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Ubiquitous Learning Experience using VR in Electronic Science Education

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Abstract

In this technology-driven society, designing, prototyping and miniaturization of electronic systems pose major challenges, which in turn makes the electronic science education more essential. The objective of electronic science education is to increase students' awareness to gain more technical proficiency to understand the miniaturized electronic system design and troubleshoot electronic systems. The evolution of electronic science with advanced technological achievements also faces contemporary challenges that virtual reality technologies are well-positioned to address. Virtual reality in electronic science education enhances learning by providing immersive and interactive experiences. It allows students to explore complex concepts, simulate experiments, and engage in hands-on activities, fostering a deeper understanding of electronic science principles. VR can create a dynamic and engaging learning environment, making abstract concepts more tangible and promoting experiential learning in a virtual space. This research study aims to encourage the active students' participation in learning about the traditional and modern practices involved in electronics systems analysis while experiencing the immersive interaction related to various real-time conditions and applications.

Keywords: Electronic systems, Virtual Reality (VR), Circuits Analysis, Fault Detection, Immersive Reality, Virtual Learning Experience.

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1. Introduction

The evolution of electronic science spans centuries, marked by significant milestones from the formulation of fundamental principles for electricity and magnetism to the modern era characterized by the utilization of advanced electronic devices and technologies. From the early experiments of Alessandro Volta and Michael Faraday to the invention of the transistor in the mid-20th century [1], the electronic science field has witnessed a continuous technological research progression to move forward towards the digital revolution. However, currently the electronic science field is facing several challenges [2]. The increasing need for electronic systems miniaturization has resulted in various physical limitations that impede further in reduction of the electronic components size. Energy efficiency has also become a significant concern as the demand for developing portable and sustainable electronic devices are continuously increasing. The complexity of designing intricate electronic systems, coupled with the need for introducing novel materials with specific properties, poses formidable challenges to both electrical and electronics researchers and engineers [3].

Virtual Reality (VR) technologies emerge as a transformative solution to these challenges. In the realm of miniaturization, VR facilitates the virtual simulation of electronic components and devices, allowing researchers to explore and test different configurations without the constraints of physical limitations [5,18]. This virtual prototyping accelerates the design process and mitigates the costs associated with traditional trial-and-error approaches. Energy efficiency concerns can also be reduced through VR-enabled training and education platforms. These immersive environments empower electronic design engineers and students to interact with virtual electronic components, fostering a deeper understanding of energy-efficient design principles. VR also facilitates collaborative design, breaking down geographical barriers and enabling teams to work together seamlessly, thereby addressing the complexity of electronic system development. Moreover, virtual reality serves as a powerful tool for the visualization of nanoscale phenomena, aiding researchers in comprehending and manipulating materials at a microscopic level. The technology's capacity for remote collaboration fosters interdisciplinary teamwork, allowing experts from diverse fields to contribute their expertise in real-time [6].

This article is organized as follow: Section 2 presents the literature review on the use of immersive technologies in electronics education. Section 3 presents the proposed virtual ecosystem. Section 4 describes the developed two VR projects using the proposed architecture. Section 5 presents the evaluation and usability of the proposed VR applications. Section 6 concludes the proposed research work and also discusses about the future research directions.

2. Literature Review

The intersection of electronic science and virtual/augmented reality (VR/AR) has gained a significant research attention in recent years, with a particular emphasis on the application development and user studies [5]. Recently, multifaceted research approaches are characterized by various researchers to leverage VR and AR technologies to advance the boundaries of electronic science [6].

In the realm of application development, researchers have explored various possibilities that are available across various sub-domains within electronic science. A significant research attention is given to the simulation and prototyping of electronic components and systems. Recently various research groups have attempted to develop immersive virtual environments that facilitate the design and testing of electronic devices [7]. Moreover, immersive environments have provided researchers with a versatile platform to iterate and optimize their innovations. This has proven particularly valuable in overcoming the challenges associated with miniaturization, as VR simulations offer a virtual space where physical constraints can be transcended, and novel configurations can be explored with greater ease [8].

