E-LEARNING SYSTEM USING SEGMENTATION-BASED MR TECHNIQUE FOR LEARNING CIRCUIT CONSTRUCTION

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ABSTRACT

This paper proposes a novel e-Learning system using the mixed reality (MR) technique for technical experiments involving the construction of electronic circuits. The proposed system comprises experimenters' mobile computers and a remote analysis system. When constructing circuits, each learner uses a mobile computer to transmit image data from the circuit to the analysis system during experiment. The remote analysis system performs automated segmentation and recognition of the circuit image and automatically supplies the user with virtual measurement and the circuit behavior simulation using a segmentation-based MR technique. This proposed system is beneficial for practical use in that an experimenter who lacks sufficient circuit components, measurement instruments, or experimental facilities can learn to construct practical circuits and evaluate their behavior. The usefulness and effectiveness of the proposed system was evaluated by analyzing circuits made by 42 university students in a class. Results showing positive responses, which indicate the usefulness of the proposed system, were obtained from all the students.

KEYWORDS

Technology education, electronic circuit, experiments involving circuit construction, mixed reality

1. INTRODUCTION

Teaching and learning electronic circuit construction is an important element in the field of technology education. Recently, several education systems have been developed to improve students' understanding of the concepts of electrical and electronic circuits. These so-called learning tools for circuit analysis (Becker et al., 2014; Holmes et al., 2014; Johnson et al., 2014) facilitate an understanding of the basic theories of electrical circuits. A learning kit to help beginners understand the functioning of fundamental components in a simple electric circuit was developed (Reisslein et al., 2013). However, these learning tools can cope with only elementary electric circuits; therefore, they are not sufficient for higher education or experiments involving the construction of practical circuits. To overcome the disadvantages of these conventional tools, several education support systems have been developed to improve students' understanding and circuit-making abilities. Stand-alone simulation systems (Abramovitz, 2011; Fitch, 2011) and a virtual circuit-making and measurement system (Takemura, 2013) are useful for students lacking physical circuit components, measurement instruments, or facilities (e.g., laboratories). However, these systems can provide learners with only the specific characteristics (e.g., current and voltage signals) of designed and constructed circuits. In addition to the specific characteristics, providing learners with a simulation of a circuit's behavior (e.g., illumination and motor rotation) is expected to be effective for understanding the construction of practical circuits and applicability to various experiments in the educational field (e.g., sensing and robotics). To this end, this paper proposes a novel e-Learning system for experiments involving circuit construction that is capable of the simulations of illuminating light-emitting diodes (LEDs) and motor rotation using the mixed reality (MR) technique, which comprises virtual reality (VR) and augmented reality (AR). The proposed system's technological novelty is that it can perform image processing on a circuit image and supply segmentation-based MR simulation to enable learners.

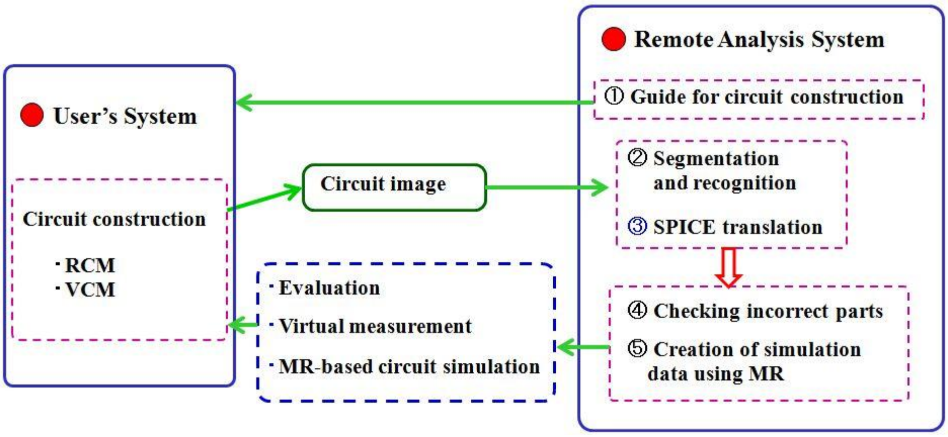

Figure 1. Schematic of the proposed e-Learning system for experiments involving circuit construction

2. METHODOLOGY

Figure 1 illustrates all necessary technological functions of the proposed e-Learning system. The system comprises individual learners' computers and a remote analysis system. All functions and technological features are described in Sections 2.1–2.3. To evaluate the proposed e-Learning system, experiments involving the construction of practical circuits to control the illumination of LEDs and rotation of motors are conducted.

