

A novel experimental teaching approach for electrical engineering based on semi-physical simulation

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ABSTRACT: Electrical engineering courses are seen as important and are offered by most universities and colleges. The electrical engineering courses are characterised by the use of experiments in the teaching of the subject. A novel experimental teaching platform for these courses is reported in this article. On the experimental platform, machinery is simulated by virtual reality (VR) in a computer connected to the real electrical control system by a group of electrical signal generators. This experimental platform is referred to as a semi-physical simulation experimental platform since it combines real physical controllers with virtual machinery. Compared with the traditional hardware experimental platform, the semi-physical simulation experimental platform is more flexible, safer, is lower-cost and easier to use.

INTRODUCTION

As electrical engineering is widely used in industrial automation, electric, electronic and mechanical systems, electrical engineering has become one of the major courses in higher education [1-4]. Therefore, electrical engineering courses are becoming more important for engineering students majoring in electrics, automation, machinery and other related engineering fields.

Many colleges offer electrical engineering courses. These include Chongqing University and Hunan University, in which the subjects include micro control units (MCU), electrical control and programmable logic controllers (PLC) [5][6]. Most electrical engineering training is practical, based on experiments [7][8].

Traditional electrical engineering courses use PLC training boxes or cognitive electronic relay test suites for training [9]. programmable logic controller training boxes have an AC power input, PLC host, programming cables, lights and other components. The external devices are made up of light-emitting diode (LEDs), DC motors, stepper motors and other executing agencies. The common cognitive electronic relay test suite consists of LEDs, switches, resistors and motors as actuators. These two platforms are physical structures that do not have a controlled mechanical object. Instead, LED displays are used to indicate the effect on a real mechanical object. A traditional training platform is shown in Figure 1. These kinds of platform are inflexible, i.e. they are not easy to update to extend their functionality. Besides, the physical electrical systems may not be safe for beginners.

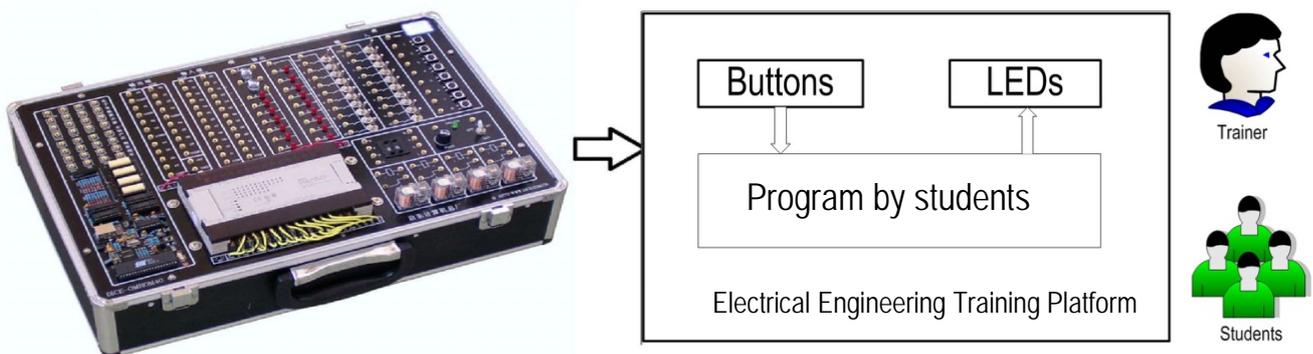


Figure 1: The traditional electrical engineering training platform.

However, the traditional electrical engineering training platforms cannot correctly emulate the behaviour of mechanical devices. As shown in Figure 1, for PLC practical courses, students download their own experimental programs into the controllers and observe the output signals (LEDs), resulting from different input signals (buttons). The traditional PLC training boxes can emulate only signal inputs and outputs and cannot emulate mechanical devices. Other mechanical models can be connected to emulate the behaviour of a full-size mechanical device, just as the common cognitive electronic relay test suite does.

Those models can be applied only to some industrial cases. However, industrial automation is a rapidly developing field [10]. Many new applications appear every year [11-14]. Electrical engineering courses should track the development of industrial automation, which requires training platforms to be updated in time to emulate the latest electrical engineering developments. But, as mentioned above, the existing platforms are not easy to update. An alternative is the timely purchase of the latest platform, but this would be expensive. These issues have caused a disconnection between theory and practice. Students cannot clearly understand the control of a real device. Therefore, it is urgent to find a novel approach by which to implement electrical engineering training platforms that are flexible, so that they can be updated quickly, as well as being safe and low-cost.

