EMBEDDING MIXED-REALITY LABORATORIES INTO E-LEARNING SYSTEMS FOR ENGINEERING EDUCATION

By

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ABSTRACT

E-learning, virtual learning and mixed reality techniques are now a global integral part of the academic and educational systems. They provide easier access to educational opportunities to a very wide spectrum of individuals to pursue their educational and qualification objectives. These modern techniques have the potentials to improve the quality of the teaching and learning process and elevate its performance to higher standards. Furthermore, e-learning in conjunction with mixed reality techniques can reduce the cost of higher education at both institutional and individual learner levels.

In this paper, the focus will be on teaching-learning of applied science such as engineering. These studies demand special requirements, such as acquiring specific technical skills and practices through training. Our objective in this paper is the explanation and design of remote laboratories in mixed-reality mode. Decision making and evaluation of performance using fuzzy logic will be embedded in the proposed design.

Keywords: E-learning, Engineering Education, Virtual Labs, Remote Labs, Mixed-Reality, Fuzzy Decision Making.

INTRODUCTION

The fast development and implementation of computers and communication technologies led to the advent of advanced and global communication tools between people such as the internet teleconferencing and mobile phone networks. The concept and implementation of e-learning which is really an on-line education approach, has, become an established educational modern and up-to-date way of learning since the nineties of the last century. It has proved its effectiveness and flexibility as a tool for teaching and learning in academic institutions. It provides a wide range of opportunities for learners and knowledge and academic qualification seekers to pursue numerous approaches to fulfill their educational objectives. While on the other hand, it also provides knowledge providers such as instructors, faculty members and professors with excellent, innovative and flexible ways to teach their students. E-learning is now an integral part of academic and educational systems. This is because it provides easier access to educational opportunities, improves quality of teaching-learning process. On top of that it has the potential to reduce the cost of higher

education at learner and institute levels (Curran, 2004; Watanbe, 2005).

In some disciplines, the application of e-learning has been to a certain extent straight forward due to the state of art of advanced technological systems. On the other hand disciplines of applied sciences such as engineering have additional requirement, where technical education to develop practical skills is essential to the engineering profession (Millar, 2009). This situation necessitated the need to integrate the function of a laboratory in the e-learning system. In order to address the idea virtual laboratory have became a reality in concept and application. There are now, local hands on laboratories, simulated laboratory, where real object and devices are replaced by virtual parts. These two types can operate in local and/or remote modes (Ma and Nickerson, 2006). The other novel approach that is receiving a rapid increasing interest is the mixing of real devices in real work space with remote simulated laboratories to generate new concepts known as mixed reality laboratory (Müller and Ferreira, 2004).

A survey of literature in the field of e-learning, virtual

experimentation and mixed reality laboratories, shows that there are numerous papers within this field addressing different disciplines of engineering. Schaf and Pereira (2009) presented a proposal to integrate mixed reality remote experimentation into virtual learning environments using interchangeable components. Schaf also published two papers for control and automation education using the combination of local, remote, virtual and mixed reality laboratories (Pereira et. al., 2012; Schaf and Pereira, 2007). They concluded, and from their experiences that these tools can make an efficient contribution to motivate the student and promote effective teaching and learning. Aleksandrov et. al. (2012) discussed the issue of real time access of the web for the purpose of mechatronics laboratory education. The paper fully uses the internet to achieve remote access laboratory to control a robot from distanced computer. Gupta et.al. (2012) developed a virtual laboratory module to teach the concepts of electronic and magnetic fields patterns in waveguides. The developed module can help the learner to gain a better and deeper understanding of the electric and magnetic patterns and modes in waveguides. Ponta and Donzellini (2007, 2008) presented the concept of a virtual laboratory for digital design for combinational and sequential logic circuits, finite state machines, microcomputers interface and programming at assembly level. Farah et.al. (2012) presented the design of an interface for multiple remote electronic virtual laboratory. The design is a flexible hardware interface based PID control techniques.

