Real-Time Visualization System of Magnetic Field Utilizing Augmented Reality Technology for Education

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In electromagnetics education, it is important for beginners, who start to learn electromagnetics, to give an illustration of magnetic field. In this paper we propose a new real-time visualization system. It can visualize a composite image of source materials and their generated magnetic field utilizing the Augmented Reality technique to the users. With this real-time visualization system, electromagnetics learners can observe the visualized magnetic field as a realistic magnetic distribution on real-time and the visualized field changes immediately they move the objects.

***Index Terms*—Augmented reality technology, electromagnetic field simulation, electromagnetics education, visualization.**

I. INTRODUCTION

IT is difficult for beginners, who start to learn electromagnetics, to understand magnetic field because it is complicated and invisible. Therefore, at the first step of electromagnetics education it is important for the beginners to understand an invisible magnetic field generated by a magnet and/or a coil. In a traditional electromagnetics class, a teacher teaches a magnetic field through experiments and/or computer simulations [1]–[7]. However, for example, in case of an experiment that students observe the magnetic field using iron sand, it involves a lot of time and effort, additionally it cannot easily deal with a complicated model. On the other hand, when the students learn the magnetic field with the computer simulations, it is too hard for the beginners to use a simulation software that is developed for design of electrical equipments. Some simulation systems have been proposed for education [4]–[7], however the students use them, and do nothing but observe the models (e.g., magnets, coils and materials) and the generated electromagnetic field on virtual space in computer.

In this paper, we propose a new education tool that combines a real experiment with a computer simulation utilizing the Augmented Reality technique [8]. The Augmented Reality technique has broadened in various fields and applications recently. It is a technique which superimposes characters, images, and objects onto a real world environment. The proposed system presents a synthetic image of objects (source materials) captured by a web camera and their simulated magnetic field to the users. It is unnecessary for the objects to be real, but mock (e.g., a painted box). With our developed real-time visualization system, the learners can easily understand the magnetic field in the "augmented real world." The proposed system has a user-friendly interface that the users can freely move the mock objects (e.g., magnets and currents) by their own hands. Additionally, the users can easily observe the interference of electromagnetic field generated by a few magnets and currents. In order to verify its usefulness we have applied this system to a few cases, and it was used and evaluated by our students.

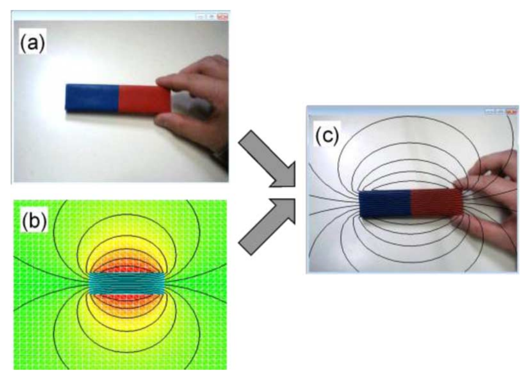

Fig. 1. Composition of the real magnet and the generated magnetic field utilizing the Augmented Reality technique. (a) The mocked magnets captured by web camera, (b) the simulated magnetic field, and (c) the composite image using the Augmented Reality technique.

II. THE PROPOSED REAL-TIME VISUALIZATION SYSTEM

In general, a visualization software for electromagnetic field runs on a PC and the users observe it on the display of PC. Hence, especially the beginners are not able to understand the electromagnetic phenomenon enough because it is only visualized in the virtual world environment. Therefore, we propose a new visualization and experience system which utilizes the Augmented Reality technique and the visualization technique of the electromagnetic field on real-time. The Augmented Reality technique has been researched and developed as a new technology which presents information such as characters and graphics in the real world [8]. With adding this outcome to a simulation technique, we have developed an effective visualization system in educating electromagnetics. Fig. 1 shows a model of a bar magnet as an example. Nobody can see the magnetic field by taking an image with a camera (Fig. 1(a)). If the students use the computer simulation, they can observe the magnetic field (Fig. 1(b)) but they cannot see it on the real bar magnet. In the proposed real-time visualization system, the students are able to observe the composite image (Fig. 1(c)) of the generated magnetic field (Fig. 1(b)) and the real bar magnet (Fig. 1(a)).

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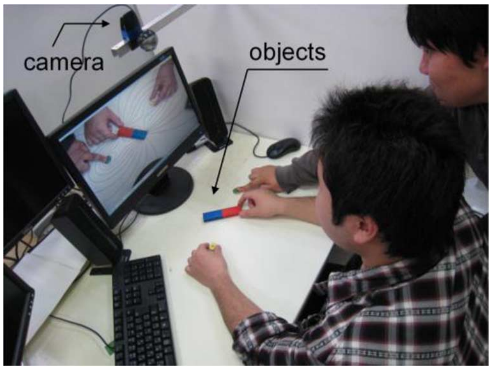

Fig. 2. Overview of the proposed real-time visualization system.

