Prototyping an Intuitive Circuit Simulator Manipulated by Hand Gestures for Elementary Physics Education

Koji Yamauchi and Hiroki Imamura
Faculty of Engineering, Soka University
1-236 Tangi, Hatiouji-shi, Tokyo, 192-8577 Japan
e14m5226@soka-u.jp, imamura@soka.ac.jp

ABSTRACT

Intuitive method of manipulating computer is always required. Projection-based interface is one of the intuitive systems. Projection-based interface consists of a projector for output and a camera for input, and it manipulates computers by recognizing hand gestures. This paper suggests applying projection-based interface to the education field and developing an integrated physical simulator for elementary physics education. Computer Graphics (CG) can visualize invisible phenomena and this interface provides intuitive manipulation. By combining these benefits, users can simulate physical phenomena intuitively by own hands without any wearable device and understand them easily. Additionally, this system reduces costs of preparing actual experiments. As the first step of developing the proposed simulator, we propose an intuitive circuit simulator based on the projection-based interface. In this paper we report prototyping and evaluating the proposed intuitive circuit simulator.

KEYWORDS

Projection-based Interface, Natural User Interface, NUI, Education, Physics, Circuit, Simulator, Hand Recognition

1 INTRODUCTION

Computers have dramatically changed the method of education. Once teachers used only a choke and a blackboard for teaching in the past, currently teachers choose each own teaching style to help students understanding the class such as using handmade texts or slideshows. In these cases, teachers choose and limit a situation as an example of what they teach. The limited example, though it can simplify what they want to explain, sometimes it cannot train student's flexibility of thinking. To avoid that, a lot of educational softwares have been released. Additionally, to assist teacher's teaching and student's understanding, recently the smart devices are adopted into education.

Computers are also used to simulate physical phenomena, for example in designing airplanes and forecasting weather. However in these simulations, the most required thing is accuracy, not usability. Conventional physical simulators need to be set many parameters and have high calculating cost, therefore that is not suitable for education. Some educational applications of physics are already developed, however most of them limit simulating situation or perform only 2-dimensional simulations. Considering the above, this paper proposes an integrated intuitive simulator for elementary physics education. This proposed simulator needs to satisfy following three demands: intuitive manipulation, configurable situation, and 3-dimensional input method. To realize the above, we propose using a projection-based interface[1][2]. A projection-based interface recognizes hand gestures and manipulate computers by only the hand gestures. We previously developed one of the projection-based interface[3], thus we develop the proposed simulator based on it. When this system is completed, a user will be able to set physical situation flexibly and simulate it three-dimensionally with only own hands: throw virtual objects, set proceeding direction and speed to virtual objects by handwriting, touch virtual water surface and observe refraction of it, and so on. By using the proposed simulator, users can obtain 4 benefits. First, by visualizing invisible phenomena with computer graphics, the users can understand the behavior of it easily. Second, users are not required to prepare actual experiments. Third, users are not necessary to have the skill of manipulating a computer. Forth, by setting situation freely, users can train flexible thinking and enjoy physics. In this paper, as the first step of the proposed simulator, we propose and prototype an intuitive circuit simulator which visualizes the flowing of electrical current with a particle model.

2 INTUITIVE CIRCUIT SIMULATOR

2.1 Overview

With this prototype simulator, users can make and simulate an electrical circuit, and observe electrical current and potential visualized with an 3D model we call "particle model". Particle model is a type of water model[4], and water model is used for describing Ohm's law. Hence this prototype simulator uses conducting wires, resistors and a power supply for making 2D circuit. The prototype is based on the projection-based interface we have developed. Figure 1 shows the architecture of the projection-based interface, and Figure 2 shows the available gestures in the projection-based interface. Figure 3 shows the flow of the prototype simulator. Explanations of each steps are following.

