# AN E-LEARNING SYSTEM WITH MR FOR EXPERIMENTS INVOLVING CIRCUIT CONSTRUCTION TO CONTROL A ROBOT

Atsushi Takemura
*Tokyo University of Agriculture and Technology, February 24, 2016, Naka-cho, Koganei-shi, Tokyo 184-8588, Japan*

**ABSTRACT**

This paper proposes a novel e-Learning system for technological experiments involving electronic circuit-construction and controlling robot motion that are necessary in the field of technology. The proposed system performs automated recognition of circuit images transmitted from individual learners and automatically supplies the learner with virtual measurement and circuit behavior simulation using a segmentation-based mixed reality (MR) technique. The proposed system is advantageous in terms of practical use because learners with insufficient or no circuit components, and/or measurement instruments, and/or experimental facilities can use the proposed system to learn about the construction of practical circuits embedded in robots and to evaluate the motion of a robot. The usefulness of the proposed system was evaluated by analyzing circuits and robots constructed by 15 university students in a class. Results showing positive responses, which indicate the usefulness of the proposed system, were obtained from all the students.

**KEYWORDS**

e-Learning for technological experiments; electronic circuit; robot design and building; SPICE; mixed reality

## 1. INTRODUCTION

The field of technology education necessitates teaching and learning of basic theories and experiments involving construction of electronic circuits. Education on robotics invention is important for students to acquire an extensive knowledge of technologies such as electronic circuits and system control. Therefore, experiments involving robot design and construction are effective in developing student faculties in the study of technologies, and increase the motivation of students towards engineering. Recently, several education support systems have been developed to improve student understanding of robotics (Behrens, 2010; Gómez-de-Gabriel, 2011; Huang, 2013; Takemura 2013). However, conventional education systems on robotics are insufficient for usage in technical education due to the following disadvantages:

- Electronic circuits equipped in a robot are either ready-made or black boxes. Therefore, it is not possible for students to learn about the design and construction of electronic circuits used in the robot.
- Conventional systems cannot cope with the wide variety of circuits designed and constructed by individual learners because they are ready-made tools and can only be applied for specific educational purposes within a subject area.
- Conventional systems require the use of proprietary software to learn about circuits and robotics.
- Conventional systems cannot be applied to or are sufficient for e-Learning for experiments.

To overcome the fore-mentioned disadvantages of conventional systems, this paper proposes a novel e-Learning system for experiments involving the construction of electronic circuits and robots. The proposed system possesses the following technological novelties:

(1) An education system for experiments to learn about the design and construction of practical circuits with sensors and DC motors that are embedded in a line tracer robot.

(2) A learning tool that can simulate the operation of circuits and the motion of robots using a mixed reality (MR) technique. This technique is effective for e-Learning in experiments because a student can learn about robot behavior without the need to constructing an entire physical robot.

(3) The proposed system is composed of web-based learning tools, and thus it is not necessary for learners to use proprietary software.

This proposed system was evaluated by undergraduate experimenters in an actual class at Tokyo University of Agriculture and Technology (TUAT).

# 2. METHODOLOGY

The proposed system consists of individual users' systems (learners' computers) and a remote analysis system. Individual learners can use their computers and learn about the construction of circuits embedded in robots and the behavior of the robots. Subsections 2.1–2.4 describe the technological features of the proposed e-Learning systems. In this paper, experiments involving the construction of practical circuits embedded in a line tracer evaluated the proposed e-Learning system. The line tracer is a robot that can detect the edge of a thick black line on a white floor and move along the black line.

## 2.1 Function for Supporting Circuit Construction

The proposed e-Learning system provides learners (system users) with necessary guides, such as circuit diagrams and specifications, to design and construct circuits. The proposed system enables learners to choose between three learning modes, namely a virtual circuit-construction mode (VCM), a real circuit-construction mode (RCM), and a mixed mode, based on the required purpose or environment (Takemura, 2013).

The VCM can be used by learners with insufficient physical circuit components or measurement equipments or facilities (e.g., laboratories). The VCM enables individual learners to use a preferred graphics editor to place virtual circuit components on a circuit-board image downloaded via a computer network and to draw colored lines to indicate connections between the virtual circuit components. Therefore, the proposed system does not require the use of proprietary graphics software. The VCM allows learners to observe and measure the characteristics of the constructed circuit by using the virtual measurement function of the system (described later in Section 2.2).

The RCM can be used by learners with physical components necessary for circuit construction. If RCM users do not possess the instruments for operating and measuring the circuit, then the RCM allows learners to observe and measure the characteristics of the constructed circuit by using the virtual measurement function of the system.

The mixed mode of the proposed system can translate a circuit image consisting of both real and virtual circuit components. This mode is useful for a learner who wants to construct a large scale circuit but without sufficient physical circuit-components necessary to construct the complete circuit.