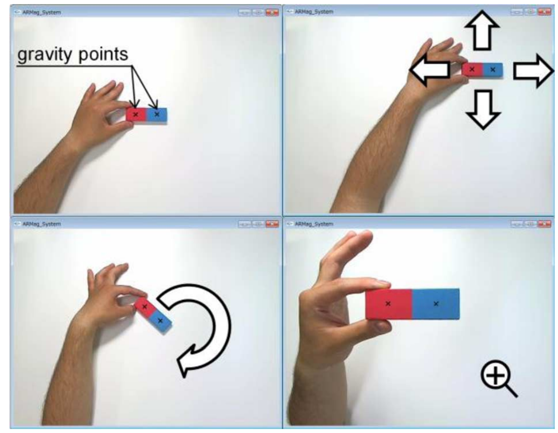

Fig. 3. Gravity points of the mock's color are identifiable as soon as the mock moves, rotates and/or zooms.

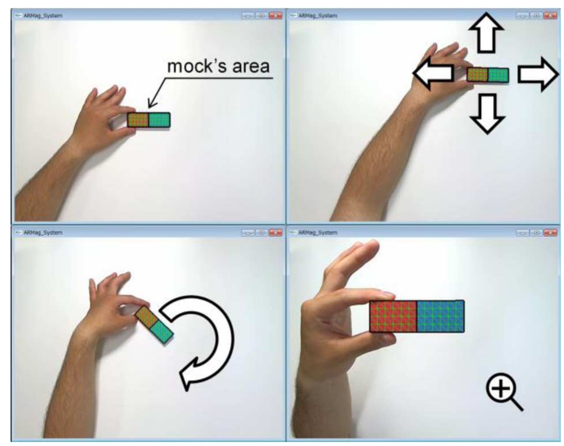

Fig. 4. Mock's area is detected as soon as the mock moves, rotates and/or zooms.

This system consists of a web camera, a PC and colored mock objects (e.g., magnets and currents). Fig. 2 shows the overview of our developed system. The main procedure of the system is as follows:

Step 1) The colored mock objects are captured on the digital web camera.
Step 2) The captured objects are identified using an image-recognition technique.
Step 3) The magnetic field distribution, which is generated by the identified objects, is computed.
Step 4) The synthetic image of the computed magnetic field distribution and the captured objects are visualized.

These procedures are carried out **in real-time** and the computed synthetic image is shown to the users **in real-time**. In this system the users only have to watch the captured image of the magnets and currents in their hands. In other words, they do not need to make any model and any mesh, and to configure any boundary condition for the simulation.

Next, the image-recognition process and the real time simulation method are explained below.

A. Detection and Recognition of Mocks (on Steps 1 and 2)

As a precondition of this system all the mocks lie on a desk and the camera is vertically fixed. The positions of the mocks (e.g., magnets or currents) are identified in the captured image by the image-recognition technique. The procedure of the detection of the mocks is as follows:

#0: The mock's color and its aspect ratio are registered on the visualization system as preprocess.
#1: The gravity point of the registered colored-mocks is calculated on the captured image.
#2: The mock's position, size and/or angle are identified by the gravity point calculated above.

Here, a red, a blue, a green, and a yellow object are registered as a north-pole, a south-pole, a positive current, and a negative current, respectively, in the paper.

An example of one bar magnet is shown in Fig. 3. The gravity points of the mock's color are identifiable as soon as the mock moves, rotates and/or zooms (Fig. 3). And then the mock's area is also identifiable (Fig. 4). The recognition of the mocks, described above, is executed **in real-time**. The image-recognition is carried out using the OpenCV (Open Source Computer Vision Library) which is a library for a real time computer vision [9]. In this system the contour detection algorithm [10] is not adopted because its calculation process is complicated and time-consuming.

B. Real-Time Simulation Method (on Steps 3 and 4)

Generally, the Finite Element Method (FEM) is employed as a simulation method of magnetic field generated by magnets, currents and/or electromagnetic materials. In the FEM it is necessary to divide the objects into mesh, to set the boundary conditions, and to setup the condition of the material characteristics. As a result, the magnetic field distribution is obtained and visualized. Therefore, with this time-consuming FEM it is impossible to achieve a real-time simulation to be required.

