Interactive Visualization System for Education and Design in Electromagnetics

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***Abstract*—A new interactive visualization system for educational and design purposes in 2D electromagnetics is proposed. The proposed system using numerically obtained results for several typical model configurations can display interactively electromagnetic field phenomena for any other model configuration bounded with the previously computed ones. It uses simple bilinear interpolation techniques in order to provide fast interactive display. This visualization system can be used for design purposes of problems with different model configurations and as an educational tool for teaching electromagnetics.**

***Index Terms*—Education, electromagnetic analysis, finite element methods, interpolation, scientific visualization.**

I. Introduction

NUMERICAL solution of electromagnetic field problems usually results with a large amount of data that is impossible to interpreted correctly without using a good visualization system. Additionally, if such visualization system can provide interaction with the computed data in real time then, this system can be very useful as an analysis tool for education and design purposes in electromagnetics. We have already proposed several visualization tools for electromagnetic field computation with main aim to facilitate grasping of the physical behavior of the analyzed field problems [1]–[3].

In this paper we present a new interactive visualization system developed mainly for design and educational purposes in electromagnetics. The main features of this visualization system are:

- Using several data sets obtained numerically for few user-defined model configurations, the proposed visualization system can compute and interactively visualize results for any other model configuration which is bounded by those previously computed utilizing simple interpolation technique.
- The system can display interactively the magnetic vector potential distribution, the magnetic flux density distribution, the magnetic flux lines and the magnetic flux density vector or any combination of them, simultaneously.

II. Proposed Visualization System

With the recent developments in hardware and software technology various interactive visualization systems have been proposed [1], [3]. Unfortunately, all of them usually provide visualization of only single set of numerically computed results in several display modes. On the other hand, for educational or for design purposes, usually it is of great interest to visualize some explicitly "nonexisting" results, i.e. results which will somehow predict the behavior of the electromagnetic field phenomena for a certain object configuration (e.g. new position or new size of coils or ferrites inside the analysis domain). Obviously, it is impossible to compute and store the exact solutions for each and any possible model configuration—this is computationally burden and inefficient. However, it is possible to compute electromagnetic phenomena at several typical configurations and later using interpolation techniques to display the same phenomenon at a new and not already computed configuration. This kind of interpolation procedure is introduced in this paper for obtaining the unknown electromagnetic distribution at any arbitrary position or arbitrary size of an object bounded by several pre-computed positions in order to realize a visualization system which is high efficient and computationally cheap.

A. Interpolation Method

We use a simple 2D model with moving ferrite shown in Fig. 1 in order to describe the interpolation procedure utilized in this paper [4]. First, we describe the interpolation method in order to obtain the unknown distributions for a new position of the moving ferrite. Next, we describe the interpolation method used to obtain the unknown distributions for a new size of the ferrite.

1) Interpolation Method for a New Position of an Object: Initially, for this model the exact field distributions are computed at four discrete positions of the ferrite inside the analysis domain, positions A, B, C, and D as shown in Fig. 1.

The interpolation procedure used to obtain unknown distributions for a new position of the moving ferrite is briefly summarized below:

Preprocessing Phase:

Step1: Define the corresponding areas and the area outside the interpolation domain for each of the pre-computed configurations. These areas we call corresponding blocks (see Fig. 2).

Step2: Decompose each area ($0 \sim 9$) into an i X j 2D grid and compute V_{paij} at each grid point, where i is the number of divisions along x-axis, defined by each corresponding block. Similarly j is the number of divisions along y–axis, V is a physical value (magnetic vector potential value or magnetic flux density value), p is the positional index of the pre–computed configuration ($A \sim D$), a is the index of each corresponding

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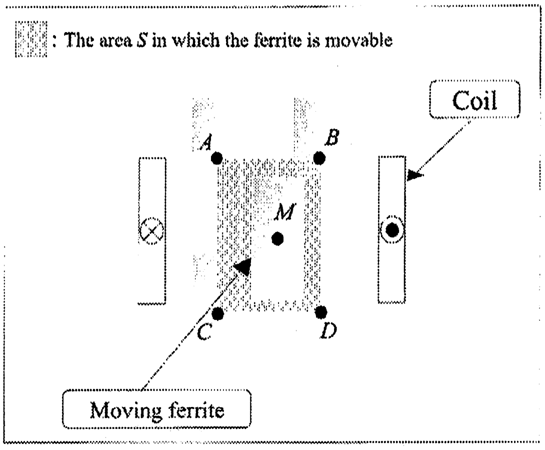


Fig. 1. The area S in which the ferrite is movable and the pre-computed positions A, B, C and D.

