

E-LEARNING SYSTEM FOR LEARNING VIRTUAL CIRCUIT MAKING WITH A MICROCONTROLLER AND PROGRAMMING TO CONTROL A ROBOT

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ABSTRACT

This paper proposes a novel e-Learning system for learning electronic circuit making and programming a microcontroller to control a robot. The proposed e-Learning system comprises a virtual-circuit-making function for the construction of circuits with a versatile, Arduino microcontroller and an educational system that can simulate behaviors of robots based on programs written by individual experimenters. The proposed system is useful and effective for comprehensive studies on electronic circuits with sensors and for programming robot control. The usefulness and effectiveness of the proposed system were evaluated by five university students. Results showing positive responses, which indicate the usefulness of the proposed system, were obtained from all students.

KEYWORDS

e-Learning system, virtual circuit making, microcontroller, construction and programming of a robot

1. INTRODUCTION

Teaching and learning both hardware and software are necessary in the field of technology education. Learning to construct an electronic circuit with a microcontroller (microprocessor) and to program machine controls (e.g., robotics) is effective in the study of technologies and increases student motivation to learn engineering. Figure 1 shows techniques needed to construct a robot and to control its motion. Students in the field of technology have to efficiently learn all techniques (1–5) shown in Figure 1. The LEGO Mindstorms system (<http://www.legomindstorms.com/>) is the most widely used for many educational purposes because it is relatively inexpensive, reusable and programmable (Behrens, 2010; Gómez-de-Gabriel, 2011; Kim, 2011; Takemura, 2013). The LEGO Mindstorms system enables users to easily construct various types of robots using a minicomputer module (RCX, NXT, or EV3) and plastic blocks, and users can study the programming that controls the robots' motion. Therefore, the LEGO Mindstorms system has been used to teach engineering technologies to students from primary to graduate levels. However, conventional LEGO-based systems are not sufficient to use for technical education because of the disadvantages as follows:

- The minicomputers of LEGO Mindstorms are black boxes. Therefore, students cannot learn electronic circuits used in the robots.

- Each minicomputer (RCX, NXT, and EV3) needs proprietary software for programming, and the programming environment is not compatible with the different types of minicomputers.

Moreover, conventional education systems on robotics are not sufficient for comprehensive studies involving technological elements (1–5) shown in Figure 1; and the conventional systems are not applicable to e-Learning. To overcome these disadvantages, this paper proposes a novel e-Learning system for comprehensive studies of robotics, including all technological elements shown in Figure 1. Specifically, the proposed system comprises the technical functions as follows:

- (a) A virtual-circuit-making (VCM) function for the virtual construction of a circuit with sensors and a generally used Arduino microcontroller (<http://www.arduino.cc/>).
- (b) An e-Learning environment to study Arduino programming to control a line-tracer robot.

(c) A learning tool that can simulate robots' motion based on the program written using function (b).

(d) Compatibility with various types of computers and operating systems.

A microcontroller is a small programmable computer board with an embedded integrated circuit (microprocessor), and using a microcontroller is an effective method for students to learn machine manufacturing and programming for machine control. Arduino is a widely used microcontroller, and open-source programming software for Arduino is generally available. The proposed system enables users to study the construction of practical circuits and programming using Arduino without exclusive software. The system was evaluated by undergraduate students in a class at the Tokyo University of Agriculture and Technology (TUAT).

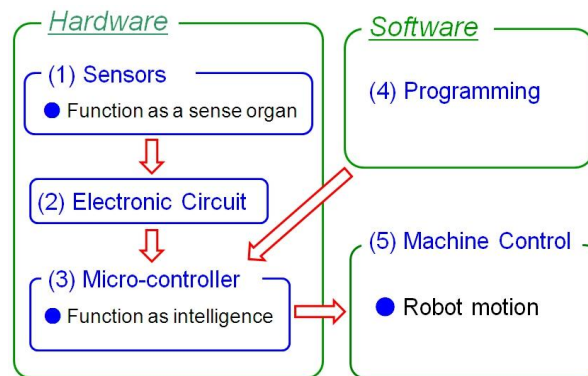


Figure 1. Schematic of technological elements necessary to teach and learn the construction of robots and their motion control.

