Real Time Simulation Method of Magnetic Field for Visualization System with Augmented Reality Technology

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In this paper, we propose a real-time visualization system utilizing Augmented Reality Technology for electromagnetics education. It gives an image of magnetic field generated by a bar magnet with a piece of iron in real-time, however the bar magnet and the piece of iron are represented by mock ones. In the newly proposed visualization system, these mocks are captured by a web camera, and mesh needed in the calculation of magnetic field is deformed. Subsequently, a finite element analysis is carried out in very short time and then the magnetic field is immediately visualized. Thereby, it is, in real-time, observable that magnetic flux lines generated by the bar magnet are attracted to a piece of iron. Moreover, when a user moves the mocks, the magnetic flux lines are immediately depicted according to the position of the mocks.

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

I. Introduction

SINCE it is impossible to observe an electromagnetic phenomenon directly, it is difficult to intuitively comprehend the electromagnetic phenomenon on electromagnetic education. Therefore the visualization of the electromagnetic phenomenon is very important for students who are studying electromagnetics. As methods in existence, they can study it from experiments and/or simulations. In fact, a several ways of using a computer simulation have been proposed [1]-[6]. However, the students are not able to intuitively understand the experiment and simulation results or a visualization of these results. Additionally, the experiments require a great labor to users. For example, an experiment of using iron sand is very laborious on preparation and clearance, and a complex model cannot be dealt with. In addition, a computer simulation lacks reality because the students just observe the result of the simulations, not think about the phenomenon carefully.

In our previous study, a real-time visualization system with Augmented Reality Technology for magnetic field has been discussed and proposed [7]. The previously proposed system presents a synthetic image of mocks (*e.g.* bar magnets and line currents), which are captured with a web camera, and their simulated magnetic field to users. They can easily understand a magnetic field with the developed real-time visualization system in an "augmented real world." However, in the previous system, the acceptable objects are only the bar magnets and the line currents, since it is easy to compute a magnetic vector potential distribution according to the superposition theorem. Therefore, it is impossible to consider ferromagnetic material such as iron.

In this paper, we report an improvement of the previous system to a new system dealing with ferromagnetic material in real-time without the superposition theorem. In the newly proposed visualization system, a way of making a mesh needed in calculation of field is improved and a finite element analysis is carried out in very short time. Thereby, magnetic flux lines attracted to a piece of iron are observable in real-time.

Manuscript received November 10, 2012. Corresponding author: S. Matsutomo (e-mail: shin@ect.niihama-nct.ac.jp).
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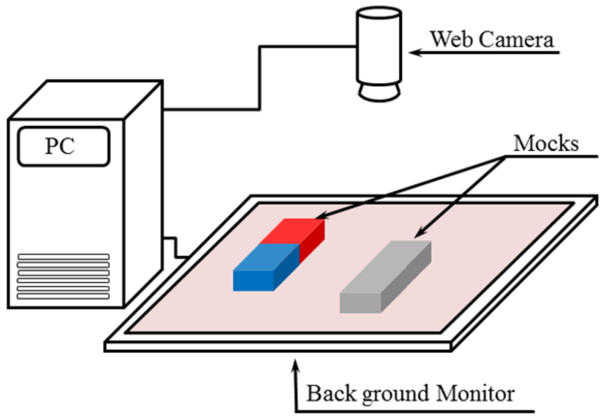

Fig. 1. The conceptual diagram of the proposed real-time visualization system. This system is composed by a background monitor, a web camera, a PC, and some mocks (e.g. magnets and iron pieces).

II. The Proposed Real-Time Visualization System

Fig. 1 shows the conceptual diagram of the proposed real-time visualization system with the Augmented Reality Technology. The developed system is composed by a background monitor, a web camera, a PC, and some mocks (*e.g.* bar magnets and iron pieces). The mocks are just on the background monitor, and they are captured by the web camera. The magnetic flux line and/or the magnetic vector potential distribution, that is virtually produced by the captured mocks, are visualized in response to the mocks moved by a user's hand on the background monitor. The main algorithm of the developed real-time visualization system as follows:

Step1. Initial data of mocks and a base-mesh are inputted to the system.

Step2. The table of node connection is created from the initial data of the base-mesh.