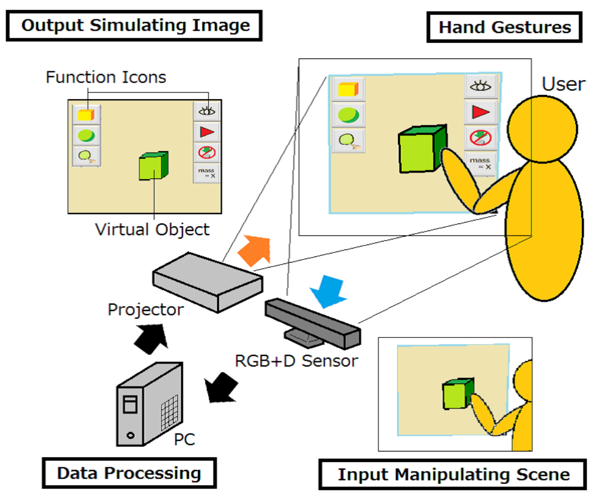


Figure 1. System Architecture

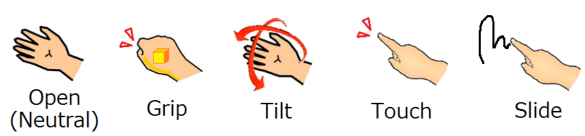


Figure 2. Available Gestures

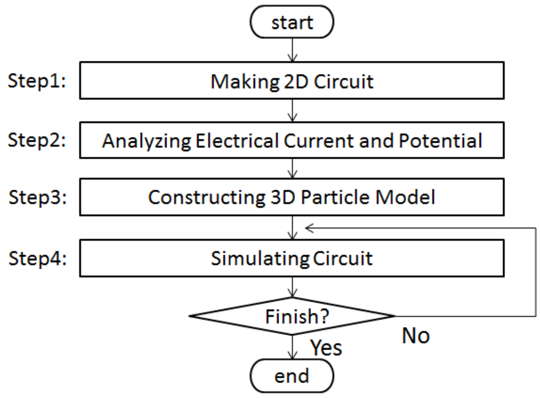
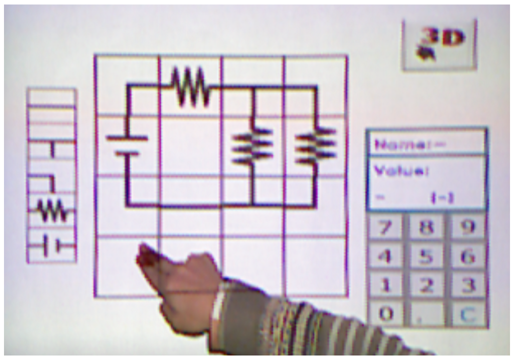
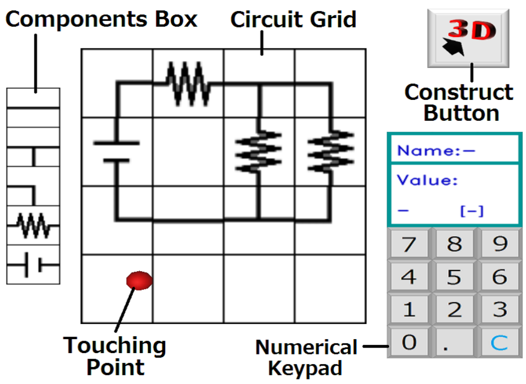


Figure 3. System Flow



(a) Manipulating Scene



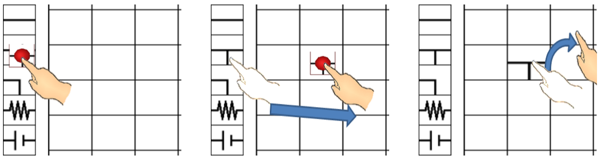
(b) Execution Image

Figure 4. Making 2D Circuit

Step 1: Making 2D Circuit

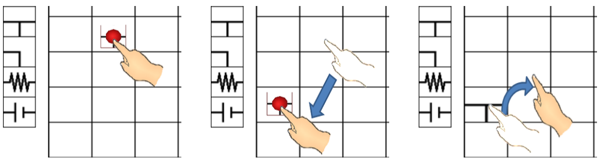
To realize this function, we use "Denshi Block"[5] as a reference. The user makes a 2D circuit by "Touch" and "Slide" gestures. In this function, the user can perform two types of manipulations: placing electronic components and rotating them. Figure 4 shows the manipulating scene and the execution image of this function, and Figure 5 - Figure 8 show each manipulation method.