Energy efficiency in electronic systems has emerged as a critical concern, and the application of VR in this domain is marked by a concerted effort to develop interactive educational tools. These tools employ VR to create engaging and instructive experiences, allowing professionals and students to interact with virtual representations of electronic components. By doing so, they gain insights into the principles of energy-efficient design, contributing to a more sustainable future in electronic science [9].

Collaborative design, another pivotal aspect of electronic science, has witnessed a paradigm shift with the integration of VR. The literature reflects an increasing trend towards collaborative virtual environments that enable geographically dispersed teams to work together seamlessly [10]. This not only addresses the complexity of electronic system development but also fosters interdisciplinary collaboration, bringing together experts from diverse fields to contribute their unique perspectives in real-time. User studies form a crucial strand of research, shedding light on the human experience within virtual and augmented electronic environments. Studies in this domain explore the usability, effectiveness, and user satisfaction of VR/AR applications in electronic science [11]. These investigations consider factors such as user interfaces, interaction mechanisms, and the overall immersive experience, providing valuable insights for refining and optimizing the integration of these technologies in electronic science education and research [16,17].

The research on the integration of electronic science and VR/AR predominantly revolves around the two main areas - application development and user studies. The former encompasses a spectrum of innovations, ranging from virtual simulations for design and prototyping to educational tools addressing energy efficiency [12]. Concurrently, user studies delve into the human factors associated with these technologies, exploring the intricate dynamics of user experience. This synthesis of application-oriented and user-centric research reflects the transformative potential of VR and AR in the future of electronics education.

3. Proposed System Model

Figure 1 depicts the architectural framework to experience the immersive nature of virtual reality simulation built for electronic science teaching that uses the virtual ecosystem concept. This overall framework consists of real-time data, electronics simulation servers, a virtual reality environment and instrumentation. Researchers have divided education simulations into two categories: physical and model driven simulation [13]. Model-driven simulations seek to abstract and simplify processes, hence increasing students' understanding of fundamental ideas. Physical simulations, on the other hand, seek to accurately mimic real-world processes. Scientific visualization, for example, uses physical simulations to replicate real-world events. In contrast, our research uses a simplified model-based simulation designed specifically for electronic science education to help students comprehend the underlying processes.

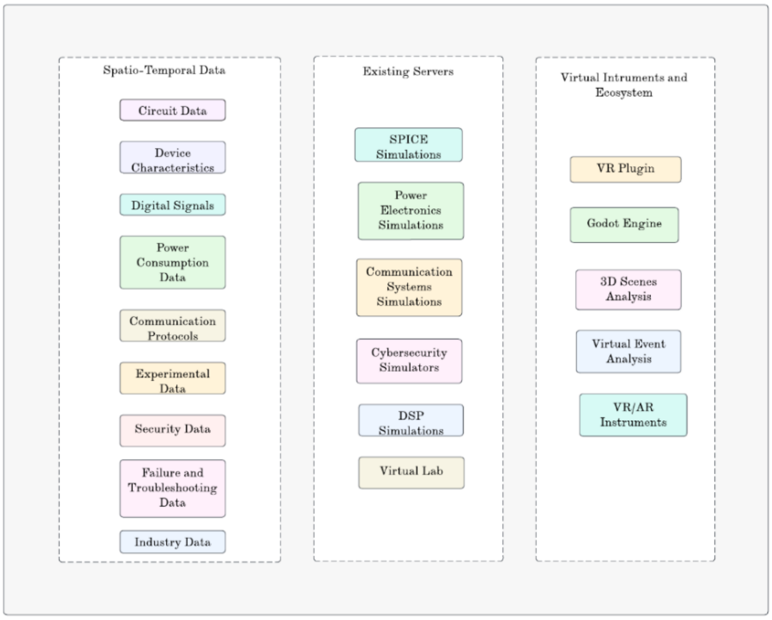

Figure 1. Proposed Virtual Ecosystem and Framework for Electronic Science Education

3.1 Data Analysis

Within the realm of electronic science education, simulation data for the virtual ecosystem encompasses diverse elements: electronic circuit components, device characteristics, experimental data, power consumption data, security data, failure and troubleshooting data and industrial electronic equipment related data. This data is spatio-temporally organized across different timelines in the past and present, enabling users to experience distinct spatial information over time.