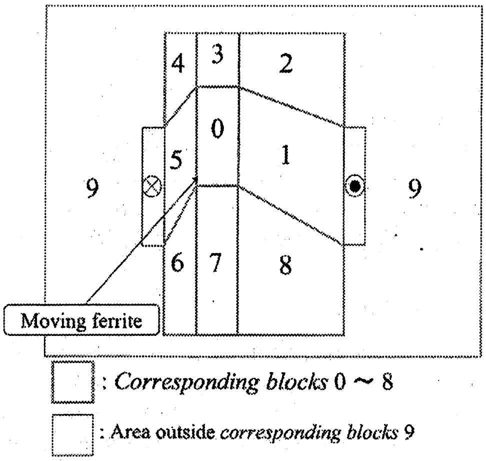


Fig. 2 Corresponding blocks and the area of outside them.

block and the area outside the corresponding blocks ($0 \sim 9$).

Processing Phase:

Step1: Arbitrary move the ferrite inside the display area M inside S using move and drag operations described above;

Step2: Decompose the display area into a set of visualization blocks and find matching pairs of blocks, among these new generated visualization blocks and the corresponding blocks constructed in the preprocessing phase;

Step3: Decompose each area ($0 \sim 9$) constructed at *Step2* into same number of 2D grid points as preprocessing ones.

Step4: Calculate the area coordinates $S_A \sim S_D$ at point M inside the area S (see Fig. 3);

Step5: Calculate physical value V_{aij} at each grid point of a corresponding block utilizing the bilinear interpolation method given below using physical value V_{paij} and the area coordinates $S_A \sim S_D$;

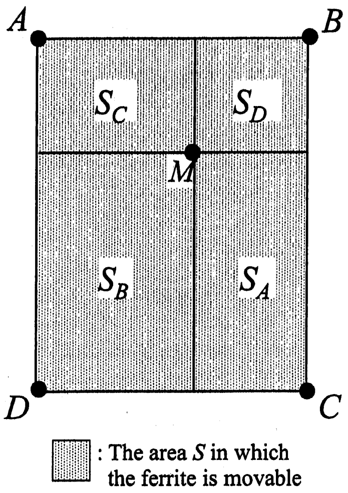


Fig. 3. The area coordinates $S_A \sim S_D$.

$$V_{aij} = V_{Aaij} \cdot S_A + V_{Baij} \cdot S_B + V_{Caij} \cdot S_C + V_{Daij} \cdot S_D \quad (1)$$

The preprocessing phase has to be executed only once, while the processing phase is executed interactively for each of the user-desired position of the ferrite.

This procedure is enough fast to enable interactive visualization, therefore, user can obtained the desired magnetic vector potential or magnetic flux density at any positions M in S in real time using move and drag operation of computer's mouse.

2) Interpolation Method for a New Size of an Object: In the previous section we described the interpolation method in order to obtain the unknown distributions for a new position of the moving ferrite, while in this section we describe the interpolation method for a new size of the ferrite. The idea behind this method is similar to the previous one. That is to say we use some exact field distributions computed for a different size of an object. We use simple 2D model (see Fig. 1) and describe the interpolation procedure in order to obtain unknown distributions for a new size of the ferrite. In order to obtain the better accuracy distribution by interpolation, we exhort to use three pre-computed results (see Fig. 4) for each position $A \sim D$. One of them is the result of standard size of the ferrite. The others are the results obtained when the ferrite size are shorten in the x direction (height) or the y direction (width) of the standard one. This interpolation procedure is briefly summarized below:

Preprocessing Phase:

Step1: Carry out Step1 of the preprocessing phase described in the previous section for each of the pre-computed result for all three different size of an object.

Step2: Compute V_{saij} at each grid point, where s is the index of ferrite size (S_h, S_s and S_w), while a, i and j have the same meaning as in the previous section.

Processing Phase:

Step1: Define arbitrary the ferrite width W and height H, with the following bounds $W_s \leq W \leq W_l$, $H_s \leq H \leq H_l$.

Step2 and

Step3: are the same like in the previous section.

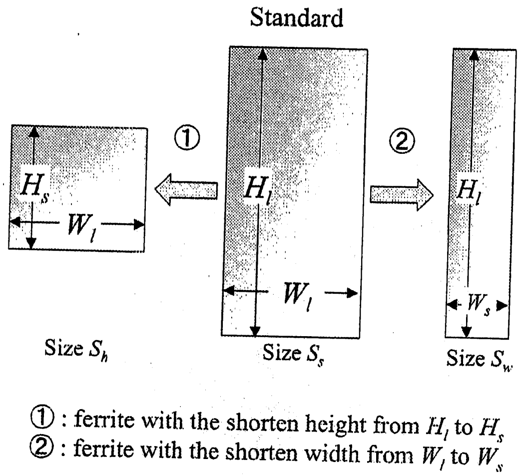


Fig. 4. Ferrite size S_h, S_s, S_w.