In placing electronic components, the user can takeout an electronic component from the components box and put it in the grid circuit by the following gestures: “Touch” the components box, “Slide” to a target point in the grid circuit, and takes own hand off the projecting plane. Additionally, when the user want to relocate or delete some electronic component, the user can pick up it by “Touch” the center part of it.
In rotating electronic components, the user can rotate an electronic component like turning the handle by the following gestures: “Touch” the peripheral part of a target electronic component and “Slide” around it.



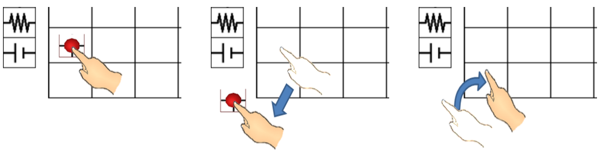
(a) “Touch” Components Box | (b) “Slide” to Target Point | (c) Taking Hand Off

Figure 5. Placing Electronic Components



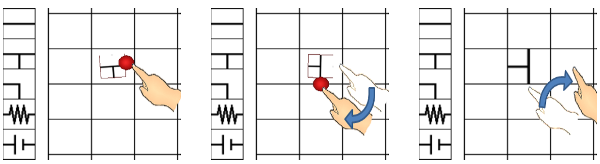
(a) “Touch” Central Part | (b) “Slide” to Target Point | (c) Taking Hand Off

Figure 6. Relocating Electronic Components



(a) “Touch” Central Part | (b) “Slide” to Outside of Circuit | (c) Taking Hand Off

Figure 7. Deleting Electronic Components



(a) “Touch” Peripheral Part | (b) “Slide” around Component | (c) Taking Hand Off

Figure 8. Rotating Electronic Components

Step 2: Analyzing Current and Potential

This step is divided into more 3 sub-steps. Figure 9 shows the detail of this step. In following, we explain each sub-steps with a sample circuit shown in Figure 10 and Figure 11.

sub-step 1: Generating Netlist

The proposed simulator generates a netlist of the circuit for the next sub-step. Netlist consists of the following data: kind and number of electronic components, connection relationships of each terminal of electronic components, and value and admittance of each electronic component. “Net” means “points linked with same conducting wire”; the terminals connecting same net have same potential. When a user made a circuit as shown in Figure 11, the netlist of that circuit is Table 1.

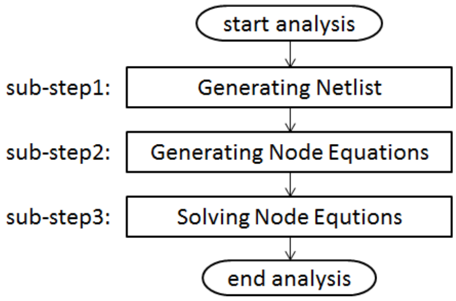


Figure 9. Detail of Analysis

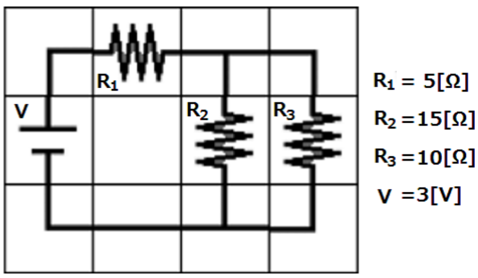


Figure 10. Sample Circuit

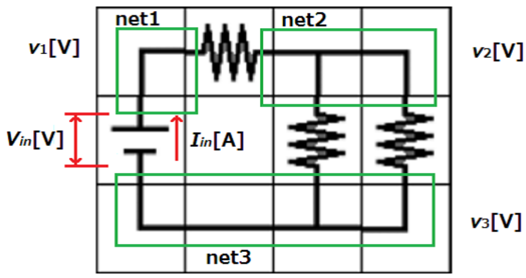


Figure 11. Nets of Sample Circuit

Table 1. Netlist of Sample Circuit

Component	Terminal 1	Terminal 2	Value	Admittance
R_1	net1	net2	5[Ω]	Y_{R_1}
R_2	net2	net3	15[Ω]	Y_{R_2}
R_3	net2	net3	10[Ω]	Y_{R_3}
V	net1	net3	3[V]	-