With the development of virtual reality (VR), computers can accurately simulate physical behavior to a certain degree [15-16]. The VR technology offers a new way to design and implement electrical engineering training platforms. The work reported in this article is a presentation of a novel training platform based on a semi-physical simulation for electrical engineering experimental education. The platform is a combination of VR simulation with traditional electrical systems, including controllers. The electrical systems retain their electrical properties, which guarantee electrical authenticity *vis-à-vis* real industrial systems.

Meanwhile, the VR simulation means the platform has enough flexibility by which to emulate a wide range of control objects. This experimental platform is referred to as a semi-physical simulation experimental platform, because it combines real physical controllers with virtual machinery. The semi-physical simulation platform is easy to update, safe and low cost. This meets the requirements for a new electrical engineering training platform. How to build a bridge between the physical controllers and the simulated virtual mechanical devices is the key to this novel electrical engineering training platform.

SEMI-PHYSICAL SIMULATION ELECTRICAL ENGINEERING TRAINING PLATFORM

Need for a New Approach to the Training Platform

The typical control equipment used in electrical engineering courses limits students to an unintuitive understanding of the process of controlling equipment. Therefore, in traditional college education it is hard to develop practical abilities that require combining theory with practice. Traditional control devices used by students are too small, but a platform with a full physical structure would be too expensive and difficult to update. Hence, the semi-physical simulation electrical engineering training platform for electrical engineering courses should be used and is presented in this article.

The semi-physical simulation electrical engineering training platform combines virtual mechanical devices with real controllers. The aim of this platform is to show students the behaviour of the machinery associated with the controller programs. As shown in Figure 2, in a typical industrial application, the controller receives input signals representing manual commands from buttons or sensor inputs from a mechanical device. The controller program receives the input signals and, then, outputs the control signals to the mechanical devices so as to control the device.

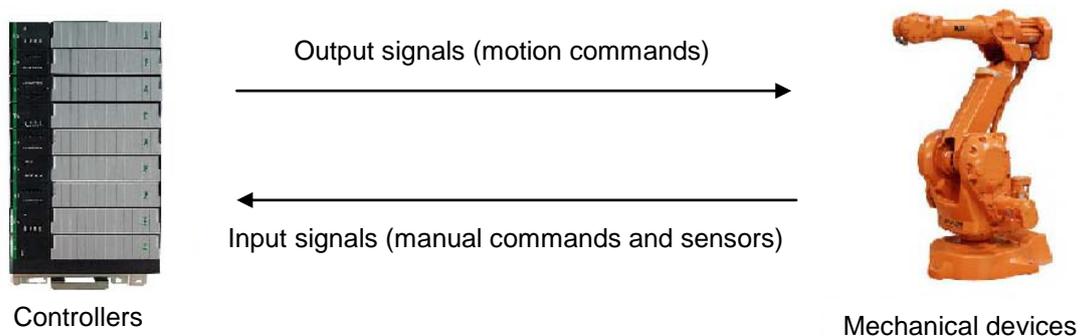


Figure 2: Real control work flow in a typical industrial application.

Current University Training Platforms

Actually, as shown in Figure 3, most colleges and universities usually do not have an actual mechanical controlled object, but rather LED displays simulate the behaviour of the controlled object. The students can only observe their

program's operation by observing the LED, as opposed to the actual behavior of the controlled object. This method is not intuitive and is not conducive to students' understanding.

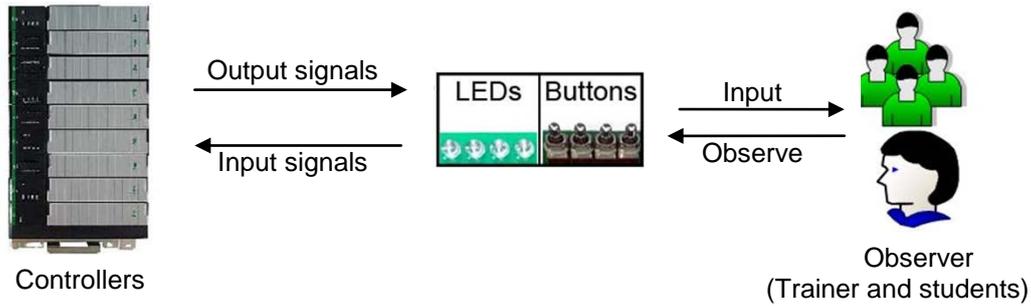


Figure 3: The control flow in a traditional university experiment.