Step4: Calculate several variables hei, wid, V_{haij} and V_{waij} given below (2) ~ (5),

$$hei = \frac{H_l - H}{H_l - H_s} \tag{2}$$

$$wid = \frac{W_l - W}{W_l - W_s} \tag{3}$$

$$V_{haij} = V_{S_s aij} + hei \times (V_{S_h aij} - V_{S_s aij}) \tag{4}$$

$$V_{waij} = V_{S_s aij} + wid \times (V_{S_w aij} - V_{S_s aij}) \tag{5}$$

where, $V_{S_s aij}$, $V_{S_h aij}$ and $V_{S_w aij}$ are the physical values at each grid point of corresponding area for each ferrite size S_s, S_h and S_w, respectively.

Step5: Calculate physical value V_{aij} at each grid point of corresponding block given below using $V_{S_s aij}$, V_{haij}, and V_{waij};

$$V_{aij} = V_{S_s aij} + (V_{haij} - V_{S_s aij}) + (V_{waij} - V_{S_s aij}) \tag{6}$$

This procedure is also enough fast to enable interactive visualization. Therefore, user can obtained the desired magnetic vector potential or magnetic flux density at any ferrite size in real time using graphic user interface.

B. Magnetic Flux Line and Vector Visualization

1) Magnetic Flux Lines: We already mentioned above, this visualization system also displays the magnetic flux line distributions, alone or in connection with the magnetic flux density distribution. It is known that for a 2D field problem, the magnetic flux lines coincide with the equipotential lines of the computed magnetic vector potential. Since the magnetic vector potential is already known it is easy to generate the magnetic flux lines. In this paper, in order to accurately compute the magnetic flux lines, we utilized the well-known "Marching Cube Method" in 2D space [5]. This procedure is computationally cheap and enables interactive visualization.

2) Magnetic Flux Density Vectors: This visualization system can also display magnetic flux density vectors. Magnetic flux density vector can be obtained at any positions M or for any size of the ferrite by using pre-computed result for the interpolation method. In this section we describe the method for obtaining unknown magnetic flux density vectors at any position M inside S of the moving ferrite as shown in Fig. 1.

Preprocessing Phase: After carrying out *Step1* and *Step2* of the preprocessing phase described in Section II-A-1, we calculate the magnetic flux density vector at each grid point generated by *Step2* and calculate the vector length L_{paij} and the angle θ_{paij} between the x-axis and the direction of the vector [see Fig. 5(a)].

Processing Phase: After carrying out *Step1* till *Step4* of the processing phase in Section II-A-1, we calculate the length of the magnetic flux density vector L_{aij} and angle θ_{aij} at each grid point of the *corresponding block* utilizing the bilinear interpolation method given below using L_{paij}, angle θ_{paij} and the area coordinates $S_A \sim S_D$.

$$L_{aij} = L_{Aaij} \cdot S_A + L_{Baij} \cdot S_B + L_{Caij} \cdot S_C + L_{Daij} \cdot S_D \tag{7}$$

$$\theta_{aij} = \theta_{Aaij} \cdot S_A + \theta_{Baij} \cdot S_B + \theta_{Caij} \cdot S_C + \theta_{Daij} \cdot S_D \tag{8}$$

By using this method we can obtain unknown magnetic flux density vectors at any ferrite position M. If we apply this method to pre-computed results for different size of ferrites, we can also obtain unknown magnetic flux density vector for any arbitrary ferrite size.

Additionally, we can choose which display method to be used by utilizing a cone or an arrow [See Fig. 5(a)]. The size or/and length of a cone or an arrow corresponds to the intensity value