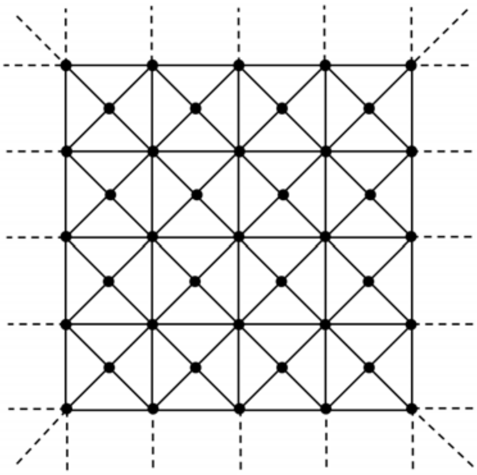

Fig. 2. Base-mesh prepared for the computation of superposing magnetic field generated by bar magnets and ferromagnetic pieces. Using a simple triangular mesh as the base-mesh, the real-time computation is achieved.

Step3. The image of the mocks are captured with the web camera, and the image data is taken into the PC.

Step4. Using an image processing, nodes close to the mocks are determined.

Step5. The area of the mocks (*i.e*. ferromagnetic materials or iron pieces) are calculated, and the information of the magnetic permeability is prepared.

Step6. A coefficient matrix is derived from the finite element method based on the above information.

Step7. The system of linear equations is solved by the CG method, and the solution is leveraged for the next calculation.

Step8. The visualized image of the simulation result (*e.g*. magnetic flux lines and/or magnetic density distribution), is displayed on the background monitor.

From the steps 2 to 8 are carried out repeatedly in real-time. Once the step 7 is executed, the steps 7 and 8 on the later iterations are speedily done because of reusing the previous solutions.

A. Mesh Deformation Method (Steps 3-5)

In the proposed real-time visualization system, the finite element method is employed because mesh is also necessary when magnetic flux lines are depicted. In this case, a mesh must be modified depending on the position of mocks captured by the web camera. Some automatic mesh generation methods for the finite element analysis have been proposed [8]-[10]. However, it is difficult to, in real-time, carry out the simulation with such automatic mesh generation methods because it takes long time and large labor to make a mesh. Therefore, any automatic mesh generation method cannot be employed in the real-time visualization system. Thus, in the developed system, a base-mesh which is structured by squares with 5 nodes and 4 elements, as shown in Fig. 2, is generated in advance.

The real-time visualization system regenerates a new mesh by deforming the base-mesh according to the state of the