In this paper, the features of all different types of laboratories are explained and the design of remote mixed reality laboratories is presented. Fuzzy logic techniques are adopted within the design of the proposed system as a tool for decision making and performance evaluation.

It would be of interest to study the relative position of Arab universities with regards to the adoption and application of e-learning in general in Arab educational system. The challenges and problems facing the Arab universities to harness the advantages of e-learning will be discussed.

E-learning and Arab Universities

In developed countries e-learning is recognized as a modern teaching-learning tool and has been integrated in the educational system. The results show that e-learning has provided a great deal of advantages and elevated the teaching-learning process to higher standards with many positive returns. In contrast, the potential and advantages of e-learning have not yet been fully harnessed to support human development in developing countries such as the Arab world. Arab universities remain far removed from the adaptation of e-learning with the exception of some shy attempts in Arab Gulf states universities. It is obvious that this essential modern tool, if adopted properly, can have really positive impact to elevate the performance of the traditional Arab educational institutes. Unfortunately, the introduction of e-learning into the present education systems in Arab universities can face critical challenges and problems, which are in some case chronic, these can be summarized as follows

- The traditional education Arab system is strained beyond limits to cope with the demographic population growth rate of almost 2.5% which is double the world rate. This generates higher demands which are beyond the capacity of Arab educational system.

- High level of illiteracy, which is mainly distributed in urban regions.

- In the last half century Arab universities have to function in an environment far from being ideal as most Arab countries had suffered or still suffering persistent conflicts, occupation, war and embargos.

- The high cost of modern laboratories in advanced disciplines is on the whole beyond the budget of Arab universities.

- Chronic shortage of skilled instructors to teach or facilitate advanced laboratories.

- Poor infrastructure of basic technological services such as communication network, computer networking and services.

- The absence of any e-learning culture in virtually all educational institutes and at all levels.

- Urgent need for responsible academic leadership that understand and appreciate e-learning and blended education.

- The need for an appropriate e-learning strategies that can over ride the challenges and accelerate the adaptation of e-learning in Arab educational systems.

- The poor state of instructors and managers for e-learning poses a special problem which is more aggravated by the persistent brain drain that leads to scarcity of proper skills and expertise.

- Present rules and regulations at Arab universities are not sufficiently flexible to accommodate the application of e-learning.

- Poor level of technical English can pose a hurdle in the communication of the learner within the process of e-learning.

With the enormity of these challenges, e-learning, virtual and mixed reality laboratories can be considered as an important key to reduce these negative aspects and turn them in the proper directions.

Classification of Laboratories

Students can deal with real experiments using physical equipments and simulated experiments with three dimensional virtual world, work with real and/or simulated experiments (Schaf and Pereira, 2007). More recently, and due to advances in information and communication technology, new laboratories have been developed by combining real and simulated components accessed through the internet. In this case, virtual reality and mixed reality concepts are applied.

Laboratories can be classified into four types according to their equipments if they are real or simulated units, as given in Table 1. These types are:

- Real (Hands-on) laboratories: Are conventional laboratories with real physical equipments accessed locally by students.

- Simulated laboratories: All equipments are simulated and accessed locally by students.

- Remote laboratories: Real components accessed emotely by authorized students.

- Virtual laboratories: Simulated components accessed remotely by authorized students.

Traditional and Remote Laboratories

The main objective of laboratories is to enable students to use their theoretical background and problem solving skills to deal with experiments to reach conclusions by observations and analyzing obtained data. Students are able to understand how devices work and how to use their knowledge and understanding practical issues of the experiment to formulate suitable solution and gain useful knowledge.

In traditional laboratories, students deal with experimental problems with limited information, since more details are given by laboratory supervisor or technician. Remote laboratories may offer students the same opportunities with a slightly different approach. Depending on graphic user interface and electronic interfaces between equipments and computer, students can follow the given procedures and can understand all details related to the experiment components and their practical issues.

