E-LEARNING SYSTEM FOR ELECTRONIC CIRCUIT CONSTRUCTION USING HANDWRITING RECOGNITION AND MIXED REALITY TECHNIQUES

Atsushi Takemura
Tokyo University of Agriculture and Technology, 2-24-16, Nakacho, Koganei, Tokyo 184-8588, Japan

ABSTRACT

This study proposes a novel e-learning system that can be used as a comprehensive learning resource for electronic circuits, covering design, theoretical analysis, and circuit construction experiments. The proposed system uses an automated recognition technique for schematic symbols that are handwritten on a touchscreen of a mobile tablet-type device and a mixed reality (MR) technique for technical experiments involving electronic circuit construction. The handwriting recognition technique improves the user-friendliness of the e-learning system, and the MR technique provides learners with a simulation of a circuit's operation (e.g., virtual measurements and machine control), which should effectively assist learners in constructing practical circuits. The effectiveness of the proposed system was verified by testing with 45 undergraduate students at Tokyo University of Agriculture and Technology. Positive results were received from all students, which indicate the usefulness of the proposed system.

KEYWORDS

Electronic Circuit, Experiment, Handwriting Recognition, Mixed Reality

1. INTRODUCTION

In technology education, it is necessary to teach electronic design theory and include experiments involving the electronic circuit construction. The ability to understand and construct electronic circuits is critical for acquiring expertise in these technological fields, for example, signal processing and robotics. However, it is difficult to efficiently and comprehensively learn about these topics, which cover theoretical analysis, design, and circuit construction.

Recently, several education support systems have been developed to improve students' understanding regarding electronic circuit concepts. These “learning systems” have been developed to help beginners understand the functioning of various circuit components (Reisslein et al., 2013), basic theories (Assaad et al., 2009), and electrical circuit analysis (Weyten et al., 2009; Holmes et al., 2014). However, these conventional education tools are based on general-purpose or ready-made learning tools and are only suitable for specific circuits within a subject area; therefore, they are insufficient as comprehensive learning resources for electronic circuit themes. To overcome these disadvantages, e-learning systems for virtual circuit construction and simulation were proposed (Takemura, 2013). However, these e-learning systems require individual learners to use their PCs on the laboratory tables during the experiments, which occupy a considerable amount of space, and the PC graphical user interface operation disturbs the experiments.

This study proposes a web-based education system that allows learners to use small tablet-type devices (e.g., mobile PCs) as comprehensive learning resources for electronic circuit themes, covering design, theoretical analysis, construction, and operation. The proposed system uses an automated recognition technique for schematic symbols that are written on the touchscreen of a tablet-type device (Takemura, 2017) and utilizes mixed reality (MR) simulations, which comprise virtual reality (VR) and augmented reality (AR) simulations (Takemura, 2016). The MR technique provides learners with a simulation of a circuit's operation (e.g., virtual measurements and machine control) and is expected to be effective for providing an understanding of practical circuit construction and the applicability to various experiments in the educational field (e.g., sensing and robotics). This study examines whether an e-learning system that combines handwriting recognition and MR techniques is effective as a comprehensive learning resource for electronic circuits.

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2. TECHNICAL SYSTEM FEATURES

2.1 Functions for Comprehensive Learning of Electronic Circuits

Figure 1 schematizes the technological novelty of the proposed education system for comprehensive learning of electronic circuit themes, including circuit design and experiments involving circuit construction and operation. This system comprises tablet-type devices used by individual learners and a remote analysis system. To improve the usability and flexibility, this system enables learners to use general software on their tablet devices. The proposed e-learning system enables learners to choose from three functions depending on the required purpose or environment (Figure 1), which are described in A–C:

A. A circuit design function that supports individual learners to draw circuit diagrams using their tablet-type device.
B. A virtual circuit construction function that removes the need for students to work with physical circuit components and equipment to learn about electronic circuit construction and operation.
C. A physical circuit construction function for learners who have the physical components necessary for circuit construction but do not have the instruments for operation and measurement of the circuit.