Semi-physical Simulation Approach

In this new approach, as shown in Figure 4, mechanical devices are simulated in computers. There are no physical wires connecting the controller with the virtual mechanical device, and the physical electrical signals cannot be directly transmitted between controller and mechanical device, as in the typical controller control work flow. Therefore, the signal generators are designed to transmit the electrical signals between the real controller and the virtual mechanical device simulated in the computer.

The signal generator, which is in a group of signal translators, receives the real electrical signals from the controller and translates them into software commands for the computer. In the reverse direction, the generator receives software commands and translates them into electrical signals to send to the controller. Hence, the signal generator generates input signals by detecting the control signals and transmits the input signals to the virtual mechanical device. The signal generator acts as a bridge between the virtual mechanical device and the controller. By binding the specific software commands to specific behaviour of the virtual mechanical device, the controllers can control the virtual mechanical devices directly just as if controlling a real mechanical device. The semi-physical simulation mimics the entire process from the controller to the controlled object and is close to a real industrial system.

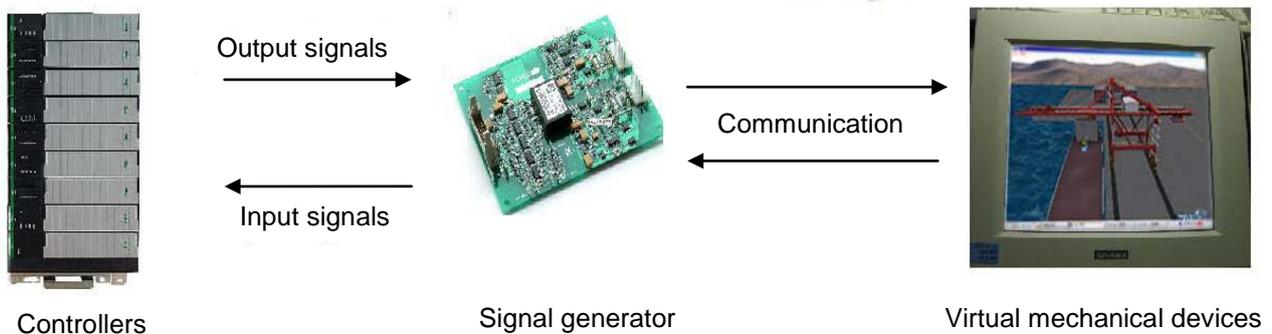


Figure 4: The control work flow of a semi-physical simulation electrical engineering training platform.

In using the semi-physical simulation electrical engineering training platform, students first write the programs according to the requirement on the digital controller and, then, run the programs on the semi-physical simulation training platform. The students can carry out the actual operations using the simulator and, because of the animation, they will be able to observe if the program is correct or could be improved.

The new semi-physical simulation platform provides a vivid animated simulation that enables students to operate the virtual devices. It is a better way to mobilise the enthusiasm of the students and cultivate the students' interest in learning. Actually, the number of controlled devices simulated can be very large. Finally, the direct control of the virtual equipment makes the running program more intuitively understandable for the student.

APPLICATIONS: SEMI-PHYSICAL SIMULATION ELECTRICAL ENGINEERING TRAINING PLATFORM

The semi-physical simulation PLC training platform was implemented at Shanghai Maritime University. The platform is used to train students in controller programming in electrical engineering courses. This semi-physical simulation platform can build virtual devices and environments, which are similar to those in real industry. Using the semi-physical simulation electrical engineering training platform, the students or trainees can acquire a more vivid and clear understanding of the electrical engineering course.

Elevator Control using a Medium-sized Siemens PLC

In electrical engineering courses, the students usually learn to write controller programs through experimentation. An example experiment is the control of a dual elevator using a Siemens medium PLC, which requires a complex controller program. In the traditional approach using the traditional PLC training boxes, students and trainees use real buttons, but LED lights to display the action of the elevator. Because of the large number of control points in the dual elevator experiment, it is difficult to simulate using the traditional approach. Contrarily, the semi-physical simulation electrical engineering training platform makes it easy.

The novel controller training platform for a dual elevator contrasted with the traditional platform is shown in Figure 5. The novel platform is composed of a virtual elevator, virtual buttons, signal generators and real controllers. The virtual dual elevator will be connected with the controller through the signal generator. The virtual elevator can be controlled by controller signals generated as a result of vertical movement of the virtual elevator.

