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3D Magnetic Field Visualization System Based on Virtual Reality Technique

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Abstract. In the field of scientific visualization, recently, several systems which utilize various virtual reality techniques have already been proposed. In this paper, we propose a visualization system for interactive visualization and postprocessing of the results obtained from the finite element electromagnetic field analysis. The developed visualization system displays interactively magnetic field distributions for any arbitrary position of an object (such as ferrite) inside the visualization space using simple interpolation technique and several precomputed distributions. Part of this paper also describes the developed user friendly graphic interface in order to increase the versatility of the proposed visualization system.

1. Introduction

For scientific visualization, several systems which utilize the virtual reality techniques in order to display the computed results more intuitively have already been proposed [1], [2]. Therefore, we believe that the development of a visualization system based on virtual reality technique for visualization of the computed electromagnetic field distributions could provide better understanding of the physical phenomena. Additionally, this system could enable interactive visualization of the physical phenomena and the interaction between various objects inside the virtual space. Using this system, we could interactively visualize the computed field distribution as a result of position or shape changing of various objects inside the display space, such as coils, ferrite, etc., in real time, which is very important for design on electromagnetic devices or for educational purposes.

In this paper, we propose a visualization system which displays interactively magnetic field distributions for an arbitrary position of an object inside the visualization space using several precomputed distributions. Recently, similar visualization systems have already been proposed, however, they are realized either by using huge memory, large computation cost, or the both. Therefore, for our system, we borrowed from the computer graphics fields a kind of morphing technique as an easy and efficient interpolation methodology for obtaining the unknown field distribution at any arbitrary position where the moving object is placed discretely using several precomputed field distributions which bound that arbitrary position. Additionally, part of this paper also describes the developed user friendly graphic user interface based on virtual reality technique in order to increase the versatility of the proposed visualization system.

2. Proposed Visualization System

The proposed visualization system is a nice combination of hardware and software compositions. Schematically, the hardware composition of the developed system is given in

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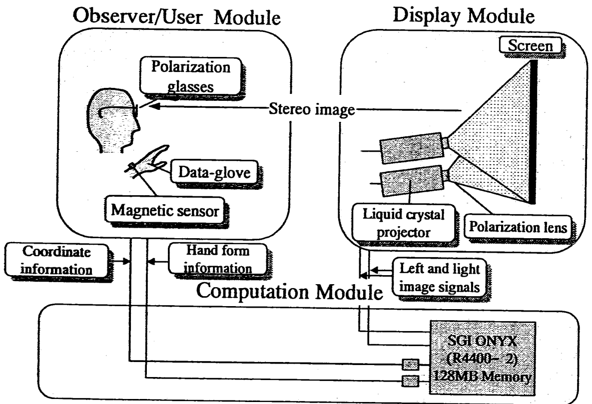


Figure 1: Hardware composition

Fig. 1. Three separate modules are visible, (1) the observer/user module which interacts the virtual space using a data-glove and a magnetic sensor as inputting devices, (2) the computation module, having the SGI Onyx Workstation as a core on which all the computation is performed, and (3) the display module, where the generated images are projected using liquid crystal projectors on a screen for visual inspection by the observer/user, which finally encloses the entire visualization circle. Due to the high specifics of the hardware composition, here we will not discuss the hardware, but rather we will present only the software aspects of our visualization system.

First, we describe in detail the interpolation algorithm which was used in our visualization system [3]. For simplicity, we describe here the 2D algorithm, although the same algorithm almost without any modifications can be also used for 3D interpolation. The interpolation algorithm is explained using a simple 2D model shown in Fig. 2 which consists of two static coils and a moving ferrite in between. As can be seen from Fig. 2, the exact field distributions are previously computed at four discrete positions A, B, C, and D of the ferrite. Later, using the interpolation algorithm, the magnetic field distribution can be computed at any arbitrary position M of the ferrite which is inside the region S bounded by the precomputed solutions $A \sim D$ as shown in Fig. 2.