## 2.2 Function for Image Processing and Circuit Translation into SPICE

The function for image processing and circuit translation performs an important role in the preprocessing of the proposed segmentation-based MR technique. Learners complete circuit construction using the function described in Section 2.1 and transmit the circuit images to the remote analysis system. In order to automatically recognize circuit construction, the analysis system performs image processing in the following manner:

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

(2) Pattern matching between the circuit image and the circuit components available in the system analysis database is used by the analysis system to discriminate the circuit components (e.g.; devices and wirings) and the nodes of the connected components.

Based on the result of the circuit recognition, 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 learners can observe circuit characteristics without the instruments for operating and measuring their circuits (Takemura, 2013). Additionally, 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 in correct circuits and those constructed by a learner. The SPICE translation is based on automated circuit recognition, and therefore the system can cope with various structures, such as circuit component layouts and wirings of circuits made by individual learners.

## 2.3 Function for Simulation Using the Segmentation-based MR

Based on the information of circuit structures obtained from the segmentation process (as described in 2.2(2)), the proposed system can simulate circuit operation and robot motion using the segmentation-based MR technique. The MR is a view that comprises of the virtual reality (VR) and the augmented reality (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 MR technique used in the proposed system generates a moving image that simulates the operation of a circuit or the behavior of a robot. The simulated moving image obtained from the MR supplies learners with simulated moving images at accurate sizes and positions in the circuit image based on the segmentation result.

## 2.4 Improvement of the Usability

The proposed system can detect incorrect parts in circuit images based on the automated SPICE translation (described in Section 2.2). To improve the usability of the preceding system (Takemura, 2013), the system sends messages to individual learners during experiments and instructs them to check their results as follows:

- When incorrect components or faulty wiring are detected from a circuit image, the analysis system indicates the errors and instructs the learner to check and correct the errors.
- When the analysis system detects a serious error (e.g., a short circuit or inappropriate power supply), the system sends a critical warning to the learner to correct the incorrect part.
- The analysis system requests the learner to check whether the simulated behavior of the constructed circuit corresponds to their specifications.

## 2.5 Experimental Methodology

The proposed system was evaluated by 15 undergraduate students in an actual class at TUAT. To evaluate the usability of each function in the proposed e-Learning system, the students were asked to perform the following experiments to construct the circuits used in a line-tracer robot:

(1) Each learner downloaded the necessary guides to design and construct circuits, such as circuit diagrams and specifications, from the Internet.

(2) The VCM function of the proposed system was used by each learner to create the virtual circuit of a line-tracer robot including an optical sensor and a DC motor. Each learner checked whether the e-Learning system indicated warnings or incorrect parts in their circuits. If warnings and incorrect parts were indicated, then the learner corrected these parts in accordance with the advice provided by the system and completed the circuit construction.

(3) Each learner observed the motion of the constructed circuit using the VCM (illumination of LEDs and rotation of motors) from the MR simulation provided by the proposed system.

(4) The RCM function was used by each learner to create the physical circuit of the line-tracer robot. Each learner performed a check as to whether the e-Learning system indicated warnings or incorrect parts in their circuits. If warnings and incorrect parts were indicated, then the learner corrected these parts in accordance with the method described in (2).

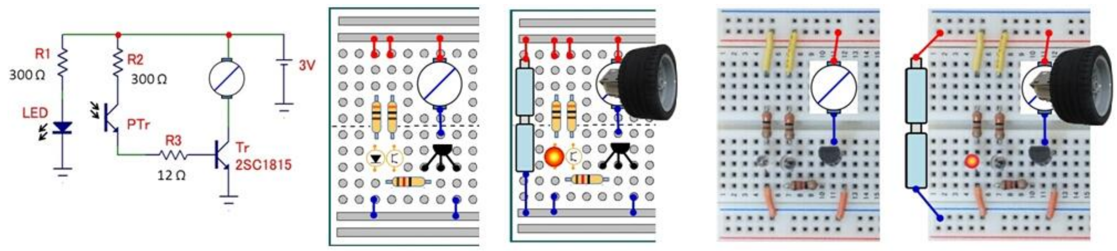
(5) Each learner observed the motion of the circuit constructed using RCM (illumination of LEDs and rotation of motors) from the MR simulation.

(6) Applying the images of the constructed circuits, each learner designed and constructed the virtual line-tracer robot using the mixed mode function of the proposed system and observed the behavior of the robot from the MR simulation provided by the system.