In the proposed real-time visualization system, the magnetic vector potential distribution is computed and prepared on a preprocessing step. In the computation the linear magnetostatic field without magnetic material was assumed and the two-dimensional FEM for the magnetic field was employed. Thus, the computed magnetic flux lines, which are scaled and/or rotated to fit the captured objects, are visualized in real-time. Fig. 5 shows an example of the mesh and the calculated magnetic flux lines. The mesh fits the mock by zooming and/or rotating (Fig. 5(a)),

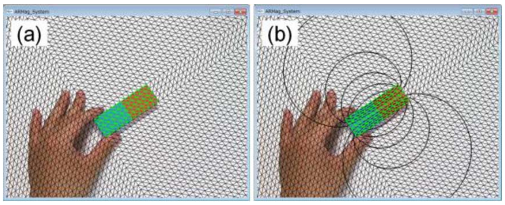

Fig. 5. Mesh and the calculated magnetic flux lines. (a) The mesh fitted on the mock by zooming and/or rotating, and (b) the visualized magnetic flux lines.

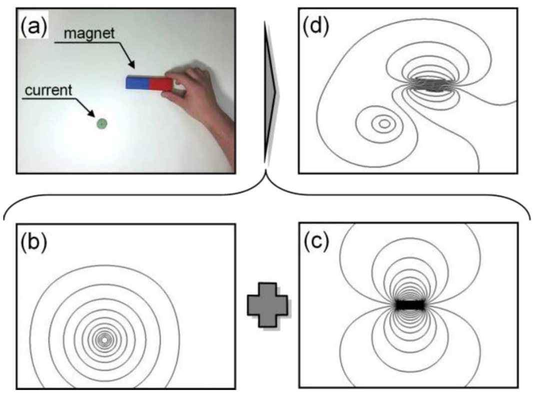

Fig. 6. Each prepared magnetic distribution is superposed for some sources. (a) The magnet and current image captured by web camera, (b) the magnetic field generated by the current, (c) the magnetic field by the magnet, and (d) the superposed magnetic field.

and then the magnetic flux lines are computed and visualized (Fig. 5(b)).

If there are some sources in space, the relative position of the sources is calculated and each prepared magnetic vector potential distribution is superposed as shown in Fig. 6. This example consists of one bar magnet and one line current. In this case the position of the bar magnet and the line current is identified. After that the magnetic flux lines, which are computed from the superposed magnetic vector potential distribution, are visualized in real-time. The magnetic vector potential distributions generated by the bar magnet and the line current are superposed on the main mesh as follows:

$$\boldsymbol{A}_{t,m} = \boldsymbol{A}_{m,s} + k\boldsymbol{A}_{c,s} \tag{1}$$

where

- $\boldsymbol{A}_{t,m}$: the total magnetic vector potential on the main mesh;
- $\boldsymbol{A}_{m,s}$: the magnetic vector potential by the bar magnet on the sub-mesh;
- $\boldsymbol{A}_{c,s}$: the magnetic vector potential by the line current on the sub-mesh;
- k: the weight coefficient.

The k is 0.3("Small"), 1.0("Medium") or 2.0("Large") in this paper. It enables the users to freely move and/or rotate each object. Of course, it also enables the users to observe the changing magnetic field.

III. GUI of the Proposed System

Generally it is necessary for the beginners to learn how to use a common simulation software, but our developed system is intuitive. This system does not need to have a complicated user interface, because the users are able to observe the magnetic field generated by the sources even if they move the mock in front of the camera freely. This proposed system has a simple GUI, as shown in Fig. 7. There are some "check boxes" to confirm the detected mocks and to show the mesh, which is used for scale and/or rotation. Additionally the system has a few "check boxes" in order to change the intensity of the electric currents and the users can choose the intensity from "OFF," "Small," "Medium," and "Large". Hereby the system shows the changing magnetic field depending on the intensity of the currents to the users. Beside this, the users are able to configure the number of magnetic flux lines.

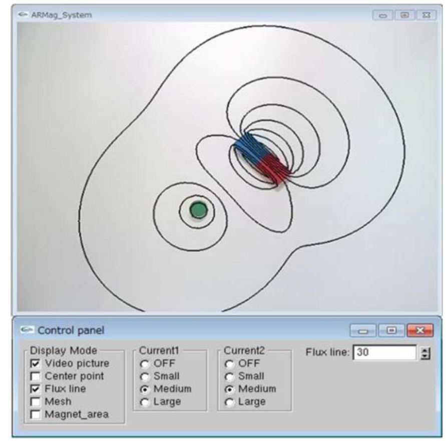

Fig. 7. GUI Design of the proposed real-time visualization system. The GUI is so simple that even the beginners can easily use the developed system.

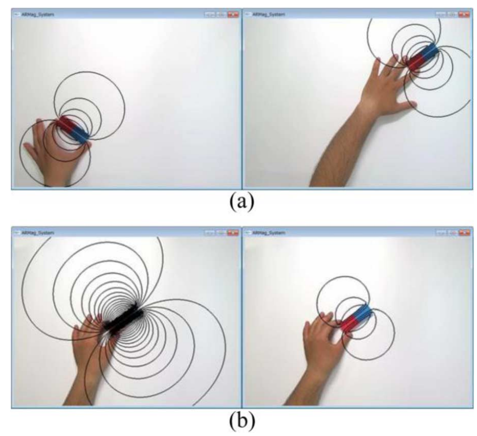

Fig. 8. Proposed real-time visualization system was applied to a one-magnet model. (a) The bar magnet is rotated and moved by user's hand. (b) The user can change the number of the visualized magnetic flux lines.