2. METHODOLOGY

To cover all necessary technological elements shown in Figure 1, the proposed e-Learning system comprises the VCM function, circuit recognition function, and translation and simulation functions of the Arduino program. Technological features of these functions are described in Sections 2.1–2.3. To evaluate the proposed e-Learning system, experiments on a line-tracer robot were conducted by university students (as described in Section 2.4). The line-tracer robot can detect the edge of a thick black line on a white floor and move along the black line.

2.1 Virtual-Circuit-Making Function

The VCM function is useful for users because they do not need to work with physical circuit components to learn designing and construction of electronic circuits. The VCM, proposed in a previous study (Takemura, 2013), enables individual learners to use graphics editors, which are installed on a learner's computer. Therefore, this system does not require the use of proprietary graphics software. To construct a virtual circuit of a line tracer, we improved the previous VCM by increasing the database of virtual circuit components, including a picture of Arduino. Figure 2 shows examples of virtual circuit components that are necessary to construct virtual circuits of line-tracer robots with the microcontroller Arduino. Each experimenter downloaded these virtual circuit components and a template circuit board (breadboard) image. Experimenters used their preferred graphics editor to indicate connections of circuit components on a virtual circuit by placing virtual circuit components on the circuit board image. The experimenters indicated the virtual circuit connections by drawing colored lines on the circuit board image using a graphical user interface.

2.2 Circuit Recognition Function

The proposed e-Learning system performs circuit recognition using image-processing techniques (pattern matching) that compare components in a virtual circuit with each circuit component available in the database of the VCM system. This function searches and recognizes circuit components connected at each node in a virtually constructed circuit. Checking the differences of circuit components at each node between the circuit diagram and the circuit virtually constructed using VCM, this system detects incorrect parts in the circuit constructed using VCM and informs the user of such parts.

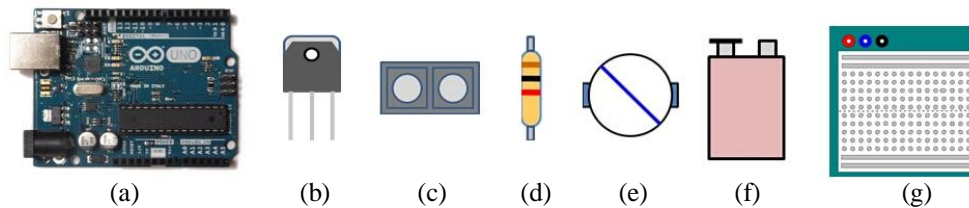


Figure 2. Virtual circuit components: (a) picture of Arduino, (b) MOS-FET, (c) optical sensor (photorelector), (d) resistor, (e) DC motor, (f) 9 V battery, and (g) breadboard.

2.3 Translation and Simulation Functions of Arduino Program

Arduino is a microcontroller that is widely used for many purposes such as manufacturing, business, and education. The programming environment of Arduino is open source and usable with various types of computers and operating systems (Windows, Mac OS X, and Linux). To program Arduino, a user can use a programming language that is similar to general programming languages such as ANSI-C or C++. Therefore, learning Arduino programming for machine control and robotics is suitable for undergraduate and graduate students in the field of technical engineering. This paper proposes a function that can translate Arduino programs written by individual users into the programming language named Processing (<http://www.processing.org/>), which is robust for image processing, computer graphics, and animation. Processing is also open source and usable with various types of computers and operating systems (Windows, Mac OS X, Linux, and Android). The grammar of Processing is based on a general programming language such as ANSI-C or C++. Therefore, translating an Arduino program to Processing is possible with some partial rewriting, for instance, the proposed e-Learning system includes a rewritten description of the signal intensity obtained from a sensor into that of the brightness of an image pixel in a Processing program. Based on translated Processing programs, users can check a robot's motion on their monitors. This technique is important because an experimenter can learn about robot motion without constructing a physical robot.

