Immersive Real-time Visualization System of 3D Magnetic Field with Augmented Reality Technology for Education

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We propose a new immersive real-time visualization system of 3D magnetic field utilizing Augmented Reality Technology for education in this paper. A real-time method of drawing flux lines in 3D space is newly developed for the proposed visualization system. It enables a user to easily observe and perceive a magnetic field generated by multiple sources (e.g. magnet and/or coil) in an augmented 3D space. Additionally, it permits the user to move the sources by own his/her hands and to observe the interfering magnetic field in real-time. As a result, the user can intuitively observe and understand the magnetic field even in 3D space.

Index Terms— **Augmented reality technology, Electromagnetic field analysis, Visualization.**

I. Introduction

In recent years, information and communication devices (e.g., smartphone, wearable device, and head mounted display) are becoming popular, and many teachers have begun using these devices as an education tool at their schools. So far, at the start of electromagnetics education, many students fail to understand or image electromagnetic phenomena because they are invisible and complicated. Therefore, the visualization of electromagnetic field is important and valuable for the students to learn a "magnetic field" generated by sources (e.g., magnet and/or coil). In this paper, a new tool for electromagnetics education is proposed.

Some kinds of visualization systems for magnetic field using Augmented Reality Technology have been reported by a several researchers [1-2]. However, they have not discussed the real-time processing of visualization systems with the magnetic field interference in detail.

In our previous study, a real-time visualization system with Augmented Reality Technology for magnetic field in 2D space has been reported [3-4]. It presented a synthetic image of mocks and their simulated magnetic field to users in 2D monitor, even interfering the magnetic of some sources. However, it was restricted to visualize the magnetic field in 2D space.

In this paper, we propose a new 3D visualization system to combine a real experiment and a computer simulation utilizing the Augmented Reality technique [5]. The proposed system indicates a synthetic image of objects (source materials) captured by two video cameras and their simulated magnetic field to a user. In the system, a real object is unnecessary, but a mock. The developed 3D visualization system can help the user to easily understand the magnetic field in an "augmented real world in 3D space." Additionally, the system has a user-friendly interface that the user can freely move mock objects in 3D space.

II. Proposed Immersive Real-time Visualization System

The developed system consists of an immersive head mounted display with cameras, a PC, and markers (mocks), as shown in Fig. 1. A mark is drawn in the mocks in advance, and it is identified by image processing technique, ARToolKit (Augmented Reality Toolkit) [3]. The position of marker is identified in a three-dimensional space, and then the magnetic flux density is analytically calculated and the magnetic flux lines are depicted on the head mounted display.

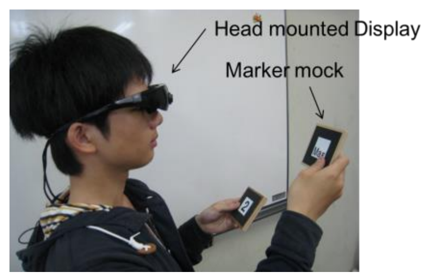


Fig. 1. Overview of proposed sysytem.

III. Real-time Calculation of Magnetic Flux Line

In 3D space, a magnetic flux line equation [6] is given as follows:

$$\frac{dx}{B_x} = \frac{dy}{B_y} = \frac{dz}{B_z} \tag{1}$$

where B_x, B_y, and B_z are the x-, y-, and z-component of magnetic flux density vector, respectively. In the developed system, the magnetic flux density vector is obtained by Biot-Savart law and the magnetic moment method due to a short calculation time. Furthermore, the virtual particle tracking method is adopted as the drawing method of magnetic flux line. Virtual particles are placed on the N pole of magnet initially, and every particle tracks a calculated magnetic density vector on 3D space. The particle position $\boldsymbol{P}_{t+1}$ on the step $t+1$ is calculated from the following equation:

$$\boldsymbol{P}_{t+1} = \boldsymbol{P}_t + \left(\frac{\boldsymbol{B}_t}{|\boldsymbol{B}_t|} \right) \Delta l \tag{2}$$

where $\boldsymbol{P}_t$ is the position of particle on the step t, and Δl is the movement distance of the virtual particle by one step. When Δl is short, the computation accuracy enhances although the computation time increases. When Δl is long, the virtual particle stray out of the correct flux line, as shown in Fig. 2.

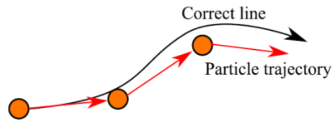


Fig. 2. Conventional virtual particle tracking method.

The developed system possesses a Δl adjusting method to take into account trade-off between the time and accuracy of computation. In the system, the length of Δl is short when the direction of the flux density drastically changes, on the other hand it is long when the magnetic flux direction gently changes, as shown in Fig. 3.

