Design of Digital Circuit Virtual Simulation Experiment Based on Situated Learning Theory

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Abstract. In response to the teaching requirements of the "New Engineering" and in line with the widespread application trend of digital electronic technology, digital circuit experiments should mainly focus on cultivating students' engineering literacy and innovative awareness of using theoretical knowledge to solve practical problems. Therefore, based on the theory of situated teaching, this article tells a virtual simulation experiment of "FPGA based smart greenhouse measurement and control" with virtual reality technology. This experiment can simulate a 3D scene of an internet greenhouse, receive digital circuits designed by students, and provide the results of greenhouse equipment and crop growth situation based on the working mechanism of the smart greenhouse. This immersive experience can stimulate students' interest in learning, enhance their understanding of the application process of digital electronic technology knowledge in practical projects, cultivate their ability to think independently and innovate, and provide support for the cultivation of outstanding talents in the "New Engineering" field.

Keywords: Digital circuit experiment, situated learning theory, virtura simulation, smart greenhouse

1 Introduction

As the fastest developing subject in current society, digital electronic technology has shown astonishing potential. In just 50 years, this technology has evolved from the original SSI circuit to today's VLSI circuit. Due to its advantages of good stability, high reliability, and ease of high integration, digital circuits and digital electronic technology have been widely applied in scientific and technological fields such as television, radar, communication, electronic computers, automatic control, and aerospace [1, 2]. Digital circuit experiments play a crucial role in students' deep understanding of theoretical knowledge and mastering basic skills about digital electronic technology. It is also related to the cultivation of basic knowledge in emerging majors such as intelligent manufacturing and integrated circuits.

Since 2017, the Ministry of Education has actively promoted the construction of New Engineering, which requires universities to cultivate composite talents with strong innovation awareness, outstanding engineering practice ability, high comprehensive quality, and broad perspectives that meet industrial needs [3, 4]. Therefore, as the main field for the growth and personality formation of students, higher education institutions shoulder a special mission, not only to impart knowledge and train skills, but also to cultivate students' engineering literacy and innovative spirit. Currently, digital circuit experiments in most universities mainly focus

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on verifying theoretical knowledge, and are less involved in complex digital systems in industrial contexts, which is not conducive to cultivating students' ability to solve practical engineering problems. Moreover, the experimental content is far from keeping up with the speed of industry development, and there is an urgent need for reform. This situation is in stark contrast to the widespread application of digital circuit technology in various fields. However, building an engineering application environment truthfully requires a significant investment, which is beyond the capacity of ordinary school laboratories. Therefore, how to cultivate students' practical abilities, mobilize students' active innovation, and improve teaching effectiveness in an efficient teaching mode under limited experimental conditions is a problem worth in-depth consideration in digital circuit experimental teaching.

Situated learning theory believes that knowledge cannot exist without context, and the learning of knowledge should be completed through continuous interaction between learners and the context in a corresponding situation. The theory also incorporates the cultural and physical backgrounds in the learning process into the research scope [5, 6]. During interacting with the context, learners can not only acquire explicit knowledge, but also unconsciously get a large amount of implicit knowledge. In this way, learners constantly practice and reflect in the context, constantly applying the knowledge learned in the context to the context, and their knowledge is also constantly growing. Virtual reality technology is a computer simulation system that can create and experience virtual worlds. This virtual world is generated by computers, and users can interact naturally with the virtual world through various sensing channels such as vision, hearing, and touch [7, 8]. With the development of virtual reality technology, virtual simulation experiments have emerged. Compared with traditional equipment experiments, virtual simulation experiments have the characteristics of low cost, safe operation process, and convenient use, becoming a new way of experimental teaching. Therefore, it is necessary to develop a realistic 3D digital circuit virtual simulation experimental software based on situated learning theory and virtual reality technology, providing learners with learning scenarios close to engineering applications and immersing them in learning activities.

2 Teaching Design Based on Situated Learning Theory

In order to meet the design requirements of modern digital circuit, teaching contents of the "Project of Digital Systems" course in our school are to guide students to gradually use Quartus II design software and FPGA development boards to achieve a digital circuit that meet specific requirements, and teaching objectives are to deepen students' understanding of digital electronic technology theory and improve their ability to build digital circuits and troubleshoot circuit faults based on certain practical engineering tasks. Under the theory of situated learning, the teaching design of this course should include the design of teaching objectives, teaching content, and teaching context.