Remote laboratories are becoming an important topic of research during recent years (Pereira et.al., 2012; Schaf and Pereira, 2007). They have the potential to provide real experimental data by sharing several experimental equipments with a group of universities. Figure 1 outlines the interaction between users and experiments in a remote laboratory, where certain experiment can be accessed by the student through the internet. Such laboratories have the following features

- Enhance the efficiency of the laboratories by increasing students intake and flexible availability of various experiments.

- Expansion of the capabilities of conventional

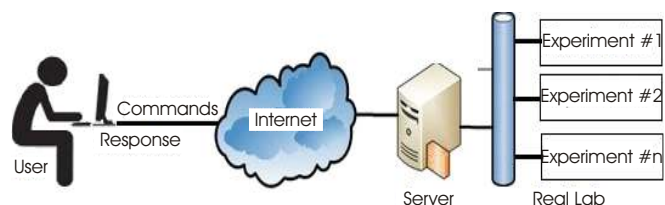| Laboratory Type	Laboratory Equipments	Access Method
Traditional lab	Real components	Local
Simulated lab	Simulated units	Local
Remote lab	Real components	Remote
Virtual lab	Simulated units	Remote

Table 1. Classification of Laboratories

Figure 1. User-Experiment Interaction in a Remote Laboratory

laboratory by additional equipments, wider spectrum of experiments and better interaction opportunities.

- Flexible time scheduling and freedom for student to report the experiment and examine the results and conclusion.

- According to reports, comparative studies in literatures show that these modern laboratories are more attractive to students.

Simulated and Virtual Laboratories

Computer simulation has become a useful tool for modeling real plants for system design, performance optimization, safety control, testing, training, education, and others. Recently, it has become possible to develop several simulated experiments using simulated components instead of real components. Simulated laboratories offer learners the chance to deal with simulated components in order to understand the objectives, technology setup, procedures and discuss the obtained results.

The advantages of using simulated laboratories are (Pereira et.al., 2012)

- They can be easily replicated.

- Learners can use multiple copies of the same simulation simultaneously.

- Learners can speed up slow dynamics systems for quick visualization.

- Safety concerns involving simulation variables limits are not as important as in real experiments since the simulated models cannot cause injuries.

Despite the advantages, simulated laboratories suffer from several drawbacks including (Pereira et.al, 2012; Schaf and Pereira, 2007);

- The main goal of engineering education is to provide students with skills to deal with problems of real devices.

- In engineering education, theory must be evaluated by testing hypothesis on real experiments.

- Students like to realize the reality and impact of all components in the experiment to deal properly with experimental results.

Recently, many attempts have been made to overcome

the above drawbacks by applying mixed reality techniques in the design of new laboratories that can be remotely accessed.

Mixed Reality-Based Laboratories

Remote Laboratories are attractive tools for teaching collaborative work skills, since they offer interesting perspectives for collaborative learning from multiple and distributed locations. However, remote laboratories separate users from the real components and equipments. Therefore, remote laboratories require a sufficient degree of interactivity to give students the impression of actually being in the laboratory (Farah et.al., 2012).

Mixed reality is a concept focuses on how the virtual and real worlds can be combined into a unified interaction space to produce new environments and visualizations, where physical and digital objects interact in real time (Young et.al., 2011; Al-Aubidy, 2005). Mixed reality creates a view of reality that is modified by computer-generated inputs. This technology is meant to add information, meaning and value to the real world in real time. This technology has a broad range of applications from enhanced advertising campaigns, to providing more relevant educational experiences (Saleem, and Al-Aubidy, 2008).

Mixed reality laboratory is defined as a hands-on laboratory whose physical devices are interfaced to the computer using set of sensors and actuators, (Figure 2). Mixed reality interfaces can overlay graphics, video, and audio onto the real world by using special devices and sophisticated software. Similarly, it is also possible to build 3D digital modules to graphically present the devices in simulated laboratories, leading to virtual reality laboratories on which the real world devices are replaced by their virtual models (Pereira et.al., 2012).