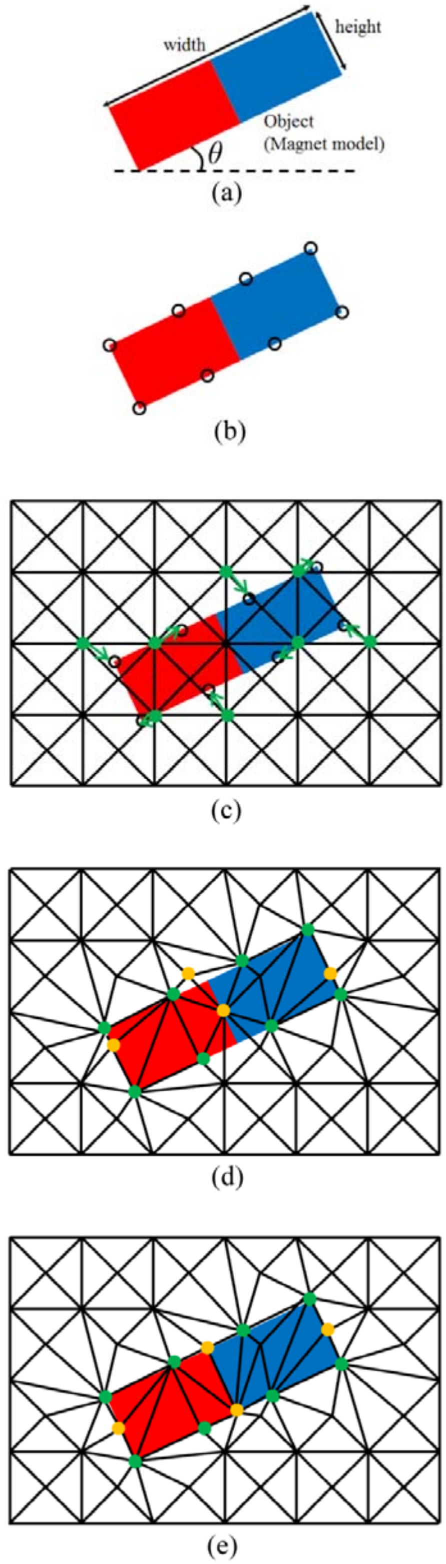

Fig. 3. Procedure to fit mesh to detected object. (a) The condition of the detected object is identified. (b) New nodes are generated on the edges of the detected objects. (c) Nodes of base-mesh, which are close to the nodes generated on the object edge, is moved to the generated nodes and identified. (d) It is necessary to check whether the base-mesh represents the shape of the object. (e) Nodes moves onto the object edge so as to represent the shape of the object.

detected mocks. The generated mesh is constructed with 2,471 nodes and 4,800 elements in 2D space. The advantages of the mesh deformation method are as follows:

- Since the system does not recreate an entirely new mesh, it can reduce a computation time.
- The number of elements and nodes are constant and the shape of most of the elements does not change, thereby most of the entries in the coefficient matrix derived from the finite element method can be reused.
- Since the connection relationship of the nodes is unchanged, the size of the coefficient matrix compressed in PC memory is also unchanged, and the amount of memory usage can be minimized.
- Since the number of nodes is constant and a phenomenon is not drastically changed, the former analysis solutions can be used as an initial value of the CG solver.

The base-mesh used in this system has to be deformed according to detected mocks. To represent the detected mocks in the base-mesh, new nodes are generated on their edge. The generated nodes have to line up with the same pitch as the node pitch of the base-mesh. The procedure of deforming the mesh according to the detected mocks is shown in Fig. 3 and explained as follows:

#1. Calculating aspect ratio (height to width) and angle of detected objects to identify the condition of the objects and to prevent false recognition.
#2. Generating new nodes on the edge of the objects.
#3. Searching base-mesh nodes close to the nodes generated on the edges.
#4. Moving the searched nodes of the base-mesh to the nodes on the edges of the objects. However, the connection relationship between the base-mesh nodes is kept.
#5. Checking whether edges between the nodes of the base-mesh form the detected objects. When the edges do not form the objects, nodes between the base-mesh nodes searched in #3 move to the middle of them on the edges of the objects. The shape of objects has been registered to the system in advance. Finally the quality of mesh is enhanced with the Laplacian smoothing.

It is easy to deform a mesh fitting to detected mocks. Since the number of elements and nodes and the connection relationship of nodes are unchanged, the computation time for the magnetic field simulation is dramatically short. The proposed magnetic field visualization with real-time simulation is achieved due to the proposed mesh deformation method.

B. Magnetic Field Analysis (steps 6-7)

The proposed system requires a speedy simulation rather than a long-time and highly accurate simulation. The CG method is employed in the developed system due to its fastness. The developed system can deal with only magnetostatic field and it does not entertain an eddy current and a displacement current so far.

A condition that a real-time simulation is achieved is that a potential distribution is not largely changed as the time passes. Therefore, under the condition, it can be realized to drastically decrease a simulation time by setting the former magnetic vector potential as an initial value of CG method at the next step.

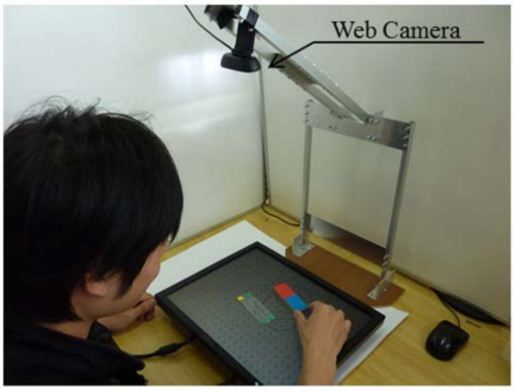

Fig. 4. Appearance of the proposed real-time visualization system. The proposed consists of a background monitor, a web camera, and some mocks. In the photo, one magnet and one iron mock are on the background monitor.

