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Investigation of software simulators for modeling combinational circuits in microprocessor technology

Abstract: This article examines the use of virtual laboratories and simulators for modeling combinational circuits in microprocessor systems. The research focuses on how students at universities and other educational institutions learn circuit design and the methodologies for developing combinational circuits in microprocessor technology. This work aims to explore existing virtual laboratories and simulators for modeling combinational circuits in microprocessor technology, analyze their advantages and disadvantages, and study their functional capabilities and educational potential. The primary research methods include analyzing literary sources and online resources to identify software simulators for modeling combinational circuits in microprocessor technology and comparing their characteristics and capabilities in terms of their applicability for educational purposes. The research findings indicate that the Electronic Workbench is the most suitable for the basic study of simple combinational circuits due to its ease of use among all the reviewed simulators. NI Multisim offers a broader range of features and allows integration with hardware platforms. Proteus is applicable for studying embedded systems and working with firmware. Future research directions may include exploring new simulators for modeling combinational circuits in microprocessor systems and developing a new simulator that combines the advantages of the tools discussed in this article.

Keywords: virtual laboratories, simulator, microprocessor technology, circuit design, combinational circuits, education.

Abbreviations:

EWB is an Electronic Workbench.

Introduction

Today, virtual laboratories are widely used as an effective tool in the educational process at universities and other academic institutions (*Nolan et al., 2016*; *Shen & Bian, 2022*; *Üstünel, 2019*). Developing such laboratories requires competencies in various fields, such as programming, UI development, and pedagogical qualifications. Such software is created by teams representing various groups, including educational, research, and industrial sectors. Virtual laboratories are being developed and applicable to a wide range of fields (*Ahmad et al., 2017*; *Peidró et al., 2015*; *Chao et al., 2015*; *Erdem et al., 2016*). Among them are simulators for modeling combinational circuits of microprocessor technology (*Makarenko & Spivak, 2016*; *Mafudi & Handhika, 2021*; *Connor et al., 2018*; *Moura & Moura, 2016*).

Three types of laboratory work can be distinguished for students when studying physical processes or electronic circuits. The first type involves working in a traditional laboratory with the necessary equipment, stands, and laboratory setups, which requires students' physical presence and direct interaction with the equipment. The second type involves virtual laboratories based on actual equipment, accessed remotely through dedicated software (*Trnka et al., 2016*). Thus, students work remotely but use physical equipment, which requires adherence to a schedule for conducting work and a stable internet connection between the laboratory and the students. The third type of virtual laboratory is software that fully simulates the physical equipment used in traditional laboratories. This software can be installed on a student's computer, allowing them to conduct experiments at any convenient time and from any location.

Using software that simulates the processes being analyzed and enables experiments without needing to visit an educational institution is undoubtedly a significant advantage, especially in distance learning.

Several scientific works that explore the use of virtual laboratories and simulators in the educational process can be cited. The work (*Ersoy et al., 2022*) discusses a developed virtual laboratory for conducting applied courses in formal and distance education. It includes working with user-programmable logic matrices and application programming interfaces. Researchers compared the two groups' performances using a virtual laboratory and traditional teaching methods. The research results showed that the developed virtual laboratory was more effective than conducting experiments using conventional techniques, and it allowed students to create combinatorial schemes more quickly.

The research (*Susilawati et al., 2021*) examines a comparison of two simulators for modeling combinational circuit schematics. Students were also divided into two groups and performed laboratory work in one of the virtual laboratories. The tasks included building simple circuits with resistors and capacitors, constructing an RLC circuit, and studying Kirchhoff's law. The studies that were conducted demonstrated the effectiveness of using both simulators.

The study (*Islahudin & Soeharto, 2020*) aimed to investigate the understanding of digital circuits using electronic circuit-building simulators among students in the physics education program. The sample included 14 students studying the course "Fundamentals of Electronics". The study was conducted in two cycles. Each cycle consists of four stages. They included planning, action, observation, and reflection. Data analysis was performed to determine the improvement in concept comprehension in cycles one and two using the t-test formula. The research results indicated that the passing score in the first cycle was 57.14%, while in the second cycle, it was 85.71%. Based on the obtained research results, the authors concluded that using an electronic circuit simulation tool can enhance students' understanding of digital circuit concepts.