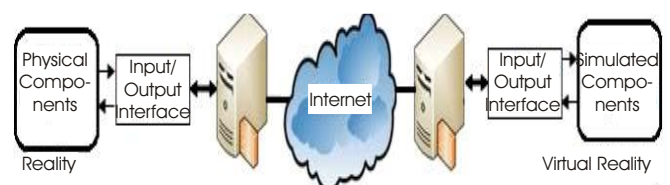Laboratories with remote access and mixed reality have

Figure 2. Interface Between Real and Simulated Objects

real advantages and positive features which can be summarized by

- *Global Access:* They provide the opportunity of educational institutes and individual students worldwide to share the services at the laboratory.

- *Cost Effective:* Remote and mixed reality laboratories minimize cost and time needed to travel to local laboratory.

- *Remote Maintenance:* Performing remote experimentation can help to develop some additional engineering skills such as remote maintenance of systems and devices.

- *Collaboration Mode:* Working in distributed team mode helps the learner to acquire the skills to act in remote group and collaboration mode.

- *Parallel Operation:* Parallel use of a set of experiments, i.e. multi-use by several students is a real possibility.

- *Specific Applications:* Some experiments in certain fields, such as nano engineering, cannot be performed in local laboratory and students must use simulated equipments and models.

- *Risk Avoidance:* Some experiments in some fields are very risky such as high voltage engineering and chemical engineering. Virtual laboratories can offer safer alternative.

Virtual Learning Environment

Virtual laboratories represent distributed environments of simulation which are intended to perform the interactive simulation of a mathematical model of a real system, which basically means a remote accessible simulated lab (Pereira et.al., 2012). Virtual reality is a realistic simulation of an environment, including three-dimensional graphics using interactive software and hardware. Virtual reality is an artificial environment that is created with software and presented to the user in such a way that the user is surrounded by a three dimensional computer-generated representation, and is able to move around in the virtual world and see it from different angles, to deal with it, and reshape it to be suitable for the desired application (Saleem and Al-Aubidy, 2008). The simplest form of virtual reality is a three-dimensional image that can be explored

interactively so that the content of the image moves in some direction or zooms in or out (Thubaasini et.al., 2010).

There are several software tools for creating virtual reality effects on personal computers, these include Bryce, Extreme 3D, Ray Dream Studio, true Space, 3D Studio MAX, and Visual Reality. The Virtual Reality Modeling Language (VRML) allows the creator to specify images and the rules for their display and interaction using textual language statements.

A special hardware and software requirements are necessary to construct an interactive virtual reality environment (Al-Aubidy, 2005). Figure 3 illustrates a typical virtual reality system consists of five basic components, these are:

- *Virtual Environment:* A user can have a complete view of equipment performance through a graphic user interface.

- *Interface Unit:* A data acquisition and distribution unit for interfacing between the computer and special sensors and actuators.

- *Virtual Reality Equipments:* Special components and tools allow user to deal with virtual reality environment. Stereo glasses are used by users to view computer-generated images in true three-dimensional stereo depth. Gloves are used to communicate with virtual environment through user's fingers control. Position detection sensors are necessary for tracking the position and orientation of the user's head and hands in three-dimensional space.

- *Virtual Reality Modeling:* Real-time software is necessary in any virtual environment, this may include; algorithms for creating virtual environments, and mathematical models of real components and plants.

- *Management Software:* An intelligent software is required to manage all tasks in the virtual environment.
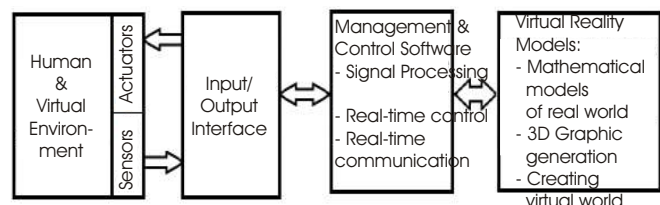
Figure 3. A Typical Virtual Reality Components

This includes signal processing and real-time control of the changing virtual reality.