sub-step 2: Generating Node Equations

The proposed simulator adopts nodal analysis for analyzing circuit. Nodal analysis uses Kirchhoff's current law (KCL). Based on the netlist, the proposed simulator writes a node equation (Formula 1). The node equation is a simultaneous equation based on KCL. The $\boldsymbol{A}$ matrix is a nodal admittance matrix, and it is generated mechanically by the rules called "stamp"[6]. The $\boldsymbol{x}$ matrix is a column vector that holds potential of each net (v_1-v_3) and the current of power supply (I_{in}). The proposed simulator regards the minus side of power supply as ground, therefore in this case v_3 is obviously 0[V]. Accordingly $\boldsymbol{x}$ doesn't hold v_3. The $\boldsymbol{b}$ matrix is a column vector that holds only known quantities. The bottom element of $\boldsymbol{b}$ is the potential of power supply (V_{in}), and others are zero. Formula 2 shows the values of $\boldsymbol{A}$, $\boldsymbol{x}$ and $\boldsymbol{b}$ of the sample circuit.

$$\boldsymbol{A}\boldsymbol{x} = \boldsymbol{b} \qquad (1)$$

$$\boldsymbol{A} = \begin{pmatrix} Y_{R_1} & -Y_{R_1} & 1 \\ -Y_{R_1} & Y_{R_1} + Y_{R_2} + Y_{R_3} & 0 \\ 1 & 0 & 0 \end{pmatrix}, \quad \boldsymbol{x} = \begin{pmatrix} v_1 \\ v_2 \\ I_{in} \end{pmatrix}, \boldsymbol{b} = \begin{pmatrix} 0 \\ 0 \\ V_{in} \end{pmatrix} \qquad (2)$$

sub-step 3: Solving Node Equations

The answer associated with $\boldsymbol{x}$ of Formula 2 is Formula 3. The proposed simulator solves the node equations by multiplying matrix $\boldsymbol{A}^{-1}$ both sides from left. After calculation, the proposed simulator calculate currents flowing through each component.

$$\boldsymbol{x} = \boldsymbol{A}^{-1}\boldsymbol{b} \qquad (3)$$

Step 3: Constructing 3D Particle Model

The proposed simulator constructs a 3D Particle model based on the connecting information of components and the analyzed data. Usually in water model, electrical current and potential be visualized respectively as the amount of flowing water and the level of waterway. However in particle model, considering the calculating cost, the present proposed simulator visualizes electrical current as the width of passageway and amount of particles passing through it. Figure 13 shows a 3D model of each component.

Step 4: Simulating Circuit

Figure 14 shows the simulating scene of the sample circuit. The user can not only observe particles (equals electrical current) but also translate and rotate a field of view. In translating, the user performs following two gestures: keep "Grip" shape and position for a second (to turn on translating mode), translate the hand to target position (Figure 15). In rotating, the user can performs following two gestures: keep "Open" shape and position for a second (to turn on rotating mode), rotate the hand to target angle (Figure 16).

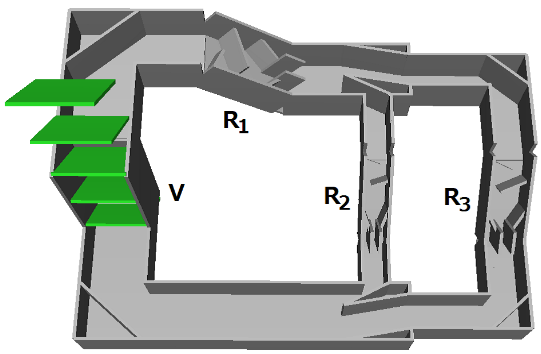
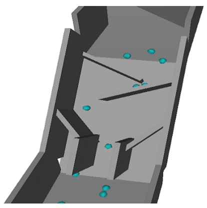
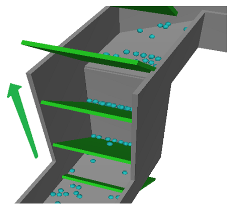