2.1 Design of teaching objectives

As the bridge to transform theoretical knowledge into engineering projects, experimental teaching should not only enhance students' understanding of the knowledge, but also improve their hands-on ability and engineering application level. Therefore, when designing virtual experiments, it is necessary to comprehensively consider the designability, comprehensiveness, systematicity, and innovation of the experimental projects.

2.2 Design of teaching content

The content in this course that students are required to master includes: schematic based digital circuit design, Verilog HDL language based design, using a custom megafunction variation, as well as the structure and functions of FPGA development boards. On this basis, considering the requirements of situated learning theory, the teaching content should also create real problem situations for learners, so that students can understand theory in application, solve problems in practice, and cultivate engineering literacy.

2.3 Design of teaching context

The "Four-New" Construction was proposed by 13 departments including the Central Political and Legal Commission, the Ministry of Education, and the Ministry of Science and Technology. It is an important content related to the comprehensive revitalization of undergraduate education in the new era and the creation of a "quality China" in higher education, including "new engineering, new agriculture, new medical, and new humanities" [3, 4]. The major characteristics of today's society are interdisciplinary integration, knowledge fusion, and technology integration, which determines that interdisciplinary and composite talents will become the main force for enterprise development. Therefore, it’s attempted to integrate new engineering and new agricultural, aiming to construct an application situation that uses modern digital electronic technology to transform agricultural production processes, laying a material foundation for cultivating students' comprehensive qualities.

3 Functional Design of the Virtual Simulation Experiment

In the modernization process of agricultural development, the construction of greenhouses has played a special role, allowing people to have fresh and high-quality food at any time. The modern smart greenhouse monitoring system was born in this context [9, 10], based on the Internet of Things and communication technology, consisting of an intelligent control device, data collection devices, execution devices, communication systems, and cloud platform software. The topology structure of a typical smart greenhouse is shown in Figure 1.

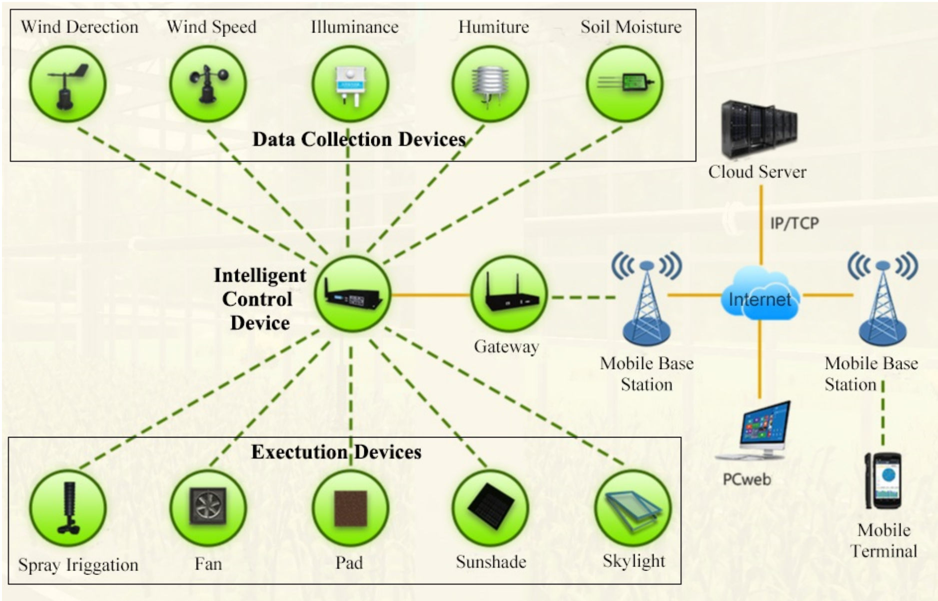

Fig. 1. Topology structure of a smart greenhouse environmental monitoring system.