Mixed Reality Laboratory Environment

According to the experiments setup and laboratory nature, some physical components are available in the laboratory, and others can be replaced by its mathematical model and simulated in real time. The simulated components can be run in conjunction with real components under mixed reality environment (Saleem and Al-Aubidy, 2008). A general layout of a mixed-reality-based remote laboratory is given in Figure 4. Remote learners can interact in real-time mode with actual environment of real laboratory using its multimedia devices such as a camera and a microphone.

Mixed reality environment may have two modes of operation, these are

- Off-Line Mode: Running pure simulation for components and plants to determine suitable values of parameters related to the experiment.

- On-Line Mode: Running real-time simulation on real components through the interface unit.

Mixed reality environment allows several experiments to be built and synthesized with different virtual components by simply replacing the component according to the experiment requirements (Saleem and Al-Aubidy, 2008). Furthermore, the mixed reality environment gives the capability to monitor the system's behavior by observing the output signals in the experiments. These signals can be stored and used to fill the experiment sheet which should be submitted at the end of the session. Moreover, these signals should facilitate the student's appreciation for the
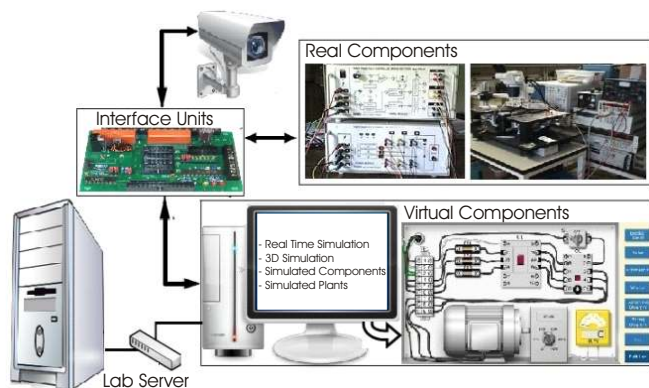

Figure 4. Mixed-Reality-Based Remote Laboratory

experiments which is normally difficult to be achieved in the case of distance learning (Saleem and Al-Aubidy, 2008; Gomes, 2007).

It is not easy to establish mixed reality environment due to the real-time interfacing for mixing real components and virtual reality environment. Such interfacing units are required to provide bidirectional information flow between real and virtual components, (Figure 2). Real components may be electrical, mechanical, hydraulic or pneumatic devices. Some of them are analog signals, others with digital signals. While, virtual components are simulated units and deals with digital signals. A flexible hybrid interface which represents a hardware and software implementation of this mechanism to convert signals in order to couple real components with virtual objects (Gomes, 2007).

The real and virtual components can be located at remote sites connected through the internet. The management software allows learners (distributed at different locations) to access online experiments. Also, learners can together solve different tasks at their virtual workbenches and export results obtained from virtual experiment to the real workbench for testing their results in reality. To take advantages of web technology, real and virtual components can be implemented as a web services by the laboratory server.

Proposed Remote Laboratory Design

The proposed remote laboratory can be designed as a web service to take advantages of the possibilities of anywhere any time access from any computer connected to the internet. The web technology is suitable for building a remote laboratory for e-learning systems (Saleem and Al-Aubidy, 2008).

The General Concepts of the Design

Remote laboratories offer experiments performed in real-time just as traditional experiments. The difference is that student dealing with physical components and/or simulated components remotely using a computer connecting to the internet. Each experiment has a local controller with an IP address that transmits data to the lab server. More than one server may be used for delivering laboratory experiences to students, as shown in Figure 5.
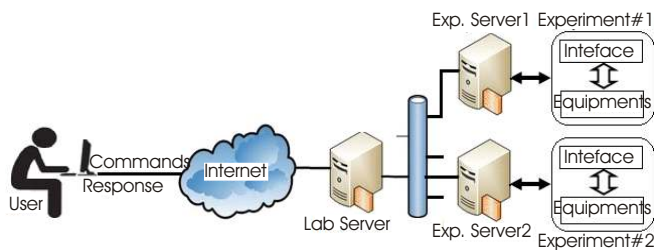
Figure 5. Remotely Access Experiments

The web implementation for a remote laboratory offers easy access to the selected experiment, such that the student can deal with each component to acquire data and identify overall performance of the experiment.