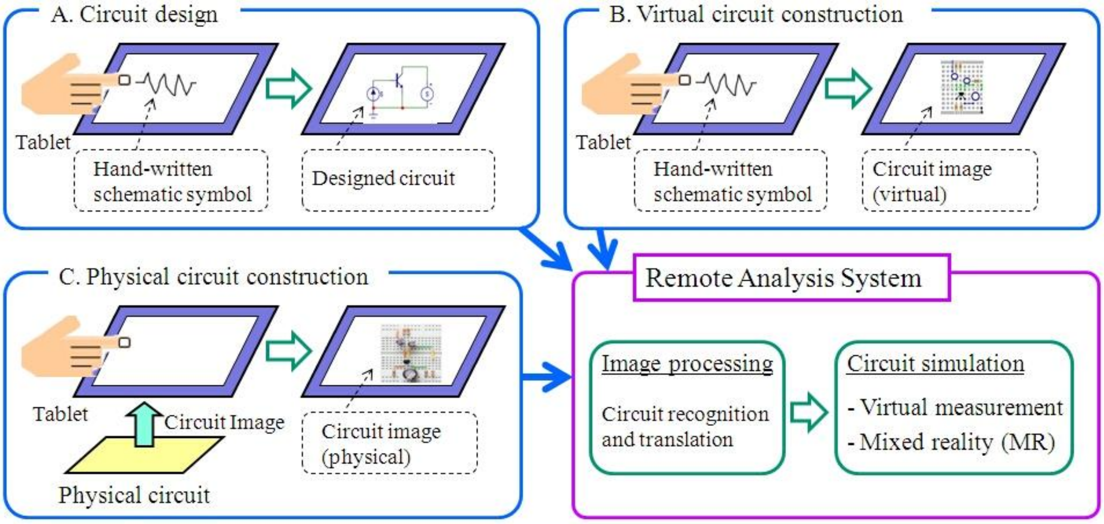

Figure 1. Schematic of the proposed e-learning system with recognition technique for handwritten schematic symbols and the MR simulation technique

To improve the user-friendliness of functions A and B, this system performs automated recognition of handwritten schematic symbols, which the learners handwrite on the touchscreen of a tablet-type device (described in Section 2.2). Functions A–C allow learners to measure the characteristics of the constructed circuits (virtual measurements) by simulating the function of the circuits work based on the automated translation of the circuits into a general circuit-description program (simulation program integrated circuit emphasis; SPICE)(Rabaey) and the image segmentation-based MR technique (described in Section 2.3). These functions of the proposed e-learning system are effective for experiments involving circuit construction, as follows:

- Functions A and B help learners to understand the design, construction, and operation of practical electronic circuits before conducting experiments using physical components and instruments.
- Simulations using functions A and B enable learners to check whether the workings of their designed and virtually constructed circuits are appropriate and satisfy specifications.
- Simulations using function C enable learners to check whether the constructed physical circuits work correctly without the need for circuit operation experiments using real instruments. This function is important for avoiding serious accidents (e.g., electric shocks and fire) that are caused by the operation of incorrect circuits.

2.2 Automated Recognition of Handwritten Schematic Symbols

Figure 2 shows the functions for the automated recognition of a handwritten schematic symbol, drawing a circuit diagram and constructing a virtual circuit using the learner's tablet-type mobile device. Figure 2 is based on the images captured from the touchscreen of a tablet-type device. The processes for designing and constructing an electronic circuit and simulating the circuit's behavior (virtual measurements) by recognizing handwritten schematic symbols are as follows:

(1) Individual learners draw schematic symbols on the touchscreen of the tablet-type devices by hand.

(2) The remote analysis system receives the transmission of the handwritten schematic symbols from the learner's tablet-type device and automatically determines the circuit components based on the pattern matching between the handwritten symbols and the standardized symbols of circuit components in the system database. These standardized circuit symbols are based on the International Electrotechnical Commission and Japan Industrial Standards.

(3) The analysis system provides learners with images of the standardized circuit symbol and the circuit component that corresponds to the handwritten symbol in Process (2).

(4) The proposed system allows individual learners to design and construct virtual circuits using the graphical editor of the learners' tablet-type device. To draw a circuit diagram and construct a virtual circuit, the learner first places images of the standardized circuit symbol and the circuit component obtained from Process (2) on a virtual circuit. They then draw lines to indicate the circuit connections by tapping and sliding a finger on the touchscreen of the tablet-type device.