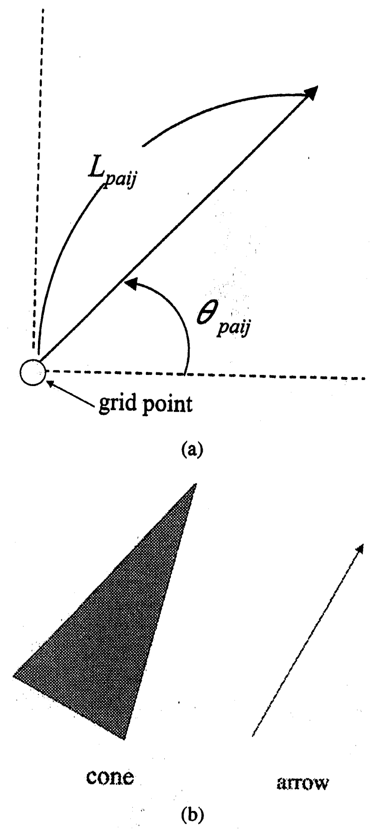
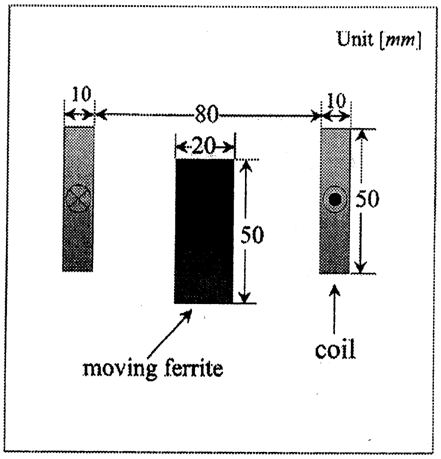
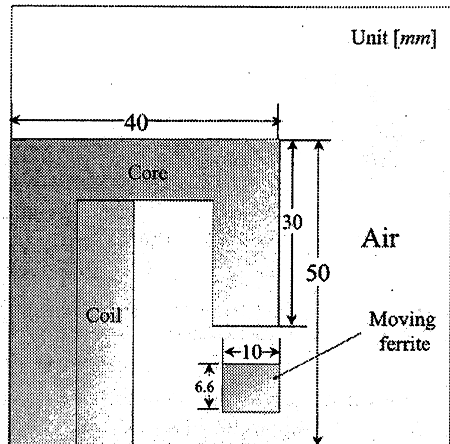


Fig. 5. Vector representations. (a) Vector length L_{paij} and vector angle θ_{paij}. (b) Simple cone and arrow for vector representation.



(a)



(b)

Fig. 6. Application models. (a) Model #1. (b) Model #2.

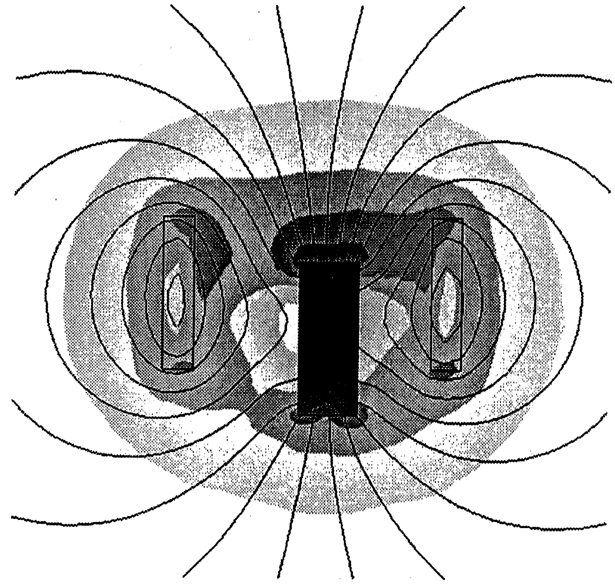
of a magnetic flux density vector. Again, the proposed visualization system can display the magnetic flux density vector alone or in connection with the magnetic flux density distribution, enough fast to enable interactive visualization.

C. Interactivity of the System

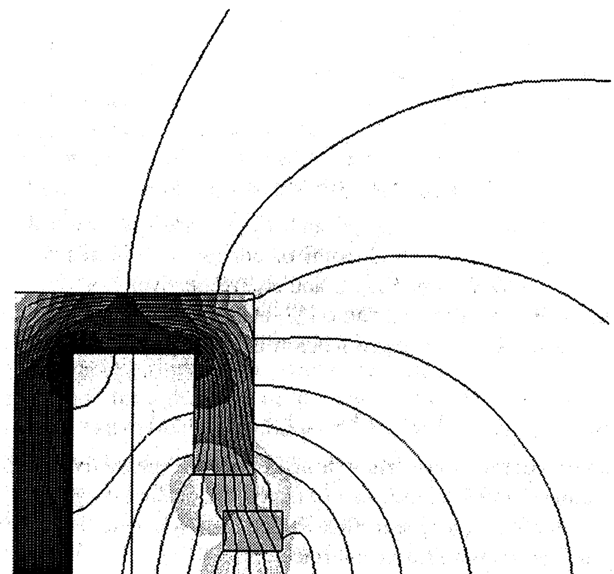
As mentioned above, using the proposed visualization method, one can easily display the magnetic vector potential, magnetic flux density, magnetic flux lines and magnetic flux density vector distribution interactively by simple move and drag operation of the computer's mouse. User can also display any of the above distribution alone or in connection by simple positioning of the mouse cursor at the desired point M inside the acceptable display space S. To increase the versatility of the system, a user-friendly graphic interface was also developed.