2.1 Function for Supporting Circuit Construction

As shown in Figure 1, the proposed e-Learning system provides users with the necessary guides to design and construct circuits (e.g., circuit diagrams and specifications). This proposed system enables users to choose between two learning modes (real circuit-making mode, RCM; virtual circuit-making mode, VCM) depending on the required purpose or environment (described in A and B). This paper has improved on the previous circuit-making system (Takemura, 2013) to integrate the segmentation-based MR technique (described in 2.2 and 2.3).

A) The RCM is to be used by learners who have the physical components necessary for circuit making but do not have the instruments for operation and measurement of the circuit. The RCM allows learners to observe and measure the characteristics of the constructed circuit using the system's virtual measurement function.

B) The VCM is useful because users do not need to work with physical circuit components to learn electronic circuit design and construction. The VCM enables individual learners to use their preferred graphics editor to indicate connections between virtual circuit components that are downloaded via a computer network and connected on a virtual circuit (Figure 2). The experimenters indicate the virtual circuit connections by drawing colored lines on the circuit board image using a graphical user interface. The VCM allows learners to observe and measure the characteristics of the constructed circuit using the system's virtual measurement function.

2.2 Segmentation and Recognition of Circuit Images

The experimenter transmits the image of the constructed circuit to the analysis system. To automatically recognize circuit construction, the analysis system performs image processing as described in (1) and (2).

(1) The remote analysis system binarizes the circuit image and detects the connecting terminals. Based on 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 differentiates between circuit components nodes from the connecting-terminals detected in the first part of the process, and circuit components connected at the nodes are identified by pattern matching between the circuit image and the circuit components available in the analysis system's database.

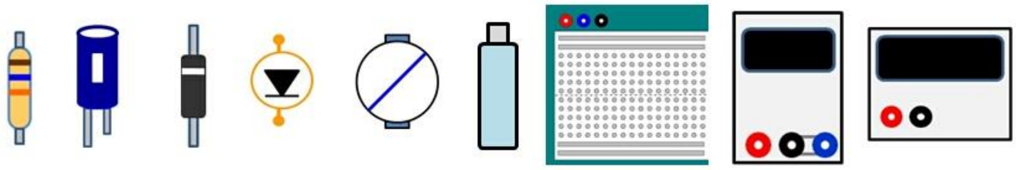

Figure 2. Examples of virtual circuit components and virtual instruments: (a) resistor, (b) capacitor, (c) diode, (d) LED, (e) DC motor, (f) 1.5V battery, (g) breadboard, (h) DC power supply, (i) synthesized function generator

2.3 Circuit Simulation based on SPICE and MR

Based on the result of the circuit recognition (described in 2.2), the analysis system performs an automated translation of the circuit into a general circuit-description language (simulation program integrated circuit emphasis, SPICE) (Rabaey). The SPICE information obtained from this automated translation process enables the simulation of the circuit operation, and individual users can observe circuit characteristics without the instruments for operation and measurement of their circuits. The analysis system can indicate the presence and location of incorrect parts in a learner's circuit by checking any differences that exist between the SPICE information for correct circuits and those constructed by a learner. This SPICE translation technique can cope with the various structures (circuit component layouts and wirings) of circuits made by individual learners. In addition, this paper proposes a novel circuit simulation function using the MR technique based on circuit information obtained from the segmentation process (described in 2.2(2)). The MR is a view that comprises VR and AR. VR is a computer-generated view that is similar to a real environment. AR is an augmented view comprising physical contents and additional computer-generated information such as computer graphics or moving image data. The proposed MR technique generates a moving image that simulates the motion of a circuit component (e.g., rotation of a DC motor) and supplies learners with simulated moving images at the accurate size and position in the circuit image based on the segmentation result.

To improve the usability of the proposed technique, the proposed e-Learning system sends messages to individual learners during experiments and instructs them to check their results as follows.

1) When incorrect components or faulty wiring is detected from a circuit image, the analysis system indicates the errors and instructs the learner to check and correct them.
2) When the analysis system detects a serious error (e.g., short circuit), the system sends the learner a critical warning to correct the incorrect part.
3) The analysis system requests the learner to check whether simulated behavior of the constructed circuit corresponds to their specification.