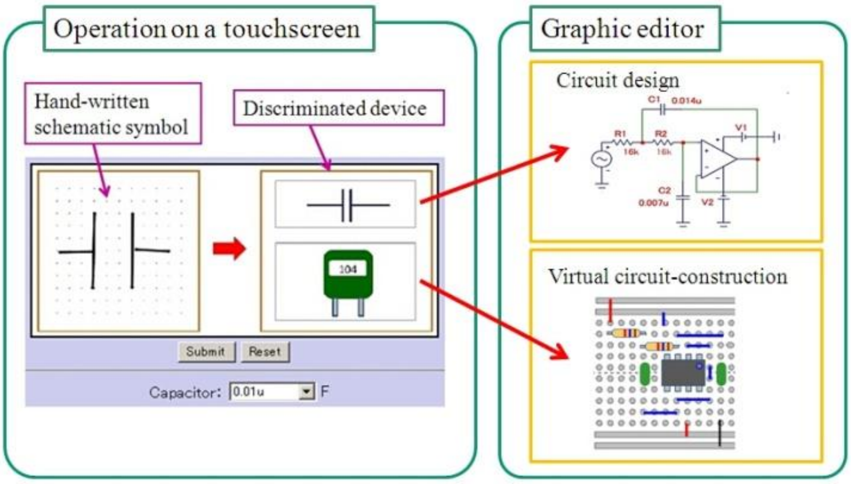

Figure 2. Schematic of the recognition technique for handwritten schematic symbols and proposed system functions for drawing a circuit diagram and constructing a virtual circuit using the learner's tablet-type mobile device

2.3 Circuit Translation into SPICE and the MR-based Simulation

Individual learners transmit the images of their constructed circuits to the remote analysis system. To automatically recognize the circuit construction, the analysis system then performs image processing as described (1) and (2):

(1) The remote analysis system binarizes the circuit image and detects the connecting terminals. On the basis of the array of the detected connecting terminals, the inclination of the circuit image is corrected, and the circuit size is measured.

(2) The analysis system distinguishes between circuit component nodes from the connecting terminals detected in Process (1), and the circuit components connected at the nodes by pattern matching between the circuit image and the circuit components available in the analysis system database.

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On the basis of circuit recognition results from Processes (1) and (2), the analysis system performs an automated translation of the circuit into SPICE. The SPICE information obtained from this automated translation process enables the circuit operation to be simulated and individual users to observe circuit characteristics without the need for operating and measuring instruments for circuits. Importantly, this step aims to prevent serious accidents, such as electric shocks, or fire. Moreover, the analysis system can indicate the presence and location of incorrect parts in a learner's circuit by comparing this with the SPICE information for correct circuits. In addition, the proposed system enables individual learners to simulate how their circuits work using the MR technique based on circuit information obtained from the segmentation process (Takemura, 2016). MR is a view that combines VR and AR. VR is a computer-generated view that is similar to a real environment, and AR is an augmented view comprising physical contents and additional computer-generated information, such as computer graphics or moving image data. This segmentation-based MR technique generates a moving image that simulates the motion of a circuit component (e.g., DC motor rotation) and simulates moving images, which have an accurate size and position in the circuit image based on the segmentation results.

3. EXPERIMENTAL METHODOLOGY

The proposed system was evaluated by 45 undergraduate students in a real class at Tokyo University of Agriculture and Technology (TUAT). To evaluate the usability of each function in the proposed e-learning system, the students used this system as a comprehensive learning resource and performed Experiments (1)–(8) to learn about a practical circuit (DC voltage controller). The order of these experiments was conducted according their purpose: (1) circuit design in experiment, (2)–(4) preliminary experiments based on the virtual circuit construction and simulation in experiments, (5)–(7) physical circuit construction and simulation in experiments, and (8) circuit operation using real instruments. The experiment descriptions are given in the following:

(1) Download the manuals and datasheets from the analysis system. Design the circuit using function A (described in Section 2.1).
(2) Construct the virtual circuits and simulate their behavior using function B.
(3) Measure the characteristics of the constructed circuit (e.g., output voltage) using the SPICE information obtained from the function of the circuit translation (described in Section 2.3).
(4) Check whether the simulation results from Experiment (3) are correct. If an incorrect part exists, correct it according to the system feedback.
(5) Construct the physical circuit and simulate the circuit behavior using function C.
(6) Measure the circuit characteristics using the SPICE information obtained from the circuit translation technique.
(7) Check whether the simulation results from Experiment (6) are correct. If an incorrect part exists, correct the physical circuit according to the system feedback.
(8) Operate the constructed physical circuit and measure the circuit characteristics.

4. RESULTS AND DISCUSSION

The proposed system was evaluated using circuits constructed by 45 undergraduate students in a class at TUAT who were tasked to design and construct a circuit (DC voltage controller) based on the experimental methodology (described in Section 3). Figure 3 shows examples of the circuits and the simulation results by a student using the proposed e-learning system. Figure 3(a) shows a circuit diagram designed using function A. Figure 3(b) shows a virtual circuit constructed using function B. Figure 3(c) shows the virtual measurement results obtained from the automated SPICE translation using the analysis system. After connecting the virtual instruments (a DC power supply and a function generator) correctly in the virtual circuit shown in Figure 3(b), the analysis system automatically changed the virtual DC motor with the corresponding MR components (rotating motor in Figure 3(d)). The motor rotation speed was controlled by the output voltage obtained from the SPICE simulation, which is based on the automated circuit translation. Figure 3(e) shows a constructed physical circuit. After connecting the virtual instruments correctly in the constructed circuit image, the rotating motor simulation was obtained using the MR technique (Figure 3(f)). Figure 3(g) shows the experiment of operation and measurement of the constructed physical circuit using real equipment.