Figure 12. 3D Particle Model of Sample Circuit



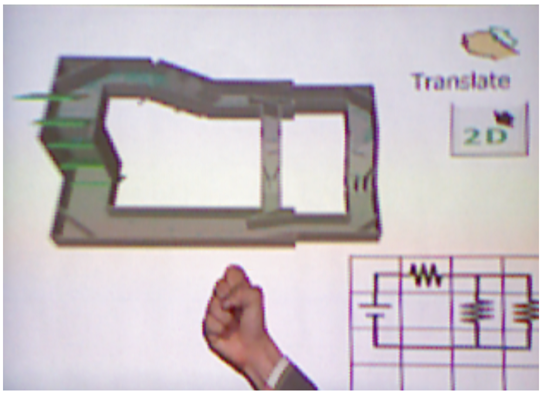
(a) Resistor



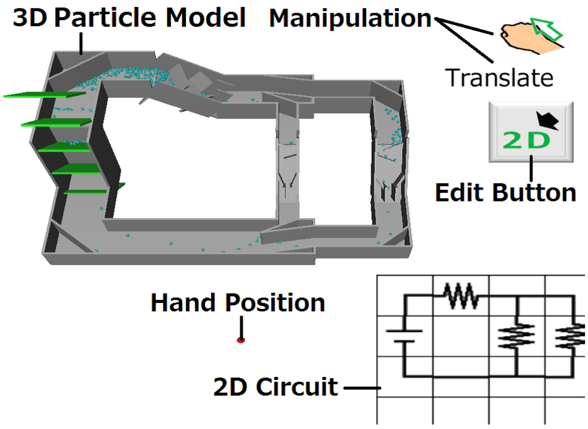
(b) Power Supply

Figure 13. 3D Model of Components

ISBN: 978-1-941968-30-7 ©2016 SDIWC

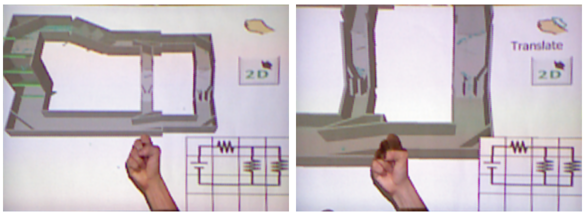


(a) Manipulating Scene



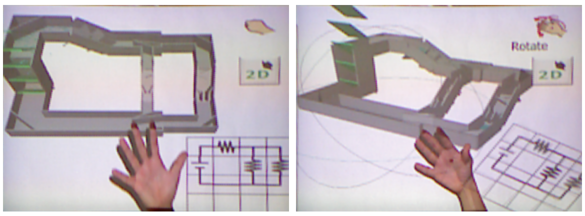
(b) Execution Image

Figure 14. Simulating Sample Circuit



(a) Keeping "Grip" for a Second (b) Translating to Target Position

Figure 15. Translating Viewing



(a) Keeping "Open" for a Second (b) Rotating to Target Angle

Figure 16. Rotating Viewing

3 EVALUATION EXPERIMENT

To evaluate the proposed simulator, we got 10 subjects to manipulate the proposed simulator and evaluate it. The subjects manipulated 5 functions: placing/rotating components and settng parameters in making 2D circuit mode, and translating/rotating viewing in simulating 3D particle model mode. The evaluating items are the following:

(1) You could manipulate each function without any explanation.

(2) The manipulation method of each function equals your imagination before receiving an explanation.

(3) Each function performed correctly as you manipulated.

(4) You could observe the difference of each electrical parameter.

(5) The visualizing method of each electrical parameter is correct.

Each evaluating item was evaluated in 5 stages; 1 is the lowest, 5 is the highest. The items (1) and (2) are to evaluate intuitive operability, the item (3) is to evaluate usability, and the items (4) and (5) are to evaluate understandability. Figure 17 shows the environment of the experiment, and Table 2 and Table 3 show the result of the experiment.