Based on intelligent control device, it can automatically monitor environmental parameters, link ventilation, irrigation, water and fertilizer execution equipment, and hand over human work to the agricultural Internet of Things system for operation, achieving the goal of reducing costs and increasing efficiency. Digital circuits with FPGA can serve as intelligent control devices for smart greenhouses. Therefore, this paper designs a "FPGA based virtual simulation experiment for smart greenhouse measurement and control" to reflect the existence of digital circuit theory in the smart greenhouse. It is based on the teaching context of "smart greenhouse measurement and control" and uses virtual reality technology to build a smart greenhouse scene. It receives users' digital circuits through human-computer interaction interfaces, and ultimately simulates the automatic measurement and control process of the digital circuit on the greenhouse environment.

According to the teaching content of this course, three digital circuit working scenarios were mainly simulated: execution device working scenario, data collection device working scenario, and environmental parameter abnormal alarm scenario, corresponding to the schematic based design method of the teaching content, the custom megafunction variation, and the Verilog HDL based design. In addition, this experiment also introduces the composition and working principle of a smart greenhouse, in order to facilitate students' learning and understanding of engineering background. The main content of the virtual experiment is shown in Table 1, and the structure and functions of the FPGA development boards are introduced in "Scene Cognition".

Table 1. Function table of the virtual simulation experiment

Scene Cognition	Greenhouse	It introduces the appearance of the greenhouse, the models and names of the data collection and execution equipment used, as well as their location in the greenhouse.
	Crops	It introduces crop models, names, economic values, and environmental requirements for each growth stage.
	Monito system	It introduces the composition and functions of the smart greenhouse, as well as the data flow of data collection and control equipment.
	FPGA boards	It introduces the structure and functions of the FPGA development boards.
	Quizzes	There will be some questions regarding the content of this section, which appear randomly.
Priciple Learning	Topology map	It introduces the composition of the smart greenhouse measurement and control system.
	Measure and control	It introduces the control process of the digital circuit composed of FPGA for the acquisition and execution devices, as well as the specific interfaces between the experimental board and each device.
	Network transmission	It introduces the wireless communication principle between data acquisition equipment, execution equipment, and digital circuits in smart greenhouses.
	Application transmission	It introduces the network communication principle between the smart greenhouse measurement and control system, the internet, and mobile terminals.
	Quizzes	There will be some questions regarding the content of this section, which appear randomly.
Case Simulation	Requirements	Introduce teaching objectives and experimental content.
	Topology building	The user uses the mouse to drag the device to complete the topology diagram of the smart greenhouse
	Hardware construction	On the 3D model of the smart greenhouse, users use a mouse and keyboard to place various devices in appropriate positions.
	Functional testing	The user clicks on each device model with the mouse to observe the simulation effect of its normal operation.
	Result simulation	It recieves a digital circuit designed by a user and feedback the corresponding experimental results.

In addition, there are navigation buttons in the upper right corner of the software interface, making it easy for users to switch between various modules. Set buttons to modify the brightness, volume, and other information of the interface. The help button explains the shortcut keys used to operate the simulation software.

This case not only provides students with application scenarios for digital electronic technology, but also helps them better integrate theory into practice, cultivate students' practical skills and engineering literacy. It can also demonstrate the application process of advanced technologies such as sensors, the Internet of Things, and network communication to students, expanding their knowledge base.

4 Implementation of the Virtual Experiment

Developing this virtual simulation experiment mainly applies technologies such as 3D MAX, Unity3D development engine, and C# programming language to vividly reflect the existence of digital circuit theory in smart greenhouse scenes. 3D MAX technology is used for the design and production of computer models of smart greenhouses, their internal crops and equipment, FPGA development boards, and other physical objects. The Unity 3D engine technology enables the construction of experimental scenes, the functionality and interaction of models, and introduces the working logic of smart greenhouses and digital circuits into the corresponding models, providing a friendly and realistic interaction interface for experimenters. The C# programming language implements complex human-computer interaction, monitoring and analysis of experimental processes, judgment of experimental results, feedback and recording, and other functions.

The experimental operation module is a key module of the virtual simulation experimental teaching software. Based on the content of this experiment, four operation modules were designed in the "case simulation" section of the software.

4.1 Principle of greenhouses

This module requires students to build a topology diagram of the smart greenhouse using a mouse and keyboard (Figure 1), as well as place data collection and execution devices in appropriate locations in the smart greenhouse (Figure 2). The operation content of this module can familiarize students with the working principles of smart greenhouses and the working processes of various equipment in the greenhouses, preparing them for designing corresponding digital circuits according to experimental requirements in the future. After completing the knowledge points of "scene cognition" and "principle learning", students can click on the "case simulation" button to enter this module.