3. Interpolation algorithm

The interpolation algorithm is based on the morphing technique which is well established as an efficient and computationally cheap interpolation method in the field of Computer Graphics.

Step 1: Input data such as analysis results, coordinates and position of the objects, etc.;

Step 2: Set an arbitrary position of the moving object (ferrite) (coordinates of point M)

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

Step 4: Calculate the coordinates of each vertex P_i, $i = 1, \ldots, N_v$, where N_v is the number of vertices which outline the moving object;

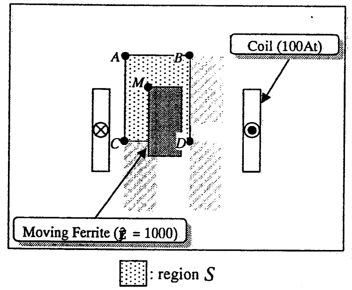


Figure.2 Precomputed ferrite positions $A \cdot D$ and interpolation region S.

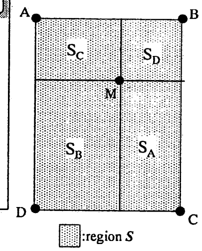


Figure 3: Area coordinate

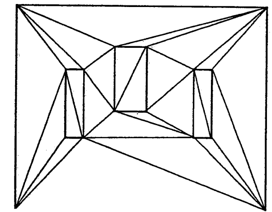


Figure 4: Delaunay decomposition

Step 5: Decompose analysis domain into a set of triangles by using only the vertices which outline the analysis domain and the shape of objects (coil, ferrite, etc.) using the *Delaunay* algorithm, when the moving object is placed at point M (Fig. 4);

Step 6: Calculate the amount and the direction of movement for each vertex of the moving object from point M to point A as so called *Displacement Vector* (shown as an arrow in Fig. 5). Figure 5 shows displacement vectors for each of the four vertices that outline moving ferrite. The displacement vectors are also defined for vertices which outline other objects such as coils and the analysis domain as well, however, those displacement vectors become zero inevitably for each static objects inside the analysis domain. Similarly, calculate the values of the displacement vectors when the moving ferrite is at other three precomputed positions $B \sim D$;

Step 7: Generate a set of sampling points S_i uniformly distributed inside the display domain.

Step 8: For each sampling point S_i dispositioned in domain, do the following procedures:

Step 8-1: Find a triangle which includes point S_i, given at *Step 7* (Fig. 6(a)).

Step 8-2: Calculate the *Offset Vector* expressed by the following Eq.(1) using the value of the *Diplacement Vector* at each vertex of the triangle found at *Step 8-1*, and calculate the area coordinates A_1, A_2 and A_3 at point S_i inside that triangle (see Fig. 6(b));

$$\textit{\textbf{Offset Vector}} = A_1 \textit{\textbf{Vector1}} + A_2 \textit{\textbf{Vector2}} + A_3 \textit{\textbf{Vector3}} \quad (1)$$

Step 8-3: Obtain the coordinate of a point P_A given by that *Offset Vector* added to point S_i. This point is called the *Correspondence Point*;

Step 8-4: Obtain the physical value V_A at the correspondence point P_A using precomputed distributions. Similarly, for point S_i, we obtain three other physical values V_B, V_C and V_D at the correspondence points P_B, P_C, and P_D;

Step 9: Calculate physical value V_{Si} according to following Eq.(2) using physical values V_A, V_B, V_C, and V_D computed at *Step 8* and the area coordinates $S_A \sim S_D$ computed at *Step 3*:

$$V_{Si} = S_A V_A + S_B V_B + S_C V_C + S_D V_D \quad (2)$$

Similar interpolation algorithm can be used for 3D analysis, however, this time, instead of four precomputed distributions, as we can see later, we need to prepare eight precomputed distributions.