## 3. RESULTS AND DISCUSSION

Fifteen undergraduate students in an actual class evaluated the proposed system through experiments (1)–(6) as described in Section 2.5. Figure 1(a) shows the circuit diagram of a circuit used as part of a line tracer to be constructed. This circuit includes a DC motor and an optical sensor that consists of a LED and a phototransistor. This circuit controls the rotation of a wheel on a line-tracer robot. Figure 1(b) shows the circuit constructed by a learner using the VCM. After the learner connected correctly the additional virtual components (DC batteries) in the image of the constructed circuit (Figure 1(b)), the segmentation-based MR simulations of the illumination of the LED and the rotating wheel were automatically indicated at specific places that were discriminated using the image segmentation process (shown in Figure 1(c)). The output voltage obtained from SPICE simulation based on the automated circuit-translation process of the proposed system (as described in Section 2.2) was used to control the rotation speed of the wheel.

Figure 1(d) shows a circuit constructed by the same learner using the mixed mode. The learner constructed the circuit by connecting the physical circuit components that were provided with the exception of a DC motor. As shown in Figure 1(e), the learner connected the virtual circuit component (DC motor) instead of the insufficient physical component and completed the circuit construction using the mixed mode of the system. After connecting the virtual components (DC batteries) correctly in the image of the circuit constructed using the mixed mode, the MR simulation of a rotating wheel was obtained. The rotation speed of the wheel was controlled based on the output voltage obtained from SPICE simulation that was based on the automated circuit-translation process of the proposed system.




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

Figure 1. Circuit diagram of a line tracer to be constructed and the results of the experiment involving circuit construction and segmentation-based MR simulation (motor rotation): (a) Circuit diagram, (b) Virtual circuit constructed using the VCM, (c) MR-simulation of the constructed circuit (b), (d) constructed circuit using the mixed mode, and (e) MR-simulation of the constructed circuit (d)

Figures 2(a) and (b) show the lower and upper surfaces, respectively, of a line-tracer robot designed by the same learner using the mixed mode of the proposed system. As shown in Figure 2(a), a virtual circuit as well as a physical circuit was embedded in the virtual robot that was designed by the learner using a graphic editor. The proposed e-Learning system performed the image processing and circuit translation of the circuit image in the virtual robot and provided the learner with a moving image of the simulated behavior of the line-tracer robot as shown in Figure 2(c).

The students in the study evaluated the proposed e-Learning system. Positive responses were obtained from all the students and these indicated the usefulness and the effectiveness of the proposed system. Specifically, the following responses were obtained:

- This education system is useful because it enabled e-Learning with respect to topics such as circuit design and experiments involving the construction of practical circuits related to robotics.
- This e-Learning system is effective because the system can cope with various structures (layouts of circuit components and wirings) of the circuits constructed by individual users
- The e-Learning system used for virtual robot construction and simulation of the robot behavior is instructive because individual users can study practical circuits with sensors to control the behavior of the robots without the use of sufficient circuit components and proprietary software.

However, the responses also indicated a few technical disadvantages and suggestions for improvement; e.g., an educational system to study various types of robots, such as robot arms and humanoids, is expected.

(a) (b) (c)

Figure 2. Line-tracer robot designed using the mixed mode and the simulation result: (a) Lower surface of the designed line tracer, (b) Upper surface of the designed line tracer, and (c) Simulation of the motion of the designed line tracer

## 4. CONCLUSION

This paper proposes a novel e-Learning system for technical experiments involving the construction of practical electronic circuits and robotics using a segmentation-based MR technique. The proposed system consists of a learning system of circuit construction with sensors embedded in a robot and a MR-used simulation system to learn about the operation of the constructed circuit and the behavior of robots. The usefulness and effectiveness of the system was verified by the responses of 15 undergraduate students in a university class. Positive responses, which related to the usefulness and efficiency of the proposed system, were obtained from all the students. The following steps were necessary steps to practically implement the proposed system:

- Evaluation of the system by more experimenters.
- Enhancing the system to study more highly developed robots with plural sensors and motors such as humanoids.

## ACKNOWLEDGMENT

This study was partly supported by a Grant-in-Aid for Scientific Research (KAKENHI) 16K01060 from the Japan Society for the Promotion of Science (JSPS).

## REFERENCES

Behrens, A. et al., 2010. MATLAB meets LEGO Mindstorms – A freshman introduction course into practical engineering, *In IEEE Trans. Education*, Vol.53, No.2, pp.306–317.

Gómez-de-Gabriel, J.M. et al., 2011. Using LEGO NXT mobile robots with LabVIEW for undergraduate courses on mechatronics, *In IEEE Trans. Education*, Vol.54, No.1, pp.41–47.

Huang, H., 2013. A contest-oriented project for learning intelligent mobile robots, *In IEEE Trans. Education*, Vol.56, No. 1, pp.88-97.

Rabaey, J. M., The Spice Page, <URL: http://bwrc.eecs.berkeley.edu/Classes/IcBook/SPICE/> (accessed Sep. 20, 2016)

Takemura, A., 2013. e-Learning system for experiments on circuit construction and robot control, *Proc. IADIS Conference Internet Technologies and Society 2013*, pp.95–100, Kuala Lumpur, Malaysia.