III. Applications

Proposed visualization system was applied to two models shown in Fig. 6. In the Model #1 a moving ferrite was used, and in the Model #2 a moving ferrite under the C-type electromagnet



(a)



(b)

Fig. 7. Application results. (a) Model #1. (b) Model #2.

was considered. Obtained results for two arbitrary positions of the ferrite (Model #1 and Model #2) are given in Fig. 7, respectively. For both models, interpolation was performed using four model configurations with pre-computed values of the magnetic vector potential and magnetic flux density. The calculation time was less than a second for each arbitrary position. Such short computation time enables real time interaction between the user and the system, while the interpolation error of the results was less than 7% that is acceptably low from the engineering point of view.

Fig. 8 shows the obtained result for arbitrary size of a ferrite at Model #1 by using the method described in Section II-A-2. This interpolation was performed using twelve typical model

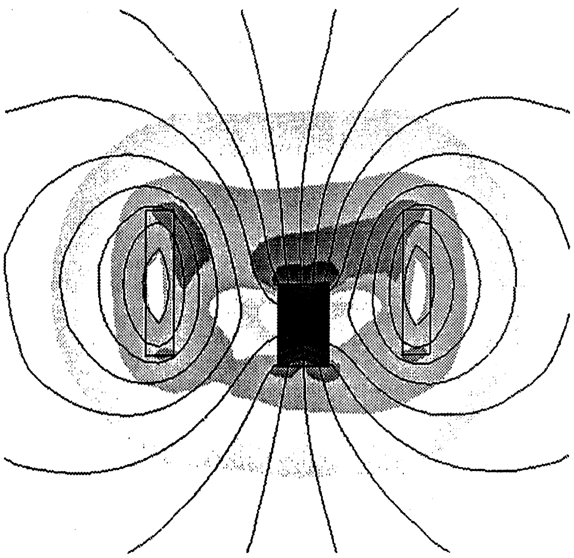


Fig. 8. Application results for ferrite with an arbitrary size.

configurations — three pre-computed results for each of the four different positions of ferrites. The interpolation error for this visualization was also less 7%.

Fig. 9 shows the magnetic flux density vector at arbitrary positions of the ferrite obtained by using the method described in Section II-B-2. Vectors are represented using cones with different sizes according to the intensity values of the magnetic flux density as shown Fig. 5(b).

IV. Conclusions

We developed a new interactive visualization system suitable for visualization of magnetic field quantities interactively. This system is based on simple interpolation procedures, such as bilinear interpolation to display distributions of objects that are placed at arbitrary positions or have changed geometrical shapes than those used for the pre-computed results. Additionally, the system has user-friendly interface in order to facilitate its application for educational and design purposes. In order to verify its usefulness we successfully applied this system to two models.

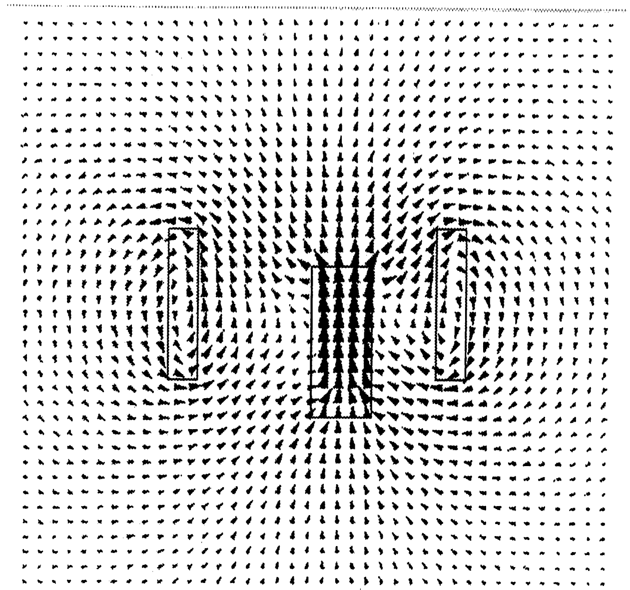


Fig. 9. Vector visualization.

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