4.2 Virtual experiments for starting and stopping the execution devices

This module requires students to design a circuit for manually starting and stopping five execution devices based on the DE2-115 FPGA development board, using schematic input method and a 3-Line to 8-Line decoder 74138 as the core. This module examines students' ability to use combinatorial logic circuits to solve problems, as well as their mastery of the process of inputting digital circuits using schematic methods in Quartus II software.

Once the user is ready, just click on the computer screen in Figure 2 within any unit of the software to enter the operation module for practice.The teaching object of the software is beginners, so for each experimental step, the software will provide operation prompts and monitor the user's actions. If the operation is correct, the software will provide a prompt for the next step, otherwise the software will pop up an error reason and correct operation prompt until the user successfully completes the experiment. The interface for viewing the results are shown in Figure 2.

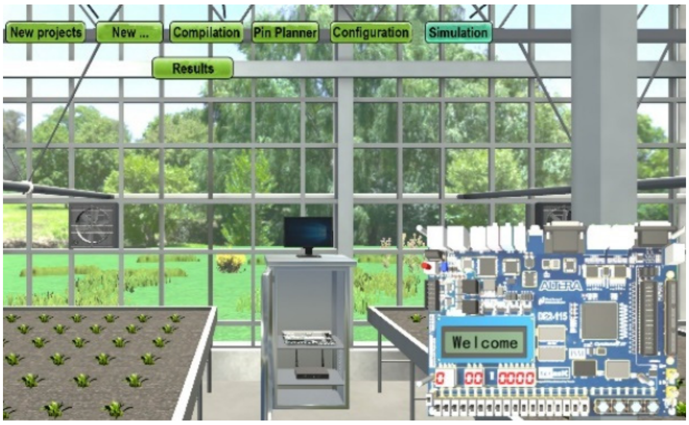

Fig. 2. Input and output windows.

4.3 Virtual experiments for regularly getting environmental parameters

This module requires students to use LPM in Quartus II software and the DE2-115 boards. The COUNTER megafunction variation is designed as the core of a frequency division circuit, which converts the 50MHz clock signal provided by the experimental board into a 1Hz clock to control the timing of the data collection device to return environmental parameters. This module is used to exercise students' ability to set up and call a megafunction variation according to experimental requirements, as well as solve problems using sequential logic circuits. The operation process of this module is the same as section 4.2.

4.4 Virtual experiments for alarm of abnormal environmental parameters

This module requires students to write a Verilog HDL program using Quartus II software based on the DE2-115 boards, to compare the actual environmental parameters collected with the environmental parameters required by the crop. If the range is exceeded, an audible and visual alarm will be triggered. The function of this module is to enable students to master the basic structure and syntax of Verilog HDL programming language, and to write corresponding control programs according to experimental requirements. The operation process of this module is the same as section 4.2.

5 Application of the Experiment

During teaching, the pre class teacher opens experimental permissions for students, requiring them to preview, experience, and discover problems. During class, the teacher demonstrated virtual simulation experiments and introduced the working principles of smart greenhouses, as well as the principles and operating procedures of virtual experiments. Then provide answers to students' personality questions. After class, students complete simulation and experimental reports for four operation modules, and teachers and students can engage in online communication, Q&A, and other teaching activities.

Feedback on experimental teaching results in two years indicates that the virtual simulation experiment has accurate and scientific content, reasonable structure, and simple operation, promoting the smooth implementation of digital circuit experimental teaching. Students have developed a strong interest in digital circuit design by experiencing the application process of digital circuits in smart greenhouse measurement and control scenarios. Many have signed up to participate in the National College FPGA Design Competition and achieved excellent results.

6 Conclusions

This article proposes a virtual simulation experimental case for smart greenhouse environmental monitoring based on the theory of situational teaching in the context of the new engineering industry. It involves the intersection and integration of multiple disciplines, improves the complexity and diversity of experimental courses, and provides necessary theory accumulation for students to solve complex engineering problems. It has honed students' independent thinking ability, practical ability, document writing ability, and cultivated innovation awareness and engineering literacy. The author will also improve and improve the virtual simulation experimental cases in digital circuit experimental teaching to better serve the curriculum.

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