2.4 Experimental Methodology

The proposed system was evaluated by five undergraduate students in a class at TUAT. To evaluate the usability of each function of the proposed e-Learning system, the students were asked to perform the experiments as follows:

A) Each learner downloaded the circuit diagram of a line tracer to be constructed (Figure 3) via the Internet.

B) Using the VCM function of the proposed system, each learner made the virtual circuit of a line-tracer robot, including optical sensors (photoreflectors).

C) Each learner checked whether this e-Learning system indicated incorrect parts in their circuits. If incorrect parts were indicated, the learner corrected such parts and completed the circuit making.

D) Each learner wrote an Arduino program to control the virtual circuit of the line tracer that was virtually constructed using the VCM function. The proposed system translated this Arduino program into the

Processing program. The learner studied how the line tracer behaved using the simulated moving image of the virtual robot's motion that was provided by the proposed e-Learning system.

3. RESULTS AND DISCUSSION

Five undergraduate students at TUAT evaluated the proposed system through the experiments described in Section 2.4. Figures 4(a) and 4(b) show example circuits of line tracers that were constructed by two experimenters using the VMC function. As shown in Figure 4(b), terminals of one of the diodes and a MOS-FET are connected at incorrect nodes, and the proposed e-Learning system shows red indicators to inform this learner about these incorrect parts.

Figure 5 shows the virtual construction and simulation of the circuit of a line-tracer robot. Figure 5(a) shows an example circuit of a line tracer with an Arduino. Figure 5(b) presents the Arduino program written by the same student. The translation function of the proposed system translated this Arduino program into the Processing program and supplied the student with the simulated moving image of the robot's motion based on the Processing program. Figure 5(c) shows a frame that was captured from the simulated moving image based on Program (b).

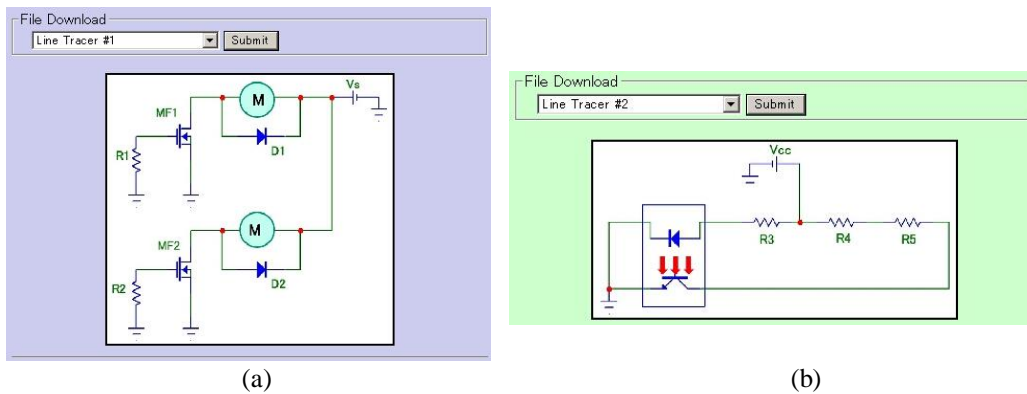


Figure 3. Circuit diagram of a line-tracer robot to be constructed using the proposed system: (a) circuit to control DC motors and (b) circuit to detect the degree of brightness (luminous intensity) using an optical sensor (photoreflexor).