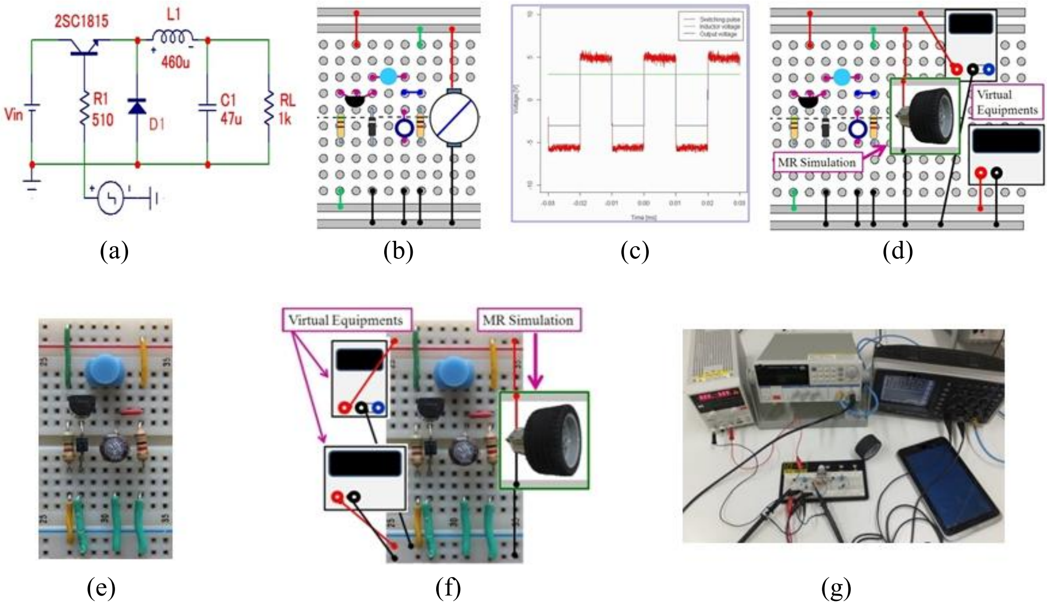

Figure 3. Results of the experiments of circuit construction and MR simulation of the DC voltage controller (step-down chopper): (a) circuit diagrams designed using function A, (b) virtual circuit constructed using function B, (c) virtual measurements based on the automated circuit translation into SPICE, (d) motor rotation simulation of the virtual circuit obtained using the MR technique, (e) constructed physical circuit, (f) MR simulation (motor rotation) of the physical circuit, and (g) experiments of the physical circuit operation using real equipments

The proposed e-learning system handled various structures (layouts of circuit components and wirings) of the student-constructed circuits and supplied each student with the correct circuit behaviors. During the evaluation, positive responses were obtained from all students, which indicate the usefulness of the proposed system. The responses were as follows:

- The handwriting recognition of the e-Learning system is convenient because the operation of the system does not disturb the experiments.
- The preliminary experiments using SPICE and MR developed the learner's understanding of the practical electronic circuits.
- The e-learning system improved safety and avoided accidents by enabling learners to check a circuit's behavior using the virtual instruments and MR simulation.
- The e-learning system was convenient and flexible because no special software was required on the tablet-type mobile devices.

However, there were also a few technical suggestions for improvement, for example, to improve the usability of various circuits studied in university lectures, including large-scale circuits, logic circuits, and practical circuits with a microcontroller.

5. CONCLUSIONS

This study proposes a novel e-learning system for use as a comprehensive learning resource for the design and construction of electronic circuits. To improve the user-friendliness of this proposed system, individual learners can design and construct virtual circuits using their tablet-type devices (mobile PCs). This system can recognize schematic symbols that are handwritten by the learners. Moreover, the proposed system uses an MR-based simulation technique to enable learners to simulate the functioning of their constructed circuits. The usefulness and effectiveness of this system was verified by testing with 45 undergraduate students in a university class. Positive responses were obtained from all students regarding the usefulness and efficiency of the proposed system. To improve the practical use of the proposed system, the following improvements should be implemented:

- Improve the usability to include experiments involving various circuits.
- Provide a quantitative system evaluation feature.

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