User Side

The user side in a remote laboratory is mainly the software required by an authorized learner to deal with experiments. The learner is guided through a set of procedures to select a certain experiment, read related teaching materials, set-up the experiment components and parameters, and get help or more related information. Depending on the selected experiment, the learner may need to send a file to the remote laboratory server, view a real-time video of what is going on in the laboratory, receiving a file with the obtained results from the experiment, interact with the experiment by changing some set-points and parameters, or any other function provided by the system.

There are several technologies for the client server design, such as Java Applets, Adobe flash, AJAX, HTML, and Active X (Gomes, 2007). Each technology application has advantages and disadvantages depending on the nature of experiments in the remote laboratory. From design point of view, it is so important to provide user with all the required functionalities of the remote laboratory through an accessible web.

Lab-Server Side

A laboratory server is required for scheduling, data collection and instructions. It offers learners with instructions and procedures for completing laboratory assignments and any other related information for all experiments.

The server side of the remote laboratory is an essential part of the remote laboratory design. The whole system quality depends mainly on the quality of the server technology used and on what characteristics needed in the client.

The chosen technology for the server should be selected to suite the laboratory requirements and to make user application flexible to deal with experiments. From design point of view, the designer must use the suitable technology to develop a secure, scalable, and maintainable server. In this case, the technologies used in one side can make the technologies used in the other side more or less suitable. Furthermore, the selected technology offers a flexible user interface and powerful control features. It can be accessed from anywhere in the world without the need for special software on the workstation. Through a browser, a learner can access any experiment and deals with several functions such as setting/changing procedures, adjusting set-points, viewing results, and much more.

In general, the laboratory server must be prepared to deal with four major parts; laboratory materials, student's information, laboratory activities management and mixed reality environment, as illustrated in Figure 6.

- Learning Material Manager: The learning materials include theoretical background of experiments, specifications and functions of all components in each experiment, procedures and parameters selection. The learning materials of each experiment have three contents; brief, normal and detailed. These materials are prepared to cope with various learners levels attending the course (Al-Aubidy, 2005; Saleem and Al-Aubidy, 2008).

- Learner Guide: Based on experiment metrics performed by the user, the learner guide suggests suitable learning materials, with suitable information and setup of the required experiment, to be reviewed by the learner. If the learner has enough knowledge,
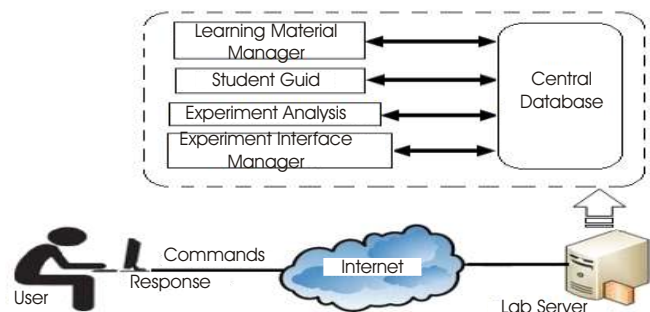

Figure 6. Basic Modules of the Laboratory Server

then the given information related to the experiment will be brief, while if the learner has no information about the experiment, then the laboratory server provides learner with full information.

- Experiment Analysis: During real-time running of the required experiment, the experiment analysis tool will perform the following

  - Compare the results of experiment performed by learner with the problem specification.

  - Generate experiment metrics which are directly related to the performance of the experiment performed by the learner.

- Experiment Interface Manager: This module interfaces the integration of real and simulated components in the laboratory with the virtual learning environment. A standard interface is usually used to provide a common, simple and reliable interface to all components. To design an interactive e-learning system, the interface manager provides real-time tool to:

  - Select experiment components (real and simulated).