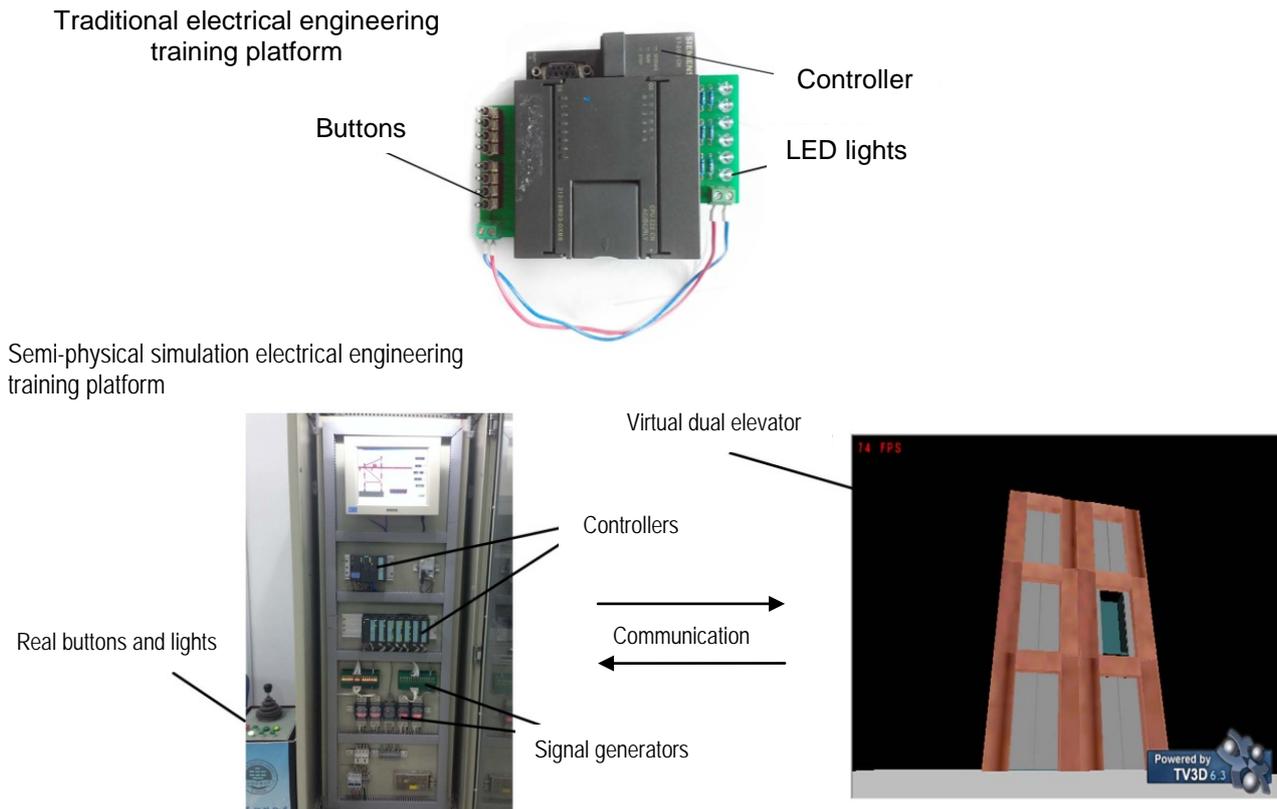


Figure 5: Traditional platform and semi-physical simulation platform for the elevator controlling experiment.

During the experiment, students compile their programs and load them into the controller in the traditional way. But, unlike the traditional way, a student can press the real buttons to operate the virtual dual elevator, displayed by animation, after loading the program. Obviously, this use of the semi-physical simulation platform can make the students' understanding of their programs more intuitive and greatly stimulates their enthusiasm for learning.

Quay Crane Control Experiment using a Siemens Medium PLC

The platform can be used to train students to learn the controller programming for the hoisting mechanism of a quay crane. This type of complex teaching experiment is unable to be completed in most universities. The crane movement can be simulated by a motor, but this method cannot let students directly see the mechanical movement. But, virtual reality, as shown in Figure 6, can overcome this limitation.

The novel controller training platform for a quay crane is composed of a virtual crane, signal generators, real buttons/lights and controllers.

This novel controller training platform for quay crane can be used to develop the control of port machinery. As shown in Figure 6, the semi-physical simulation platform can send signals from the controller, which hosts the student program to the simulated system through the interface. Then, the students can operate the virtual crane through handles, as with a real crane driver. Compared with the traditional platform, this semi-physical controller training platform simulates the actual operation of the quay crane in port. Obviously, this is a better way for students and trainees to test their programs.

