LEARNING SYSTEM USING CROSS REALITY TECHNIQUE FOR PHYSICAL ELECTRONIC CIRCUIT CONSTRUCTION AND VIRTUAL MID-AIR OPERATIONS

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ABSTRACT

Science and technology education necessitates teaching and learning experiments involving electronic circuit construction and measurements using experimental equipment. In this study, a novel cross reality system for learning physical circuit construction and performing virtual experiments using virtual experimental equipment with mid-air haptics is proposed. The proposed system possesses a technical novelty that enables a learner to operate virtual equipment with the same motions of his hand and fingers as the operations of the real equipment. An evaluation test using 150 patterns of virtual experiments verified the proposed system's effectiveness.

KEYWORDS

e-Learning, Experiment, Electronic Circuit, Cross Reality, and Mid-Air Operation

1 INTRODUCTION

To acquire the knowledge and skills of creating high technologies (e.g., electronics and robotics), science and technology education necessitates experiments involving electronic circuit construction and the operation of experimental equipment. However, most educational institutions have difficulties in ensuring a sufficient number of materials and equipment for experiments because of high costs and student-to-instructor ratios. To solve this problem, several education systems have been developed, such as virtual measurements of electric circuits (Garcia-Zubia, 2017) and online experimentation in engineering education (Lei, 2021). However, image-based learning using conventional systems does not enable the learning of the real operations necessary for experiments (e.g., measurement using experimental equipment). To overcome this shortcoming, this study proposes a novel cross reality (XR) system that enables learners to learn the physical circuit construction and experiments involving the virtual operation of experimental equipment with the same motion and tactile stimuli as the real experiments. This proposed system is useful for learners with only small and inexpensive physical components (e.g., circuit boards and devices) for circuit construction but not large-sized and expensive experimental equipment.

The remainder of this article is organized as follows. Section 2 presents the technical features of the proposed system. Section 3 presents the experimental methodology for evaluating the proposed system. Section 4 presents the quantitative evaluation of the proposed system. Finally, Section 5 presents the conclusions of this study.

2. TECHNICAL FEATURES OF THE PROPOSED SYSTEM

Figure 1(a) schematizes an experiment with the construction of a physical circuit and operation of virtual equipment indicated on a PC monitor. The device generating mid-air haptics is placed between the constructed circuit and PC monitor. This device comprises ultrasonic phased-array transducers and a hand-tracking camera. Subsections 2.1 and 2.2 describe the technological novelties and features of the proposed XR system.

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2.1 Acquisition of the Circuit Image and Virtual Measurements

During the physical circuit construction, a web camera, connected to the learner's PC, acquires image data of the constructed circuit and transmits the data to the remote analysis system. This analysis system performs image recognition to identify the experimental circuit. Moreover, as shown in Figure 1(b), the analysis system performs a circuit translation (Takemura, 2020) that can automatically translate the information obtained from the circuit-recognition process into a general circuit-description language—simulation program with integrated circuit emphasis (SPICE) (Rabaey). Based on this SPICE information, the analysis system can simulate how the constructed circuit works and provide the learner with the virtual measurement results. Corresponding to the hand motion for the virtual operation and measurements with mid-air haptics (described in Subsection 2.2), the learner can watch the workings of the constructed circuit and measure the circuit characteristics.

2.2 Virtual Operation of Experimental Equipment with Mid-Air Haptics

To realize mid-air operations for the virtual measurements of the physical constructed circuit, this study proposes a novel technique combined with the automated recognition of the motions of a learner's hand and fingers using a three-dimensional (3D) motion sensor (hand-tracking camera) and tactile stimuli (mid-air haptics) obtained from airborne ultrasound [Figure 1 (a)]. The proposed system allows a learner to draw lines using a graphics editor to indicate the wiring between an image of the constructed circuit and images of the experimental equipment (e.g., oscilloscope and function generator). In addition, the system has the following novel technical features: (1) it enables a learner to operate the virtual experimental equipment with the same motions of his hand and fingers as the experiment using real (physical) equipment and (2) it gives a learner's hand and fingers the tactile stimuli when operating the virtual equipment. To automatically recognize the motions of a learner's hand and fingers and generate the tactile stimuli, the proposed system is developed using a device equipped with an ultrasound phased array and an infrared-based hand-motion sensor: "Ultrahaptics" (https://www.ultraleap.com/haptics/). Table 1 presents the necessary motions of a learner's hand and fingers for the parameter setting and mode selection of the virtual equipment.