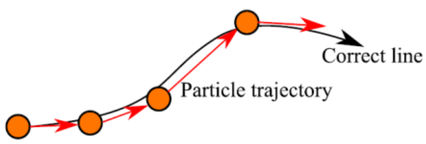


Fig. 3. Proposed virtual particle tracking method. Due to length adjustment, virtual particle correctly traces on flux line with short computation time.

In order to achieve the adjustment of Δl length, the following equation is applicable.

$$\boldsymbol{P}_{t+1} = \boldsymbol{P}_t + \left(\frac{\boldsymbol{B}_t}{|\boldsymbol{B}_t|}\right) k_t \Delta l \tag{3}$$

where k_t is the distance adjustment parameter as follows:

$$k_t = \begin{cases} \alpha & r_t \geq \beta \\ \alpha + (1-\alpha)(1-\dfrac{r_t}{\beta}) & \text{otherwise} \end{cases} \tag{4}$$

where r_t is the change ratio of the direction of $\boldsymbol{B}$, as follows:

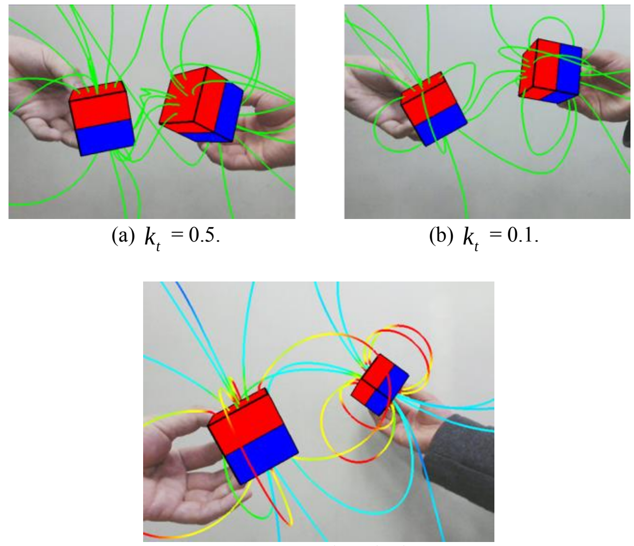
$$r_t = \frac{1}{k_{t-1}\Delta l}\cos^{-1}\left(\frac{\boldsymbol{B}_t}{|\boldsymbol{B}_t|}\cdot\frac{\boldsymbol{B}_{t-1}}{|\boldsymbol{B}_{t-1}|}\right) \tag{5}$$

α is the minimun ratio of distance Δl ($0 < \alpha \leq 1$), and β is the threshold of the change ratio.

IV. Application of Proposed System

Fig. 5 shows the execution screen of the developed visualization system. In Fig. 5 (a), k_t is fixed to be 0.5, and in Fig. 5 (b), k_t is fixed to be 0.1, i.e., Δl is equal to the length of the magnet. In Fig. 5 (a), although the average computation time is 23.0 fps, the magnetic flux lines are unnatural and wrong. In Fig. 5 (b), the average computation time is 10.3 fps, but the magnetic flux lines seem to be natural. On the other hand, the execution screen employing the proposed method is shown in Fig. 5 (c) ($\alpha = 0.1$, $\beta = \pi/90$), and the average calculation time is 23.0 fps (frame per second). In Fig. 5 (c), the color of the flux lines indicates the length of $k_t\Delta l$ for explanation (i.e., red means short and blue long). By using our proposed method, it is possible to establish a well-balanced the computation time and the simulation accuracy. Furthermore, this system has various functions; e.g., the cone plot visualization from a magnet (Fig. 6 (a)) and a magnetic field interfering between an iron core and magnet (Fig. 6 (b)).

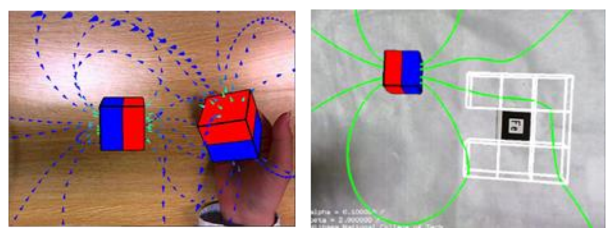
In this paper, we have proposed a method of providing a real-time observation of a static magnetic field including multi source objects in 3D space. The method utilizes the augmented reality technology. The users are able to easily receive the magnetic field visualization image of magnetic field as magnetic flux lines on the augmented reality world. Moreover, when a user moves an object, the image is updated in the real-time.



(a) $k_t = 0.5$. (b) $k_t = 0.1$.

(c) Proposed method.

Fig. 5. Execution result of the developed system with two magnets.



(a) Cone plot. (b) Magnet and iron core.

Fig. 6. Execution screen of the developed system.

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