  - Synchronize timing behavior of virtual and real components (Schaf and Pereira, 2009).

  - Run the experiment according to the given setup.

Figure 7 illustrates the control flow activities for the integration between virtual environment and mixed reality environment in the proposed remote laboratory.
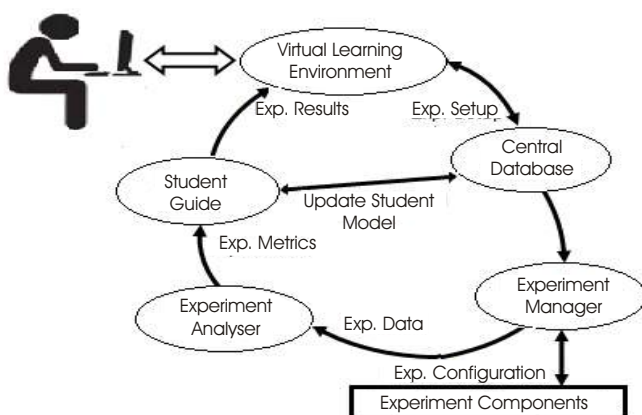

Figure 7. Control Flow Diagram of Proposed Remote Laboratory

Decision Making and Performance Evaluation

One of the most important requirements to achieve an attractive mixed reality based laboratory is to adopt an intelligent decision making and performance evaluation module to deal with the progress of the learning process, which include:

- Providing appropriate learning materials for each learner according to his/her knowledge level.

- Managing the learning materials related to each experiment.

- Examining the learner's degree of understanding to the selected experiment.

- Analyzing the collected information about each learner to update his/her knowledge level.

It is necessary, and in order to provide the appropriate learning material to each learner, the learner model must be updated according to his/her progress. In this case, it is required to adopt suitable methods for knowledge representation, acquisition and real-time modeling and evaluation.

The knowledge representation used for decisions learning management has a great importance in designing mixed reality based laboratory. The sequence of the learning events that is based on the laboratory objectives, experiment requirements, and ability of the student to deal with the selected experiment. Fuzzy logic can be a suitable tool to deal with vague knowledge and the process of decision making and evaluation in such a system. For real-time modeling and decision making, fuzzy-based software can be adopted to deal with the following

- Updating learner model.

- Specifying the learner knowledge level during each experiment test.

- Modeling of real world environments.

- Generating on-line 3-D graphic animation.

- Creating virtual environments.

- Real-time control of the changing virtual reality.

- Choosing suitable learning path for the learner.

- Overall evaluation of the learner.

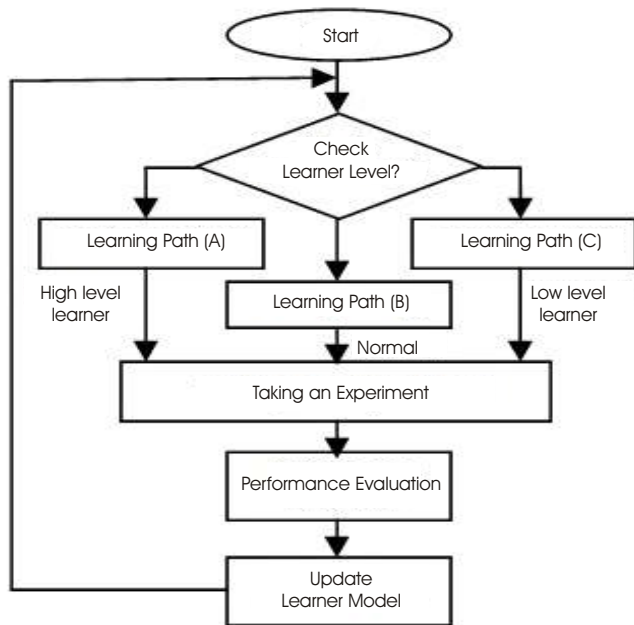Figure 8 outlines the flowchart of the decision making and

Figure 8. Decision Making and Evaluation Performance Process

evaluation performance process required to update learner model. The proposed learning system has three learning levels

- Learning path (A): Includes a summary of the learning material for the selected experiment, which is quite enough for high level learners.