To create a virtual reality application for any inquiry made regarding electronic science education, defining electronic systems related data settings aligning with the student's learning curriculum is crucial. This involves correlating user interactions with attribute data for various electronics equipment and objects. For instance, designing an application for automated circuit simulation and analysis necessitates setting electronic components like resistors, Arduino modules and sensors, allowing the virtual environment to dynamically respond to user interactions. JSON data format and scripts are employed in the proposed applications to incorporate simulation data seamlessly into lesson plans.

3.2 Integration of Simulation Servers

In the 2nd model, the simulation server functions as a repository for electronic configuration data. It facilitates linking the spatiotemporal data with persistent data analysis and visualization.

For Example: For circuit simulations, SPICE Simulations (Simulation Program with Integrated Circuit Emphasis) is integrated to analyze and simulate the behavior of electronic circuits, helping students understand circuit design, voltage, current, and component characteristics. Next, by using fault injection simulators, students can easily simulate electronic system failures and practice troubleshooting and diagnosing issues in a controlled virtual environment.

3.3 Virtual Environment for Electronic Science Education

The virtual environment receives data from the server, presenting it in a visually compelling three-dimensional space representing the virtual ecosystem. The landscape is generated through 3D modeling parameters based on various input factors given by simulation servers. User interaction is a key feature, allowing users to navigate the virtual space from a user's perspective to measure the relevant data.

Implemented using Godot Engine and VR plugin, the virtual reality system employs HTC VIVE to enable the virtual reality environment. The proposed system includes head-mounted display, virtual base stations and controllers for providing users with a natural and immersive experience within a 3D virtual activity space.

3.4 Visual Data Instrument

In the context of electronic science education, electrical, electronics and communication device monitoring is pivotal for enabling data analysis using virtual and augmented reality. This research introduces a data instrument facilitating users in measuring, collecting, and directly observing the simulated data from virtual environment or through a supplementary mobile or wearable device. This instrument visualizes environmental data as images or text, enabling users to intuitively comprehend the phenomena and transfer the gained knowledge to real-world. By providing direct control or observational learning, users enhance their self-efficacy in understanding the challenges faced by electronics and communication systems.

4. Developed VR Applications

This section introduces two electronics science education applications utilizing VR simulations using the proposed model: "Circuit Analysis" and "Fault Detection". The "Circuit Analysis" project represents an immersive VR game to provide students with an experiential understanding of the electronics education has now been simplified without any hard manual circuit connections to setting up a virtual circuit analysis lad and automation, spanning the period from 2000 to 2023. Concurrently, "Fault Detection" stands as an immersive VR game strategically designed to captivate students with the knowledge of industry 4.0 and how they can easily automate and simply scan an electronic device to know the faults in it. This engaging educational tool directly addresses the academia and industry gap, aiming to instil a sense of technological awareness among students.

For evaluation purposes, we have randomly invited 15 students who were pursuing their Undergraduate Degree in the field of "Electronics and Communication Engineering" to experience the developed VR applications.

Table 1 shows the overview of how the proposed model is applied within these applications by mentioning its key characteristics and functionalities.

Table 1. Overview of the Proposed Virtual Reality Model

Application	Industry Type	Spatial-Temporal	Data Instrument	Persistency
Circuits Analysis	Academia	Measurement Instruments; Components; Breadboards and Wiring; Cables and Connectors; Testing and Debugging Tools; Electronic instruments; Computing Devices	Voltage (DC/AC), Current (DC/AC); Voltage waveforms, Frequency, Amplitude, Time; Digital signal levels;	Improvement of Virtual Analysis over time