Results

As demonstrated above, virtual laboratories and simulators provide the opportunity to overcome the limitations of traditional laboratories and enable the conduct of classes for a more significant number of students in more comfortable spatial and temporal conditions. Using simulators can also track students' academic progress and receive feedback on material comprehension and any issues that arise (*Budai & Kuczmann, 2018*). Significant advantages include working remotely at a convenient time for students. Moreover, with simulators, students cannot damage the equipment or injure themselves when conducting experiments incorrectly. Therefore, using such an educational tool reduces the responsibility placed on the instructor concerning student safety and the preservation of laboratory equipment.

Integrating simulators into the educational process is associated with significantly lower costs, eliminating the need for laboratory setups with expensive electronic equipment. Virtual equipment in the simulator does not age or wear out like actual equipment and does not require maintenance expenses. Additionally, modeling new experimental tools using simulators does not require material resources, unlike working with physical equipment. An important advantage of simulators is their ability to model scenarios that are difficult to replicate in actual conditions. For instance, it is possible to make significant changes to the system configuration of equipment or alter the values of several system parameters. Such changes are typically challenging to implement with actual equipment. Simulators also enable students to learn from mistakes without consequences, providing a safe environment for conducting various tests and experiments that would be difficult or risky to perform on actual equipment (*Aliev et al., 2024*).

Thus, with the increasing complexity of electronic devices, traditional teaching methods based solely on theoretical analysis and physical experimentation are becoming insufficient for training qualified specialists. Simulation software, including tools for modeling combinational circuits in microprocessor technology, offers capabilities that cannot be fully achieved in traditional laboratory settings.

Modeling electronic circuits requires focus, attentiveness, and precision. Software simulators enable students to work with virtual circuit models that closely resemble real ones, significantly accelerating the process of mastering complex circuit design concepts. Furthermore, simulators provide immediate feedback, which is crucial for a deep understanding of the principles of microprocessor technology. It makes the learning process more interactive and visual, eliminating barriers previously caused by limited access to equipment or the inability to study rare or expensive components.

The specified tools contribute to developing students' systems thinking and analytical skills, which are crucial for solving engineering problems. Modeling complex combinational circuits using software products helps students study device operation and allows them to practice their optimization.

The author offers to consider some of today's popular tools for modeling combinational circuits in microprocessor technology.

EWB is software for modeling and analyzing electronic circuits (*Electronic Workbench, 2024*). At its emergence, it was one of the most intuitive and accessible programs for studying the fundamentals of circuit design and digital circuit engineering. EWB allows users to design electronic circuits in a virtual environment and analyze their behavior using built-in tools such as oscilloscopes, multimeters, and signal generators.

Several factors drive using EWB in education, particularly in microprocessor technology and combinational circuit design. The software enables students without working experience with hardware to learn theory through practice. This is accomplished through a simple interface, various components, and analysis tools. For beginner specialists, observing how specific elements interact is crucial. EWB provides visualization capabilities without requiring work with physical circuits, thereby simplifying the learning process.

At the same time, using EWB in teaching has its limitations. One such nuance is the simplified component library, which includes standard elements of circuit design (resistors, capacitors, transistors) and basic microprocessor modules. It makes the software less suitable for modern microprocessor systems, requiring a more complex modeling and analysis approach. However, for studying combinational circuits such as logic gates, multiplexers, and decoders, the software remains an effective tool, especially at the basic level.

Another important aspect is the limited integration of EWB with real hardware. Modern engineering education requirements involve modeling and testing the created solutions on physical devices.

However, despite the mentioned limitations, the EWB remains helpful in teaching the fundamental aspects of circuit design and introducing microprocessor technology. The software provides a convenient environment for conducting laboratory work, developing simple projects, and studying electronic circuit component interaction fundamentals. Its use can be especially beneficial in the early stages of learning when students need to focus on understanding theoretical principles rather than the complexity of working with physical equipment.