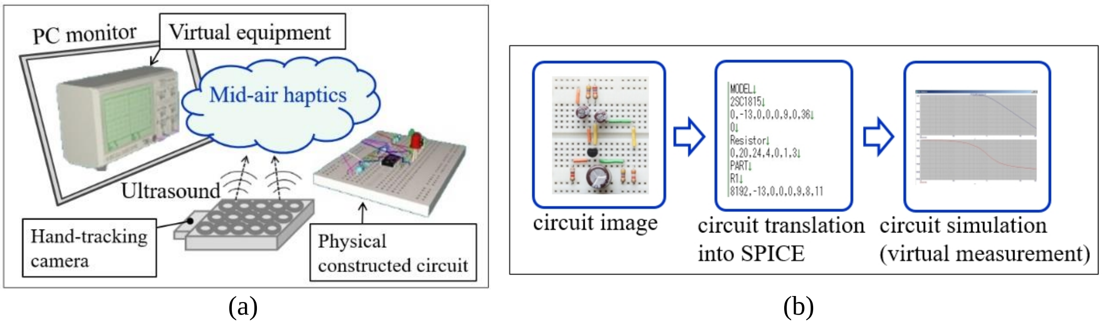


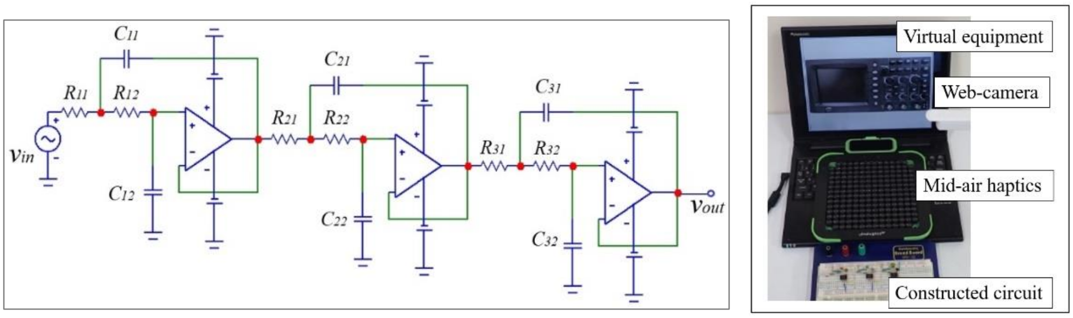
Figure 1. Schematic of the proposed learning system: (a) composition of the proposed XR system and (b) translation and simulation technique for the virtual measurement

Table 1. Necessary mid-air motions of a learner's hand and fingers for the parameter setting and mode selection of virtual experimental equipment

Virtual equipment	Adjustment of parts of the virtual equipment		
	Rotary knob	Push bottom	Numeric keys
Function generator	Amplitude adjustment	Waveform selection	Adjustment of frequency and a duty factor
Oscilloscope	Position of waveform indications	Channel selection	–
Multimeter	—	Selection switches	–
DC power supply	Voltage adjustment	–	–

3. METHODOLOGY FOR EVALUATING THE PROPOSED SYSTEM

In this study, the proposed system for the virtual operation and measurements with mid-air haptics was evaluated by five students aged 19–22 at the Tokyo University of Agriculture and Technology (TUAT) using physical circuits constructed by 30 undergraduate students in an actual class at TUAT. Therefore, 150 patterns of the experimental results were used for this evaluation. Figures 2(a) and (b) show the circuit diagram of a sixth-order active low-pass filter to be physically constructed in the experiment and the experimenter's system for the virtual operations and measurements with mid-air haptics, respectively. Individual students in the aforementioned class were tasked to construct physical circuits based on the circuit diagram shown in Figure 2(a). Using the constructed circuits, the five students performed virtual experiments involving the operation of the virtual experimental equipment and measurements of the constructed circuits' characteristics using the proposed technique described in Subsection 2.2. Through the evaluation test, the five students checked and reported the effectiveness of the mid-air operations relating to the accuracy of the following points: (1) the positions of finger motions to control the virtual equipment based on Table 1 and (2) the positions and intensities of tactile stimuli obtained from the mid-air haptic device.