Fault Detection and Trouble shooting	Industry	Multimeter; Oscilloscope; Function Generator; Thermal Imaging Camera; Network Cable Tester; Circuit Tracer/Probe; Voltage/Current Probe; Emission and Immunity Test Equipment	Cable continuity, Wiring faults; Visual inspection of solder joints, circuit traces, and components; Insulation resistance;	Industries continue to evolve with respect to time

4.1 Circuit Analysis

The circuit analysis application is mainly developed to understand the impact of virtual lab resulting from virtual circuit analysis, analysing the complexities faced by students while connecting circuits and how VR technologies can profoundly automate the traditional circuit connection using breadboard. Utilizing virtual reality technology as a supplementary tool to traditional educational approaches reliant on books, this application seeks to deliver an immersive and touchable educational experience elucidating the evolution of circuit analysis spanning the years 2000 to 2023. Drawing insights from the “IEEE Consumer Electronics Society - Virtual Reality and Augmented Reality Working Group Meeting” [14], the application strategically employs spatio-temporal coordinates for a particular time period, offering users a dynamic exploration of the evolution of digital electronics over the specified timeframe. The interactive timer enables users to navigate the temporal spectrum from 2000 to 2023, allowing for a targeted exploration of the virtual electronics laboratory for a selected year through the innovative "timer jump" feature. Users can employ the VIVE controller touchpad to launch a virtual line, facilitating a seamless transition to the physical and virtual circuits laboratory environment corresponding to the selected year upon triggering the controller.

Figure 2 and 3 shows the difference between the electronics experimentation procedure and the use of hardware components in 2000s and 2020s in academic labs. Figure 2 shows the traditional physical laboratory environment and how hardware components are connected and used to generate the output. When we use the “time jump” option to move to the 2022, the user will enable a virtual line with the help of a touchpad based VIVE controller, it triggers and generates a virtual reality tour to a virtual circuits experimentation and analysis lab where all the components are virtually connected and analysed.

Figure 2. Traditional Laboratory in 2000s

Figure 3. VR Enabled Virtual Lab in 2020s

4.2 Fault Detection and Troubleshooting

This Fault Detection and Troubleshooting application can be used to train the student interns in an industry and also the industry professionals with the latest technological innovations and how the field has been evolved in the recent years. The project was developed by obtaining the basic insights from the book "Practical Electronic Fault-Finding and Troubleshooting". It deals with major electronic faults, such as solder joints, circuit traces, insulation resistance, cable discontinuity, wiring faults as well as identifying the idle or inactive circuit components. Using the Advanced Fault Detection (AFD) API, the emerging electronic faults data will be collected, trained and stored in the virtual ecosystem once in a day. Based on this information the virtual environment will help the students to detect the faults of any electronic system by just scanning it.

The developed Fault Detection and Troubleshooting is composed of an industry scene where it was divided into two different sequences, the one given in Figure 4 shows the traditional electronic fault detection process to the students. Another one given in Figure 5 shows the automated electronic system fault detection process where a smart tab or gadget can be used to scan the electronic system and find the faults. This avoids the process of manual inspection. Playing this game and changing the year from 2000s to 2020s will helps the student interns in an industry to understand the difference between the manual and automated inspection with their own experience on playing this VR gaming Fault Detection and Troubleshooting application.

Figure 4. Manual Inspection in 2000s

Figure 5. Automated Inspection in 2020s

5. Evaluation

As stated in section IV, after developing the two projects, we have invited 15 students and asked them to experience the proposed application. The participants were allowed to use the two applications freely for 15-20 minutes. After that, the participants were asked to fill out the ratings for the applications. The students' demographic information and ratings on a scale of 1 to 5 were collected based on 5 different categories (Enjoyment, Immersive Experience, User Friendliness, Interactivity, and Learning Impact). Enjoyment refers to how far the found the transition enjoyable and fun to time travel the evolution of electronics systems analysis. Immersive experience reference to how far the proposed applications visuals were realistic to them. User-friendliness refers to how easy the applications' option was to understand the virtual laboratory and electronic system analysis concept. Interactivity refers to the liveliness of the proposed application and how the user can feel their presence in the virtual environment. Finally, the learning impact will let us know how far the students have gained knowledge about the virtual laboratory and its uses in both academia and industry

