonic interaction with the whole lab, obligating the necessity to create it with an interactive development environment supporting prototyping and evolutionary development [10] such as the Microsoft dot Net environment, which offers an integrated environment with powerful user-interface tools and rich libraries for creating user-interface components to enable data to be displayed in many forms.

As Fig. 1 shows, the representation of the experiment components such resistors and transistors etc. as well as the used instruments are real using real-time video pictures [11]. As a result, the experimenting student deals with the reality and not with a simulated world, e.g. she/he sees real resistors and instruments and, therefore, she/he can read its value by either using the color rings on the resistors, or calculating resistor values through displayed voltages and currents of these resistors. In this research, wiring of the real represented experiment circuit will be performed based on the AR, where, as previously mentioned, real video pictures are overlapped with virtual wires. The experimenting kit of the AR remote lab visualized on the client user-interface contains all required components and instruments. Using the interaction devices mouse and keyboard, the student can wire his experimental circuit using the last picture taken; this step leads to reduce the distortion of the transferred image that depends on the bandwidth of the Internet. A connection between two nodes on the circuit board is implemented by clicking on the first node and then clicking on the second node, causing that a line between them is drawn (see Fig. 1). So when the student wire point one (x1 , y1) with point two (x2, y2), the software take the (x , y) coordinates of these points (pixels) and refer for node matrix, then take the entries N(x1 , y1) that present the node's number of first clicked node and N(x2 , y2) that present the node's number of second clicked node, put these two elements as a row in matrix, when the student start wiring second wire previous steps again time and put the taken nod's numbers from node matrix in new row and so on.

IV. Comparative Evaluation

One of our objectives of this research study is to find out how much effective augmented reality Internet labs assist students in understanding and reinforcing their theoretical concepts. Swan and Gabbard carried out a survey study showing that between 1998 and 2004, less than 10% of a representative sample of AR scientific publications reported studies with real users [12]. As an example is an evaluation to find out limitations of usability issues of an augmented virtuality environment dedicated for design [13]. An obvious way for doing that would be a comparative evaluation, which compares our system, the AR remote lab, with hand-on and virtual labs. Evaluation of new practical educational systems depends on student surveys to measure the achievement of the required practical skills of the students from these categories of labs, compared with other traditional ones.

A survey questionnaire of closed end questions was implemented and the raw data was collected in order to investigate student perceptions of their experiences of hand-on, virtual, and augmented reality labs in this case study. Closed-end questions are questions in which all possible answers are identified, and the respondent is asked to choose one of the answers (Strongly disagreement, Disagreement, Neutral, Agreement, Strongly disagreement). According to Reja et al. [14], closed-ended questions have advantages: closed-ended questions are generally more straightforward and offer choices for respondents, closed questions guide respondents to specific information needed, closed questions permit to ask more questions in less time, and the data (answers) are easy to tabulate, and to analyze.

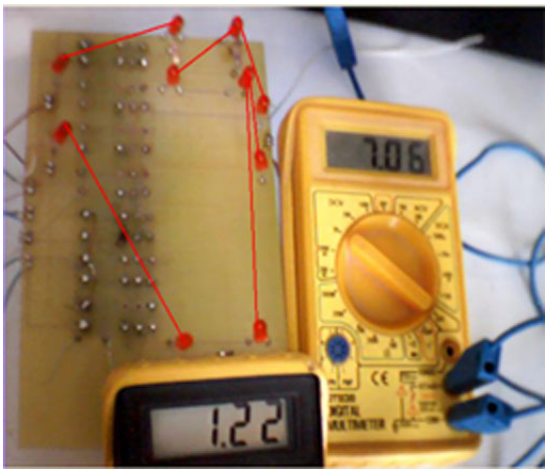

Fig. 1 A virtually wired real circuit in the AR remote lab leads to AR based visualization.

A total of 30 engineering students (13 females and 17 males) from Electrical Engineering Department at Khadoori University were involved in answering in the survey questions. The lab experiment is a circuit that can be configured either in series or in parallel, including electrical and electronic components and instrument such as resisters, power supply, and ammeters. This same experiment exists as hands-on, AR remote lab and virtual lab. Students carried out the same experiment (series and parallel circuit) using the hand-on lab, virtually using an electronic workbench program, and by using the implemented AR remote lab. After completing the three sessions, every student answered the prepared survey questions. The used survey questionnaire consisted of eight questions for evaluating the student perception of hand-on, virtual and AR remote labs, and five other general questions on the usage of the AR remote lab, using a five point, where scores of 1-5 were used to indicate levels of agreement with the statements. The results of the survey questionnaire are discussed in the following section.

After the students finished his experiment on the three types of labs, they answered a list of common questions. The raw data is collected and analyzed. Fig. 2 displays a comparison of the labs regarding the students' perceptions and responses.

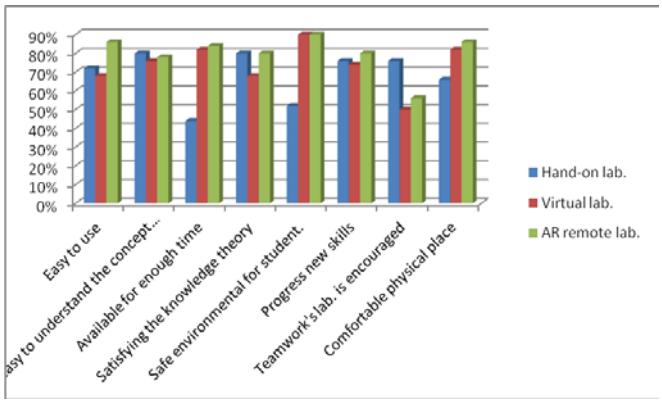

Fig. 2 Survey results on hand-on, virtual, and AR remote labs.