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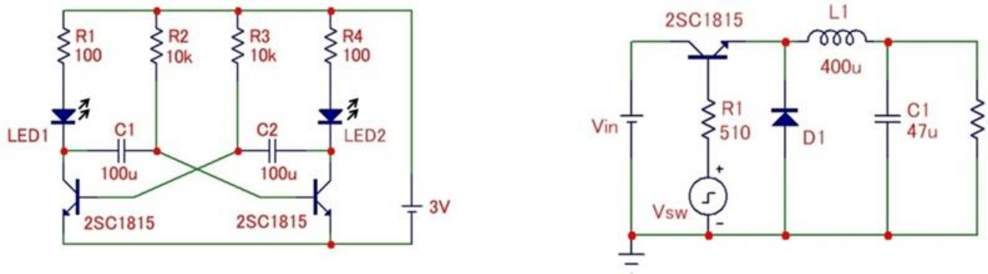
3. RESULTS AND DISCUSSION

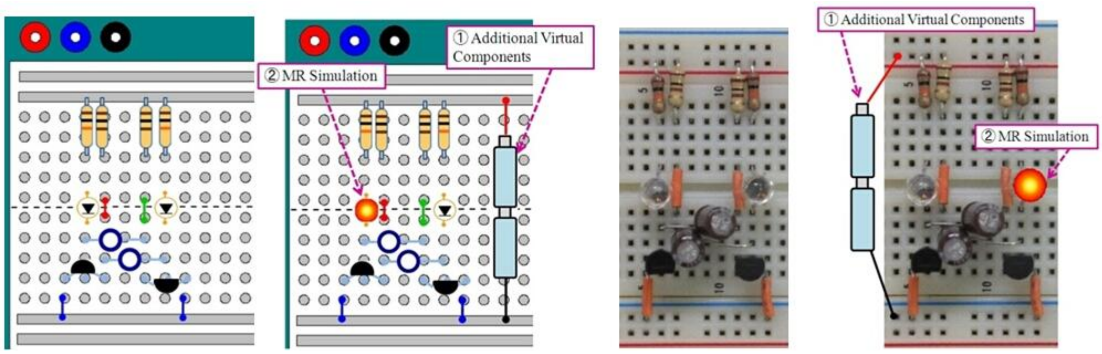
The proposed system was evaluated using circuits constructed by 42 undergraduate students in a class at Tokyo University of Agriculture and Technology. Figure 3 shows the circuit diagrams used for evaluation. The circuit in Figure 3(a) is a square pulse generator, namely, multivibrator. This circuit alternately turns two LEDs on and off. Figure 3(b) shows a circuit to control DC voltage. Individual students constructed the circuits using the VCM and RCM. The students were allowed to use both virtual and physical circuit components as necessary but the DC battery and instruments for operation and measurement (DC power supply and the function generator) were not provided. Therefore, the students used the proposed MR simulation function to measure the characteristics of the constructed circuits and evaluate the circuit behavior (illumination of LEDs and motor rotation).



(a) (b)

Figure 3. Circuit diagrams for circuit-making experiments: (a) multivibrator (square pulse generator) and (b) DC voltage controller (step-down chopper)