From Table 2, we consider that almost manipulating methods are quite intuitive and usable. However, we should consider again the manipulation method of rotating components in making 2D circuit mode. As mentioned above, to

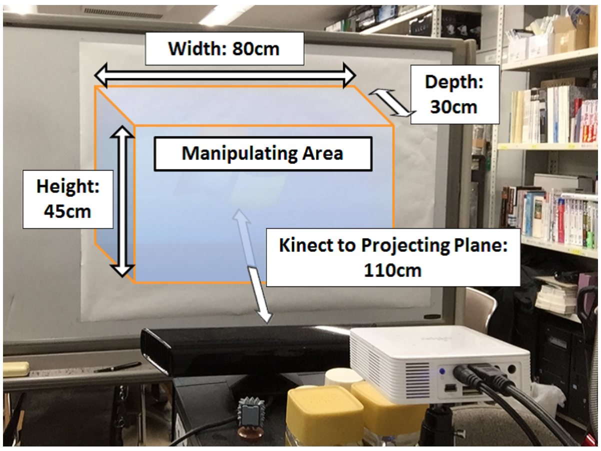


Figure 17. Environment of Evaluation Experiment

Table 2. Evaluation of Each Function

Evaluating Item	Mean (Standard Deviation)				
	in Making 2D Circuit			in Simulating 3D Particle Model	
	placing components	rotating components	setting parameters	translating viewing	rotating viewing
(1)	4.9(0.30)	2.9(1.45)	4.8(0.40)	4.4(1.28)	3.9(1.14)
(2)	4.7(0.46)	3.1(0.94)	4.7(0.46)	4.7(0.64)	4.1(0.83)
(3)	4.9(0.30)	4.5(0.50)	4.7(0.46)	4.8(0.40)	4.2(0.75)

Table 3. Evaluation of Visualization

Evaluating Item	Mean (Standard Deviation)	
	electric current	potential
(4)	4.5(0.50)	4.7(0.64)
(5)	4.6(0.49)	5.0(0.00)

rotate a component, the user touch peripheral part of a component and slide around it. Most of subjects try to rotate a component by touching it with two fingers and rotate their hand. We consider the reason why they perform such gestures is due to spreading smart devices. Additionally, the evaluations of the item (1) on translating and rotating viewing are not low, however divided. It seems to be difficult for subjects to notice "keep shape" to transform viewing. From Table 3, it can be said that the visualization methods of electrical current and potential are correct and the constructed 3D particle model is understandable.

4 CONCLUSION

In this paper we proposed a physics simulator for education based on our projection-based interface. As first step of it, we developed a prototype of an intuitive circuit simulator. This prototype simulator can create electrical circuit flexibly, analyze it easily and simulate it intuitively with 3D particle model. We evaluate operability, usability and understandability of the prototype simulator through an experiment. From the result of it, we consider that the prototype simulator is useful for elementary physics education. As next step of this simulator, we will implement handwriting recognition for more intuitive manipulation. After that, we will implement other types of simulators: for dynamics, thermodynamics, wave mechanics, and so on.

REFERENCES

[1] H. S. Adeen, A. Atia, A. Amin, A. Victor, A. Essam, E. Gharib and M. Hussien, "RemoAct: Portable Projected Interface with Hand Gesture Interaction", Journal of Computer Science, 2015, pp.738-749.

[2] F. Ferreira, M. Cabral, O. Belloc, G. Miller, C. Kurashima, R. de D. Lopes, I. Stavness, J. Anacleto, M. Zuffo and S. Fels, "Spheree: A 3D Perspective-Corrected Interactive Spherical Scalable Display", SIGGRAPH2014

[3] K. Yamauchi, H. Imamura, "Development of the Projection-based Interface to Operate 3D Objects by Three-dimensional Motion of the Hand", vol. 114. IEICE technical report, 2014, pp.117-122

[4] H. Kameyama, "Investigation about the Analogy between the Electric Circuit and the Model of the Fluid Flow(I) : The Electric Potential Difference(Voltage)", Bulletin of the Faculty of Education, Shizuoka University. Kyoka kyoiku series, 1981, pp.197-209

[5] DENSHI BLOCK MFG., "Denshi Block for training and teaching materal of the electrical circuit", Internet:http://www.denshiblock.co.jp/, Released in 1965

[6] T. Watanabe, "Computer simulation of the electric circuit", Knowledge base (IEICE), 2008, Internet:http://www.ieice-hbkb.org/files/01/01gun_07hen_07.pdf