Traditional electrical engineering training platform



Semi-physical simulation electrical engineering training platform

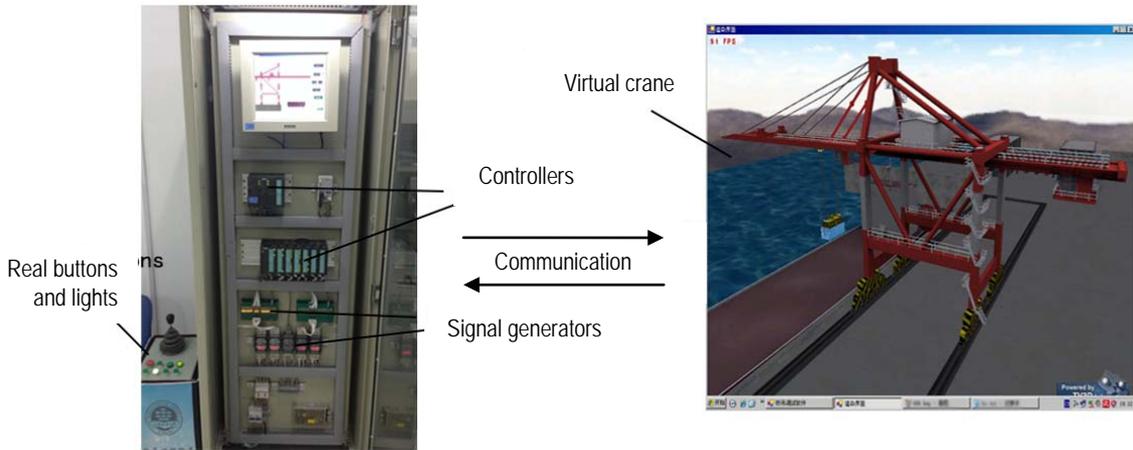


Figure 6: 3D virtual model of a quay crane.

With the virtual crane, students and trainees can undertake their experiments in a visual way, which is safer and more flexible. If the mechanical device is changed, the system can be updated by simply drawing a new virtual mechanical device and binding the specific signals to the specific behaviours of the mechanical device. Using this platform, much industrial application can be simulated more easily than in the traditional ways. Thus, this platform is lower-cost, easy-to-use and flexible.

TEACHING EFFECT

Table 1: Comparison of the traditional platform with the semi-physical simulation platform.

Factor	Traditional electrical engineering training platform	Semi-physical simulation electrical engineering training platform
Cost	Equipment maintenance and updating; loss of equipment through wear	Simulation platform maintenance; virtual device updates
Flexibility	Single controlled object and controller; simple controlled object; limited experimental content	Multiple types of controlled objects or controllers; easy-to-replace controlled objects without replacing other parts; capable of controlling complex objects; different experimental content for different teaching demands
Teaching effectiveness	There is only the controller training box; students learn by observing the state of the controller's port; non-intuitive for students	Animation of virtual environment and devices; more interaction with students; close to actual industry; Attracts the attention of students; enhance students' ability to understand
Safety	Hidden risk in peripheral wires and machinery	No risk in virtual equipment

As shown in Table 1, this semi-physical simulation electrical engineering training platform is a novel engineering education system for electrical engineering courses. The students are allowed to participate fully in the controller programming and implementation process. Through the operation of this simulation platform, students can improve their practical ability and engineering knowledge. They also can learn about real mechanical operations, hence

preparing them for future employment. Furthermore, the platform can stimulate the students' analytical skills and innovative abilities.

CONCLUSIONS

A novel experimental education platform for electrical engineering training based on semi-physical simulation was reported in this article. Compared to the traditional way, the novel platform is more flexible and low-cost to upgrade to support a new controlled device. By using virtual mechanical devices rather than real ones, costs are contained, and the platform can be used to train students and trainees for new and varied industrial applications.

As for the students, this platform is safer for beginners to learn and test their programs because mechanical devices are only virtual simulations in the computer. This platform allows students and trainees to directly observe the relationship between mechanical devices and their programs. This type of teaching can stimulate students' learning, deepen the impact of learning and improve innovative thinking.

This platform is easier to use and is a better, direct way for training students and trainees. The semi-physical simulation electrical engineering training platform provides a more flexible, lower-cost, safer and easier way to teach electrical engineering. In the future, virtual models of controlled objects increasingly will be developed and this repository of objects will further reduce the cost of using the simulation platform. In conclusion, the semi-physical simulation platform will make an outstanding contribution to teaching in the future.

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