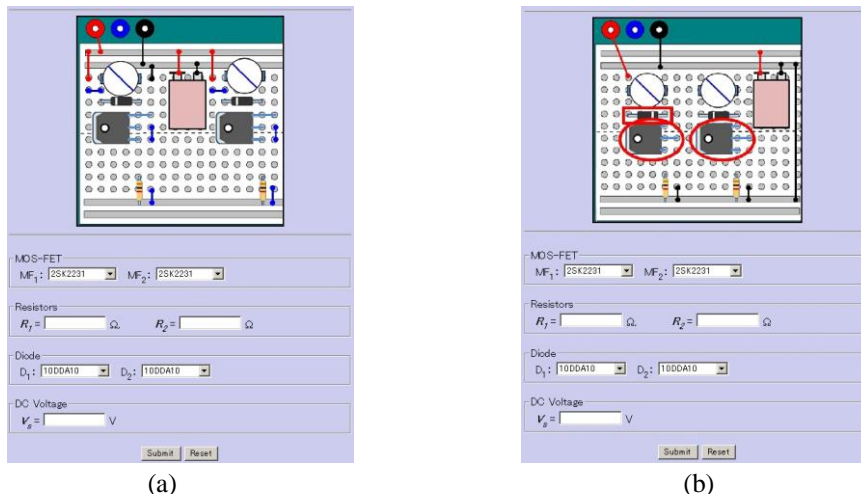
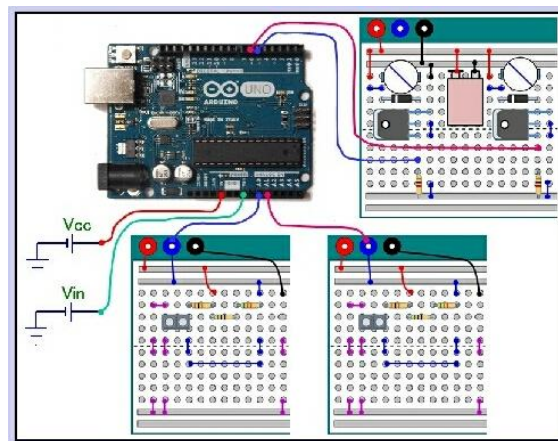


Figure 4. Circuits of line tracers constructed by two students using the VCM function: (a) correct circuit and (b) incorrect circuit and automated indication of incorrect parts.

From the results of the evaluation by five experimenters at TUAT, positive responses, which indicate the usefulness of the proposed system, were obtained from all students; the responses are as follows:

- The e-Learning system was useful for learning the construction of practical circuits with microcontrollers and programming a microcontroller to control machines.
- The e-Learning system was convenient and flexible because all software used in the system was open source.

However, there were also a few technical suggestions for improvement, e.g., to improve the user friendliness of the e-Learning system, a more advanced graphics such as three-dimensional computer graphics should be used.



(a)

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Program Source (Arduino):
File:   

int Motor_Left = 5;
int Motor_Right = 6;
double Threshold = 400.0;

void setup(){
  pinMode( Motor_Left, OUTPUT );
  pinMode( Motor_Right, OUTPUT );
}

void loop(){
  int leftSensor = analogRead( A0 );
  int rightSensor = analogRead( A3 );
  delay(1);

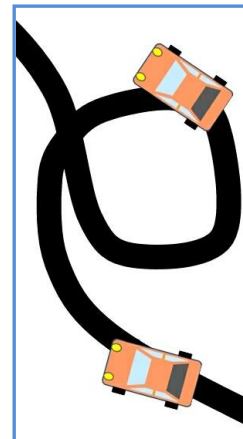
  if( leftSensor < Threshold )
    digitalWrite( Motor_Left, HIGH );
  else
    digitalWrite( Motor_Left, LOW );

  if( rightSensor < Threshold )<BR>
    digitalWrite( Motor_Right, HIGH );
  else
    digitalWrite( Motor_Right, LOW );
}

```

(b)



(c)

Figure 5. Results of the virtual construction and simulation of the circuit of a line-tracer robot: (a) virtual circuit of a line tracer constructed using the VCM function, (b) Arduino program written by the student, and (c) one frame that was captured from the simulated moving image based on Program (b).

4. CONCLUSION

This paper proposes a novel e-Learning system for learning the construction of electronic circuits and programming a microcontroller to control a robot's motion. The proposed system comprises a system to learn the construction of electronic circuits in a line-tracer robot with the general-use Arduino microcontroller and a simulation system to learn behavior of robots. The usefulness and effectiveness of the system were verified by five undergraduate students in a university class. 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:

- Improve the graphical environment, as was reported by the experimenters.
- Enhance the e-Learning system to study more highly developed robots with various types of sensors.

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