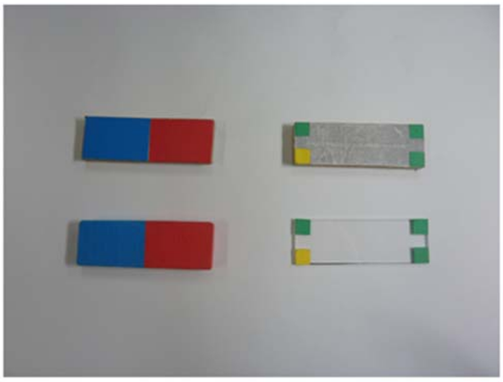

Fig. 5. Mocks representing bar magnets (left) and iron pieces (right). Left: blue and red color mean N- and S-pole, respectively. Right: yellow and green color mean markers. The yellow square markers represent the origin of the mocks, and it is recognized first. The green square makers represent the corners of the mocks. Using transparent material, a phenomenon on the display is observable even under the iron-piece mock.

Additionally, the table of node connection relationship and the position of the non-zero entries of the coefficient matrix, that are prepared in the preprocessing, shorten a time to make the system of linear equations.

Moreover, since mock's movement by a user is slow enough compared with FEM computation, the magnetic vector potential to be obtained is not greatly changed. Therefore, the proposed magnetic field visualization with real-time simulation can be achieved.

III. Test of The Proposed System

The developed real-time visualization system is applied for the purpose of verifying its usefulness. Fig. 4 shows the developed real-time visualization system. The system is constructed by a web camera that is attached to the top of an arm and a LCD display of the background monitor. A few manipulatable mocks can be put on the background monitor, and a user can manipulate the mocks and observe the phenomenon simultaneously. The developed system accepts bar-magnet and iron-piece mocks as shown in Fig. 5. The

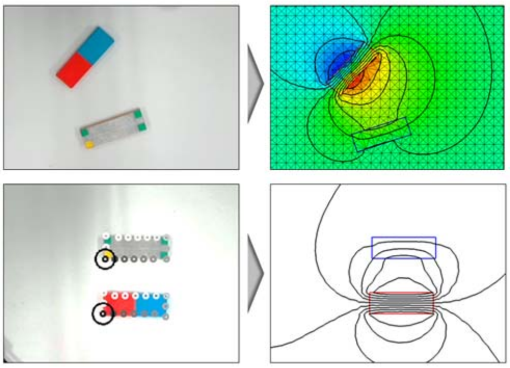

Fig. 6. Image captured with a web camera (upper left), image of captured mocks and nodes generated on their edge (lower left), computed magnetic field distribution and magnetic flux lines generated by the captured mocks (right).

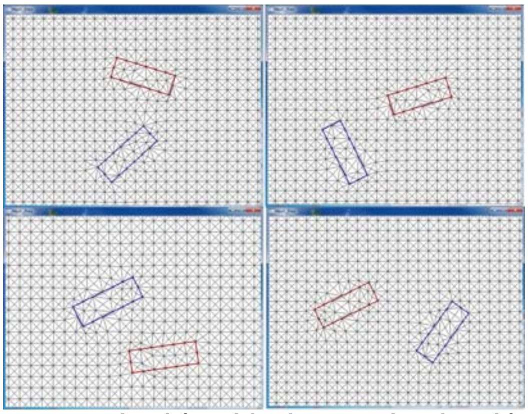

Fig. 7. Base-meshes deformed by the proposed mesh modification method according to the position of the mocks. Red- and blue-colored objects means a bar magnet and an iron piece, respectively.

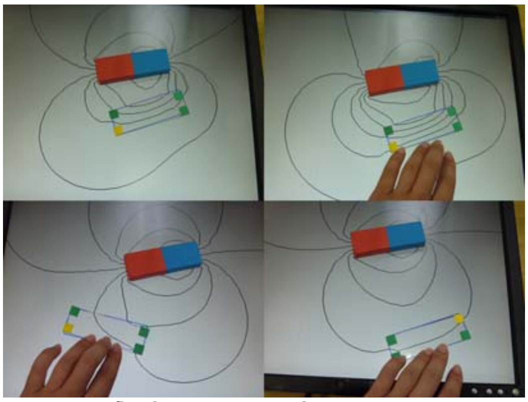

Fig. 8. Magnetic flux lines, magnet, and iron on various positions. The magnetic flux lines are depicted immediately a user moves the magnet or the iron.

yellow and green square on the iron mocks are markers which are used for an image processing.