VR Application Ratings Questionnaire

Demographic Information:
Age:
Gender:
VR experience level (novice, intermediate, expert):
Frequency of VR usage:

1. **Enjoyment:**
   - ☐ 1 - Not Enjoyable at All
   - ☐ 2 - Slightly Enjoyable
   - ☐ 3 - Moderately Enjoyable
   - ☐ 4 - Very Enjoyable
   - ☐ 5 - Extremely Enjoyable
2. **Immersive Experience:**
   - ☐ 1 - Not Immersive at All
   - ☐ 2 - Slightly Immersive
   - ☐ 3 - Moderately Immersive
   - ☐ 4 - Very Immersive
   - ☐ 5 - Extremely Immersive
3. **User-Friendliness:**
   - ☐ 1 - Not User-Friendly at All
   - ☐ 2 - Slightly User-Friendly
   - ☐ 3 - Moderately User-Friendly
   - ☐ 4 - Very User-Friendly
   - ☐ 5 - Extremely User-Friendly
4. **Interactivity:**
   - ☐ 1 - Not Interactive at All
   - ☐ 2 - Slightly Interactive
   - ☐ 3 - Moderately Interactive
   - ☐ 4 - Very Interactive
   - ☐ 5 - Extremely Interactive
5. **Learning Impact:**
   - ☐ 1 - No Learning Impact
   - ☐ 2 - Slight Learning Impact
   - ☐ 3 - Moderate Learning Impact
   - ☐ 4 - Significant Learning Impact
   - ☐ 5 - Substantial Learning Impact

Figure 6. Ratings Questionnaire Given to Participants

By analysing the Questionnaire collected from all the 15 participants, the average rating has been calculated for the proposed application is illustrated in Table 2. Based on this qualitative analysis, most of them have responded that the VR based learning is more interesting than theoretical education. However, some participants have responded that the virtual environment generated lacks real-world context and some have responded that there is only less user freedom to change or use the applications. Despite few comments, overall the participants have said that by using the proposed application they have become aware of the electronic systems and the ways to analyse and use it using modern technologies.

Table 2. Average Rating Received for the Developed VR Applications

Application Feature	**Score**
Enjoyment	3
Immersive Experience	3
User Friendliness	4
Interactivity	3
Learning Impact	4

6. Conclusion

Developing virtual environment to carry out laboratory experiments stand as pressing global need, prompting extensive research efforts in the fields of electrical, electronics and communication engineering. Notably, the implementation of virtual reality (VR) applications for electronics education has gained increasing popularity. While the focus on traditional engineering education is often centered on imparting knowledge, virtual education necessitates a unique approach for experimenting the electronic components. It will not only convey information but also seek to influence learners' dimension towards electronic education and the application of gained knowledge in real-world. The goal is to enable users to comprehend the recent advances in electronic system analysis and detect the system faults accurately, equip them with the requisite knowledge and encourage active participation in solving the problems in modern electronics. Virtual reality offers a powerful tool for electronics and communication engineering education by providing controlled simulations that mimic real-time hardware implementation. Here, an immersive VR application was developed to understand the importance of electronics education and continually engage users by depicting how the field has evolved in recent years. The simulation, based on a virtual ecosystem model, showcased interactive links between electronic device factors, spatial and temporal fluctuations, and instrument-measured data, maintaining a persistent learning environment. Evaluation results indicated a positive effect, with participants expressing a deeper intuitive understanding of how electronic systems are evolving to satisfy the human requirements. Despite the small participant size, the study highlights the potential of immersive virtual reality simulations for enhancing electronic science education. Future research will focus on conducting systematic usability and model evaluation studies in engineering colleges as well as high schools, refining the learning pedagogy, improving system architecture, and expanding the proposed VR model to enable collaborative education with simultaneous use of virtual reality and augmented reality. This ongoing effort will state the importance of continued research to leverage immersive technologies for an effective engineering education.

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