The analysis of the survey results gives these indicators as shown in the following:

- Easy to use: The survey data indicates that while carrying using the hand-on lab, the student faces some difficulties in the experimental work like wiring the circuit that must be isolated between wires in order to avoid any touch between them. In the virtual lab, the students need additional effort to learn how using the software program of the virtual lab. In the AR remote lab, the design of the kit assists the student in the experimental work as all the components and instrument present on his screen. Thus, the student just needs to wire the required components in correct way to take the results from his screen through the Webcam.
- Easy to understand the concept theory: As is obvious, the survey data of the three lab categories gives nearly the same degree in this question because all of these labs are established to demonstrate the theories, providing the students with additional skills of how to deal with these components and instruments in order to prove the concepts.
- Available for enough time: The hand-on lab is not available for enough time for that huge numbers of students to become familiarized with the electrical lab instruments and its components. On the contrary, virtual and AR remote labs are available for students. Using the virtual lab, which is realized a software program running on a PC. In the case of the AR remote lab, the students interact with the AR remote lab from any terminal computer that is connected to the Internet. The student can choice his experiment and its time through schedule time of the experiment to preserve his experimental time. An AR remote lab offers more enough time than hands-on to enable more training and understanding of the problematic.
- Satisfying the knowledge theory: carrying the experiment using the hand-on and AR remote labs, the students deal with real components and instrument so they obtain real results in their environment of the lab. But in the virtual lab, students interact with a simulated experiment realized on a computer and take the results from a mathematical model. In a simulated experiment, there are many errors that may be occurred are ignored such as tolerance errors from manufactories or surrounding temperature of components and instruments, that cause some actual experiments (hand-on) not to work properly.
- Safety environment: In the hand-on lab, the students directly deal with electrical instrument, so the instructor must review the student's connections before executing his experiment, especially for high voltage connections, that need more attention from students and instructor for avoiding any critical error. These errors may harm the students or damage the instruments. In the virtual lab, the students deal with a mathematical model where it represents a safely environment for the students, and thus, we do not need to frighten from any occurring error. In the AR remote lab, the students work their experiment away from the electrical instrument, eliminating the students to be frightened from directly dealing with dangerous instruments. Additionally, by using the implemented e-instructor in the AR remote lab, sensitive instruments and components are protected against damage. We can conclude that the AR remote lab offers a safely environment for both the students and instruments.
- Progress new skills: the survey data show nearly equal results of these labs because of the facts that these labs are created to satisfy the electrical and electronic engineering theory through dealing with electrical components and instruments to prove theses concepts of new practical skill.
- Teamwork's lab is encouraged: Team-work and communication skills can often be found in hand-on lab training. The virtual and AR remote labs, if are not designated for this purpose, could discourage direct collaboration and communication skills. Further work is required in the design of AR remote labs to incorporate collaborative assignments and discussions that may enhance students' transferable skills.
- Comfortable physical place: The results from this questions indicated that the virtual and AR remote labs offers relaxed feeling while a student performs his experiment from his computer and at his wanted time and away from electrical instruments. On the contrary, the hand-on lab is not only restricted in time and place, but the students, instruments and instructors must be presented at the same place, making frighten feeling from tedious wiring and measurements that might damage the electrical instruments.
- Experimental time: The required time for carrying out the experimental work for the same experiment in each lab is different. This is caused according to the different environments of the experimented labs. In the hand-on lab, the students, instruments and instructor must be at the same physical place; the experimental work needs instructor's supplement, which requires additional time, to verify the correctness of experimental connections before feeding the circuit with power supply to avoid possible damaging errors. In the virtual lab the student takes the experiment results of his experimental circuit directly from the mathematical model applied. During the experiment, the student just spends the experimenting time with choosing the components and with connecting the virtually modeled circuit via a computer.

In the AR remote lab, the student accesses his experiment through the Internet, and he is permitted to access the AR remote lab if he has a login name and a password to execute the experiment. It is undeniable that the bandwidth of the Internet influences the experimental time. For small Internet bandwidths, we are enforced to increase the time between two taken successive frames of the Web cam in order to avoid the delays occurring due to the speed of transfer data in Internet. This is allowed in our AR remote lab because the actions of the students relative to the response time of the circuit and the instruments, whose states and outputs are sent to the client as a live video stream, are very slow.

V. CONCLUSION

The results obtained from the comparative evaluation shows that the AR remote lab was generally well accepted from the students. However, the feedback from students' answers indicated that students perceived AR remote lab as easy to use, easy to understand the concept theory, flexible to use in relation to time and place, safety environment and satisfying than virtual labs overall. AR remote lab is considered as synchronous interactive graphics system after recognizing and understanding the captured image of the experimental kit. The user can make the allowing connections using the interaction devices keyboard and mouse. After validating these connections and changing the state of the relays that are responsible for to connect the experiment components with each other by the server, measured data from the experiment is obtained from instrument's screen through the Web camera, which transfers a live video stream of the real experiment to the remotely located student's computer screen.

Students agreed that the AR remote lab experiment assists for illustrating concepts learned in class. In addition, they feel that the AR remote lab is an effective system for enhancing their knowledge of their understanding of the lectures. They have an improved ability to identify the inaccuracies and uncertainties between experimental and theoretical results because there is no simulation in an AR remote lab, indicating the AR remote lab environment experience closer to a hands-on experiment. This is mostly achieved through overlaying real kits (stream video) with virtual (graphical) objects. We can summarize that the students are immersed in their activity while carrying out experiments through the AR remote lab. As the term of immersion examines the strengths of real world and virtual world in the manufactured environment, the average value of the survey results of the AR remote lab, which is superior to hand-on and virtual labs, exposes that the students are “strongly” immersed in their activity of carrying out experiments through the AR remote lab.

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