- Learning path (B): Includes the normal information about selected experiment as that given for normal learners.

- Learning path (C): Includes the detailed information that facilitates the learning process for beginners.

This learning system allows high quality learners to go through the experiment easily with minimum time, while low ability learners take more time with higher effort to pass each experiment. The operation of the proposed e-learning system illustrated in Fig.8 can be summarized as the follows

- A pre-test is required to specify the learner knowledge level, which enables him/her to download materials and procedures related to the selected experiment.

- The learner guide will test the learner ability at the end of each experiment to update his/her model and to specify the new learning path. According to his/her test in the current experiment, the learner with grade

"Good" or "Very Good" can transform from learning level (B) to (A) or from (C) to (B) in the next experiment, while the learner with grade "Fail" will transform from the current learning path (A or B) to learning path (C) and remains at the same educational unit.

- If the test result of the learner at learning level (C) is (Fail), then the system will advise the learner to leave this laboratory.

This can be achieved by applying fuzzy logic as a tool for knowledge presentation and decision making. The linguist variable of the learner test (T), for example, can be represented by five fuzzy sets; Excellent (Ex), Very Good (VG), Good (G), Pass (P), and Fail (F), as illustrated in Figure 9. In the same way, the learner ability to deal with experiments is represented by three sets (A, B and C).

Table 2 illustrates a set of fuzzy rules combine the current learning path and experiment test result to update the learner model by generating the next learning path. In general, a rule is an implication statement expressing the current learning level, test result and learning path in the next experiment in a given laboratory. For example, the rule:

If CLC and TVG then NLB

This means that if the current learning path is path (C) and the experiment test is very good (VG) then the next learning path (NL) is path (B). In this system 15 rules have been used

| | | Current Learning Path | | |
		CLA	CLB	CLC
Learner Test	TEx	NLA	NLA	NLA
	TVG	NLA	NLA	NLB
	TG	NLA	NLB	NLB
	TP	NLB	NLC	NLC
	TF	NLB	NLC	OUT

Note: (C) Current , (T) Test , (N) Next , (L) Learning Path
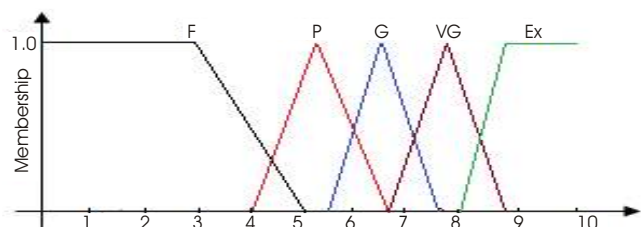
Table 2. Fuzzy Decision Making Rules

Figure 9. Fuzzy Sets of Learner Progress

to specify the decision making and performance evaluation.

Conclusion

The application of the advanced technological systems in the learning-teaching process is paving the way to the development of a powerful innovative educational paradigm. E-learning with mixed reality laboratories in remote mode of operation is proving to be an education tool of choice in modern higher education institutes. Progressive research and development in this field show that this tool of learning has proved to be popular with student as the system provide the appropriate material level and at suitable pace that the learner favors. The system can be considered as automated performance evaluator and feedback tool for the university administration in real-time mode.

The issue of running and maintenance cost is in the favor of this tool due to the global sharing between different universities. The expansion and further development and application of any virtual laboratory is readily possible and available, which made these laboratories advanced, updated and at the edge of the frontier technology.

E-learning and application of mixed reality laboratories and due to the reduction of cost and their availability anywhere anytime make these laboratories ideal to be introduced into the educational Arab system. They are really the answer to the many problems facing Arab universities.

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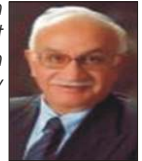
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