Another popular simulator is NI Multisim (*Multisim, 2024*). This powerful software for modeling electronic circuits significantly surpasses EWB's capabilities and functionality. It is designed to meet the needs of both educational processes and professional engineering practices. Multisim combines an intuitive interface, an extensive component library, and modern simulation tools, making it an effective tool for studying and designing electronics.

Multisim's main advantage is its extensive component library, which includes essential circuit elements and complex digital devices, microcontrollers, processor cores, communication modules, and specialized integrated circuits. This makes it ideal for working with microprocessor technology, where interactions between analog and digital components and the modeling of complex combinational circuits are crucial.

Multisim integrates with hardware platforms such as Arduino, allowing students to transition from virtual modeling to real-world testing. This enables learners to study theoretical aspects and verify the functionality of their circuits on physical equipment. An additional advantage is the presence of powerful analysis tools, including frequency response analysis, transient analysis, parametric analysis, and noise analysis.

However, NI Multisim has several drawbacks that should be considered for educational purposes. First, the high cost of the license can be a significant limitation for educational institutions, especially when access needs to be provided to many students. Second, the abundance of features and the complexity of the interface may pose challenges for beginners. Students without sufficient foundational knowledge may struggle to master the software, requiring additional instructor guidance.

Another disadvantage is its high demand for computing resources. Multisim requires powerful hardware to handle complex circuits, which can be problematic when using low-performance computers.

Thus, Multisim's capabilities may be excessive for the initial learning stage, where the interface's simplicity and limited functionality are required. However, the advanced stage of studying electronics and designing microprocessor systems offers unparalleled opportunities for learning and practice. It is well-suited for in-depth study of digital and analog systems for senior students with foundational circuit design knowledge.

Proteus should also be mentioned in the context of circuit simulation software. Its key features are its ability to simulate programmed microcontrollers and microprocessors (*Proteus, 2024*). Unlike EWB and NI Multisim, Proteus allows actual binary firmware files to be uploaded and tested into virtual microcontrollers. This makes the software indispensable for studying areas of microprocessor technology where both hardware and software components are important.

Proteus also offers extensive capabilities for simulating peripheral devices such as LCDs, keyboards, sensors, motors, and other components used in control systems. This enables students to study combinational circuits and design and debug complex embedded electronic systems, including smart devices and IoT solutions.

The program's interface integrates hardware and software components, making Proteus an ideal tool for projects requiring microcontrollers to interact with external devices. Another significant advantage of Proteus is its visualization capabilities. The software allows the creation of interactive projects where the operation of virtual displays, motors, and other elements is shown in real time. It dramatically reduces the difficulty of working with abstract circuit designs.

However, Proteus has a high entry threshold, requires substantial student preparation, and has a high cost for user licenses. Additionally, its circuit analysis tools – such as noise analysis, frequency response, and other specialized methods – are less developed than NI Multisim's.

In summary, Proteus may be too complex for beginners in circuit design, and its analytical tools may be insufficient for deep circuit analysis. However, it is one of the best tools available for advanced studies of microcontrollers and their programming, including working with real firmware.

Conclusion

Using software simulators to teach circuit design and microprocessor technology allows students to master complex concepts and develop practical skills. These tools ensure the accessibility of experimentation without expensive equipment, allow students to study intricate processes in a safe virtual environment, and make the learning process more interactive and visually engaging.

Each of the reviewed programs has its optimal use cases. EWB is the simplest to use and is ideal for acquiring fundamental knowledge of circuit design. NI Multisim offers a wide range of analysis tools and enables the simulation of both analog and digital circuits. It stands out for its robust functionality and integration with hardware platforms, making it suitable for studying more complex systems. Proteus is distinguished by its ability to simulate microprocessors and work with firmware, making it the optimal choice for studying embedded systems. Selecting the appropriate tool should be based on the specific educational objectives and the student's level of preparation.

Integrating software simulators into the educational process accelerates learning, simplifies the process, and enhances the students' experience. Thus, software simulators are key tools for improving the quality of engineering education and training highly qualified specialists.

Conflict of interest

The author declares that there is no conflict of interest.

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