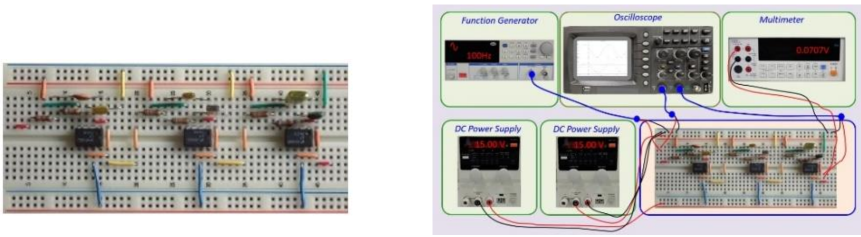


(a) (b)

Figure 2. Circuit to be constructed and XR system for evaluating the proposed technique: (a) the circuit diagram of a sixth-order active low-pass filter using three operational amplifiers and (b) the experimenter's system enabling the operations and measurements with the mid-air tactile stimuli

4. RESULTS AND DISCUSSION

Figures 3(a) and (b) show an image of a physical constructed circuit and the results of the virtual operations and measurements obtained by one student, respectively. This student correctly connected the wiring between the circuit image and virtual equipment and adequately adjusted the setting of the virtual equipment with the necessary motions for mid-air operation, as presented in Table 1. Therefore, this student could measure the correct physical circuit characteristics (e.g., current and voltage) using the virtual multimeter and observe the correct waveforms on the virtual oscilloscope display.



(a) (b)

Figure 3. Result of one student's virtual operations and measurements of the constructed physical circuit: (a) physical circuit constructed based on the diagram shown in Figure 2(a) and (b) virtual operation and measurements using the virtual equipment with mid-air haptics

Through the evaluation test using 150 patterns of virtual experiments by the five students (described in Section 3), the following positive responses, which pertain to the usefulness and efficiency of the proposed system, were obtained from all students.

- The virtual operation of experimental equipment with mid-air haptics is effective because it enables virtual experiments similar to real experiments without the actual equipment and laboratories.
- The positions of the tactile stimuli were accurate. Therefore, the mid-air haptics was effective in improving the reality of the virtual experiments.

However, there are a few technical disadvantages and room for improvement.

- The virtual equipment indicated on a two-dimensional display should be improved using a 3D vision device.
- The accuracy of the recognition of hand gestures when rotating knobs in virtual equipment should be improved because the setting parameters using rotary knobs did not change proportionally with the rotation angle.
- Occasionally, tactile stimuli when operating the virtual equipment were not exact because the ultrasound vibrations of mid-air haptics were given from only a certain direction.

To improve the applicability and usefulness of the proposed system, the following study should be implemented.

- Combination with 3D vision (e.g., volumetric display).
- Improvement of the accuracy and reality of tactile stimuli by developing multidirectional mid-air haptics.
- Quantitative evaluation of mid-air haptics using more circuits and experimenters.

5. CONCLUSIONS

This paper proposes a novel learning system using XR that enables a learner to construct a physical circuit and perform an experiment involving virtual operations using virtual experimental equipment with mid-air haptics on the learner’s hand and fingers. The proposed system enables a learner to operate the experimental equipment with the same motion as the operation of real experiments. The evaluation test using 150 patterns of virtual experiments verified the proposed system’s effectiveness. In future study, the effectiveness and usefulness of the proposes system will be further improved using 3D vision.

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REFERENCES

Garcia-Zubia, J., et al., 2017, Empirical analysis of the use of the VISIR remote lab in teaching analog electronics, *IEEE Trans. Educ.*, vol. 60, no. 2, pp. 149–156.

Hasegawa K., et al., 2018, Aerial vibrotactile display based on multiunit ultrasound phased array, *IEEE Trans. Haptics*, vol. 11, no. 3, pp. 367–377.

Lei, Z., et al., 2021, 3-d interactive control laboratory for classroom demonstration and online experimentation in engineering education, *IEEE Trans. Educ.*, vol.64, no.3, pp.276–282.

Rabaey, J. M., The Spice Page, <URL: http://bwrc.eecs.berkeley.edu/Classes/IcBook/SPICE/> (accessed Sep. 10, 2022).

Takemura, A., 2020, e-Learning system for the comprehensive learning of electronic circuits, *Proc. IADIS Conference CELDA 2020*, pp. 349–354.