When one bar-magnet and one iron-piece mock exist on the background monitor, these mocks are captured with the web camera, and then a mesh is deformed based on the captured image. With the deformed mesh, magnetic flux lines virtually generated by these mocks are computed. Fig. 6 shows the image captured with the web camera and the computed magnetic flux lines. As can be seen in Fig. 6, it looks like the mocks' generating the magnetic field.

Fig. 7 shows the base-meshes with various positions of mocks. As seen in Fig. 7, it is confirmed that the base-meshes are adequately deformed according to the position of the bar-magnet and the iron-piece mock.

Fig. 8 shows magnetic flux lines computed on various positions of a bar-magnet and an iron-piece mock. We can observe the magnetic flux lines pulled by the iron-piece mock. Additionally, the depicted magnetic flux lines change immediately the mocks are moved. The developed system can provide an intuitive observation of magnetic field which includes magnetic material to a user. The user can easily understand to the phenomenon of magnetic field generated by a bar magnet with ferromagnetic material.

IV. Conclusion

We have proposed an education system which can provide the drawing of magnetic field that is generated by a bar magnet and ferromagnetic material. The proposed system utilizes the augmented reality technology.

The developed system consists of a background monitor, a web camera, a PC and some mocks. The magnetic flux lines are depicted on the display immediately the mocks on the display are captured with the web camera. Moreover, when a user moves the mocks, the magnetic flux lines are immediately depicted according to the position of the mocks.

References

[1] E. Okayama, V. Cingoski, S. Noguchi, K. Kaneda, and H. Yamashita, “Interactive Visualization System for Education and Design in Electromagnetics,” *IEEE Trans. Magn*., vol. 36, no. 4, pp. 995-999, Apr. 2000.

[2] F. Buret, O. Fabregure, D. Muller, A. Nicolas, L. Nicolas, and F. Thollon, “About the Implementation of the Finite Element Method for Computer Aided Education in Electrical Engineering,” *IEEE Trans. Magn*., vol. 34, no. 5, pp. 3439-3442, May 1998.

[3] J. Lu, “High Performance Computation and Interactive Visualization of Electromagnetics for Engineering Education Programs,” *IEEE Trans. Magn*., vol. 48, no. 2, pp. 299-302, Feb. 2012.

[4] M. Hafner, M. Schöning, M. Antczak, A. Demenko, and K. Hameyer, “Methods for Computation and Visualization of Magnetic Flux Lines in 3-D,” *IEEE Trans. Magn*., vol. 46, no. 8, pp.3349-3352, Aug. 2010.

[5] D. Buendgens, A. Hamacher, M. Hafner, T. Kuhlen, and K. Hameyer, “Bidirectional Coupling Between 3-D Field Simulation and Immersive Visualization Systems,” *IEEE Trans. Magn*., vol. 48, no. 2, pp. 547-550, Feb. 2012.

[6] M. Schoning and K. Hameyer, “Applying Virtual Reality Techniques to Finite Element Solutions,” *IEEE Trans. Magn*., vol. 44, no. 6, pp. 1422-1425, Jun. 2008.

[7] S. Matsutomo, T. Miyauchi, S. Noguchi, and H. Yamashita, “Real-Time Visualization System of Magnetic Field Utilizing Augmented Reality Technology for Education,” *IEEE Trans. Magn*., vol. 48, no. 2, pp. 531-534, Feb. 2012.

[8] S. Nagakura, S. Noguchi, H. Yamashita, and V. Cingoski, “Automatic Hexahedral Mesh Generation for FEM Using Shape Recognition Technique and Tree Method,” *IEEE Trans. on Magn*., vol. 38, no. 2, pp. 417-420, Feb. 2002.

[9] Y. Zhao, S. Niu, S. L.Ho, W.N. Fu, and J. Zhu, “A Parameterized Mesh Generation and Refinement Method for Finite Element Parameter Sweeping Analysis of Electromagnetic Devices,” *IEEE Trans. Magn*., vol. 48, no. 2, pp. 239-242, Feb. 2012.

[10] S. Matsutomo, S. Noguchi, and H. Yamashita, “Adaptive Mesh Generation Method Utilizing Magnetic Flux Lines in Two-Dimensional Finite Element Analysis,” *IEEE Trans. Magn*., vol. 48, no. 2, pp. 527-530, Feb. 2012.