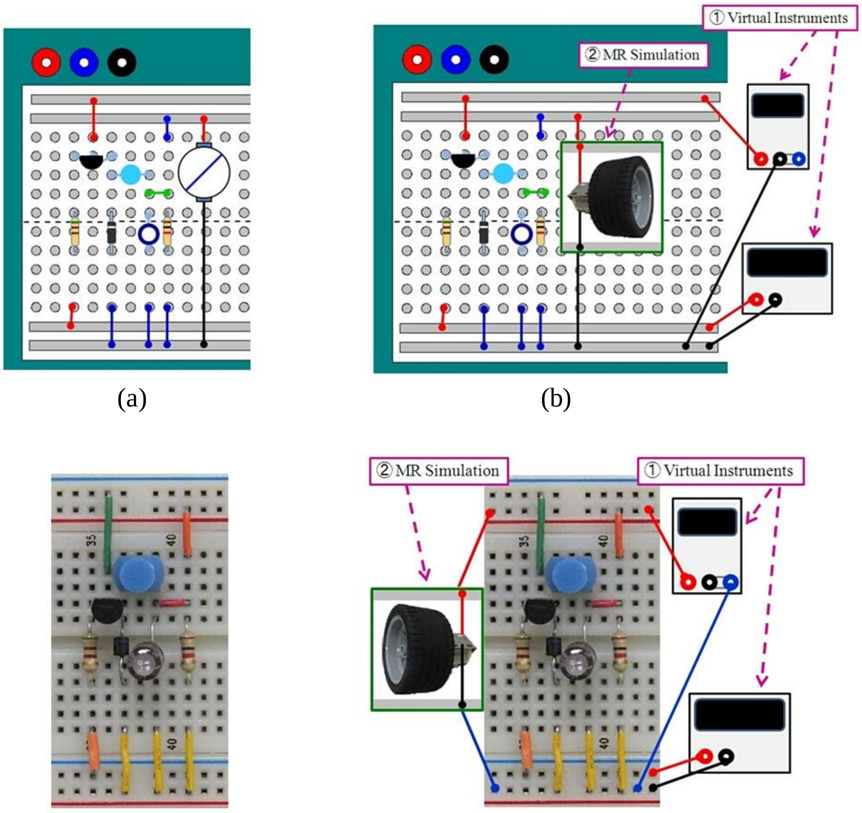
Figure 4 shows examples of the circuit (multivibrator) that was constructed by a student using the two modes (VCM and RCM) of the proposed system. Figure 4(a) shows the circuit constructed using the VCM. Figure 4(b) shows the virtual DC battery that was connected using VCM at the correct position and the MR simulation of illuminating LEDs was performed by the proposed segmentation-based MR technique; here the placement of the virtual LEDs was set using image segmentation. Figures 4(c) and 4(d) show the circuit constructed using RCM and the MR simulation of illuminating LEDs, respectively; here the placement of the virtual LEDs was set using image segmentation.



(a) (b) (c) (d)

Figure 4. Circuit construction and MR simulation of multivibrator: (a) virtual circuit constructed using the VCM, (b) simulation of illuminating LEDs on the virtual circuit created using the proposed MR technique, (c) constructed physical circuit, and (d) MR simulation illuminating LEDs of the circuit constructed using the RCM

Figure 5 shows examples of the circuits (DC voltage controller) that were constructed by a student using the proposed system. Figure 5(a) shows the circuit constructed using the VCM. Figure 5(b) shows the result of a simulation created using the proposed segmentation-based MR technique. The analysis system located the region of the virtual DC motor in the circuit image (Figure 5(a)) and changed this virtual component with the corresponding MR components (rotating motor). The rotation speed of the motor is controlled based on the output voltage obtained from SPICE simulation. Figure 5(c) shows a constructed physical circuit. After connecting the virtual instruments (DC power supply and function generator) correctly in the image of the constructed circuit, created using the RCM, the simulation of a rotating motor was obtained using the proposed MR technique (Figure 5(d)).



(a) (b)

(c) (d)

Figure 5. Circuit construction and MR simulation of the DC voltage controller: (a) virtual circuit constructed using the VCM, (b) simulation of motor rotation of the virtual circuit obtained using the MR technique, (c) constructed physical circuit, and (d) MR simulation (motor rotation) of the circuit constructed using the RCM

The proposed system coped with various structures (layouts of circuit components and wirings) of the circuits constructed by students and supplied each student with the correct circuit behaviors. Positive responses, which indicate the usefulness of the proposed system, were obtained from all students during the evaluation; the responses are as follows.

- The e-Learning system was useful for learning the construction and behavior of practical circuits without expensive instruments and facilities (e.g., a laboratory).
- The e-Learning system improved safety because learners were able to check a circuit's behavior using the virtual instruments and MR simulation, thus avoiding serious accidents (e.g., electric shock and fire).
- The e-Learning system was convenient and flexible because no special software was required to be used exclusively on users' computers.

However, there were also a few technical suggestions for improvement, e.g., to improve the usability to various circuits studied in university lectures (e.g., logic circuits and robotics).

4. CONCLUSION

This paper proposes a novel e-Learning system for the construction of electronic circuits using a segmentation-based MR technique. The usefulness and effectiveness of the system was verified by 42 undergraduate students in a university class. The analysis system of the proposed system performed accurate circuit image processing and translation into SPICE. This SPICE information and the proposed segmentation-based MR succeeded in providing learners with virtual measurement and simulated behaviors of the constructed circuits. Positive responses, which pertain to the usefulness and efficiency of the proposed system, were obtained from all students. The steps that are necessary to practically implement the proposed system are as follows.

- Increase available content for MR simulation and improve the applicability to various circuits.
- Make the system more user-friendly (e.g., availability of mobile tools).

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