IV. Applications

A. One-Magnet Model

First of all the proposed real-time visualization system was applied to a one-bar-magnet model shown in Fig. 8. The appropriate magnetic flux lines are visualized as soon as the bar magnet is rotated and moved (Fig. 8(a)) by the user. In addition, the user can easily change the number of the visualized magnetic flux lines (Fig. 8(b)). The mocks can be scaled to any size within a window. When the user moves and/or rotates the magnet with his/her own hand, the appropriate magnetic flux

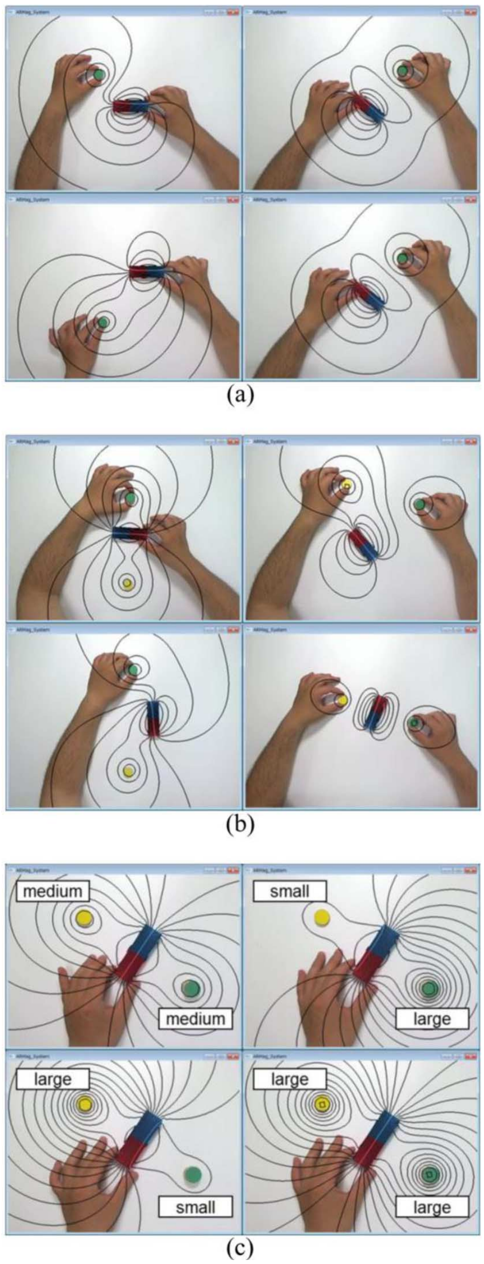

Fig. 9. Execution screens for magnets and currents model. (a) One bar magnet and one line current. (b) One bar magnet and two line currents. A green mock and a yellow mock are a positive current (downward) and a negative current (upward). (c) Users can change the intensity of the electric currents. The labels represent the intensity of the electrical current of mocks.

lines for any position and orientation of the magnet can be visualized in real-time. By this method, the user obtains the illustration that the magnetic flux lines look like to exist in the real environment.

B. Magnet and Currents Model

The system was applied to a magnet and currents model shown in Fig. 9. In this case, the magnetic field vector potentials generated by some sources interfere with each other. Fig. 9(a) shows the interference of the magnetic field generated by one magnet and one current. Next, an example of one magnet and two currents are shown in Fig. 9(b). In both cases, the appropriate magnetic flux lines are visualized even if the mock's positions are changed by user's hand. The users can change the intensity of the electric currents with the check boxes (Fig. 9(c)). In this sample the intensity of the magnets is fixed but the intensity of the electric currents can be changed relatively. However, in this example of Fig. 9(c), the position of the magnet and the currents is fixed, only the intensity of the electric currents is changed for comparison.

In this system, the user can freely and independently change the position of magnets and currents. The user can, in real-time, observe and understand the magnetic field which is caused by the interference.

V. Conclusion

We have developed a new real-time visualization system suitable for electromagnetics education. This system is based on the Augmented Reality technology and the numerical analysis for the electromagnetic field. The main features of this system are the ability to visualize the computed magnetic field on the real objects and the fact that the position of the objects can be changed by the user's hand. We applied the proposed system to a few models in order to verify its usefulness. To utilize the system, the beginners can easily observe the magnetic field as if the magnetic flux lines were visible. To add a library of various objects to this system and to verify the pedagogical aspect are future works.

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