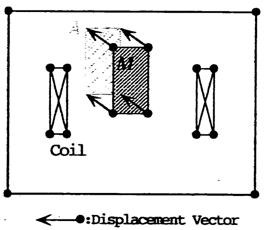
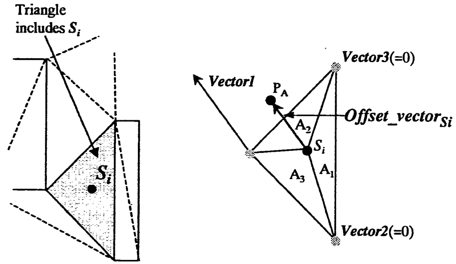


Figure 5: Displacement vector.



(a) Found Triangle includes S_i (b) Offset Vector

Figure 6: Corresponding point P_A.

4. System's Interactivity

One of the main advantages of the virtual reality based visualization systems is the real-time interaction between the user and the visualized data, and the real time transfer of the input/output commands from the user to the computer where computation, manipulation and display of various scientific data actually occurs. For that purposes, a fast computation method must be developed. For 2D visualization, due to the nature of the data, their small amount and the recently highly increased computational speed of the hardware, this can be achieved without any difficulties. However, when we are dealing with complex 3D structured or unstructured computation data, then the interactivity becomes very important and can not be easy and always achieved. For example, using the above described algorithm for 2D data, the computational time for a model with 30×30 = 900 sampling points was approximately 0.02 s, which is enough short to provide interactive visualization. However, for the similar 3D model and 3D data shown in Fig. 7, using 50×50×50 = 125,000 sampling points the computation time increased almost 900 times, reaching almost 18 s. This computation time is not acceptable for interactive visualization, therefore, we developed three additional routines in order to decrease the computational time.

- Whenever the moving object is moving, display the wireframe model only.
- Perform calculation only for the sampling points which lie on the surface of the display area.
- Increase the number of sample points progressively, progressive interpolation – start with coarse grid of interpolation points and progressively increase the density of the sampling points grid.

Using these three routines, we can decrease the computation time down to 3 ~ 4 s, and realize almost an interactive visualization system.

Figure 8 shows the comparison between the results obtained from the above described interpolation procedure using 8 precomputed magnetic potential distributions (*A*)~(*H*) as shown in Fig. 7, and the results obtained directly from the finite element analysis for the same position of the ferrite, in the center of the coil. For bounded display area $-200 \leq x \leq 200$, $-200 \leq y \leq 200$, $-100 \leq z \leq 100$, the average relative error in comparison with the exact solution obtained by means of the finite element analysis was about 8.6 %, which is satisfactory from the engineering point of view.

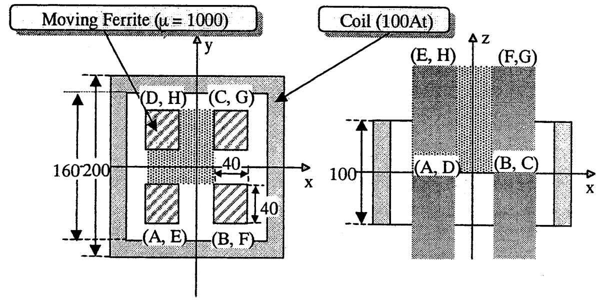
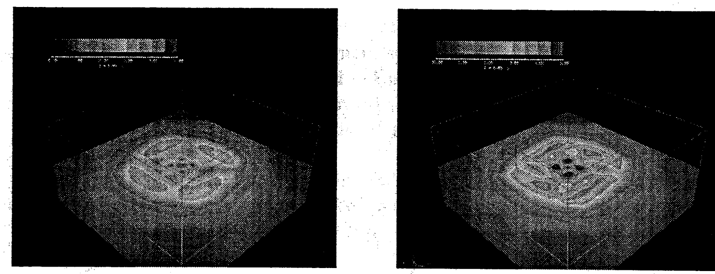


Figure 7: 3D experimental model with the precomputed ferrite position.



(a) Distribution obtained by interpolation (b) Distribution obtained by FEA

Figure 8: Display for 3D field visualization – Cutting plane at Z = 0.

5. Graphic User Interface

To increase the versatility of the developed visualization system an adequate graphic user interface (GUI) is necessary. This GUI must facilitate the usability of the entire system and provide easy commands input and manipulation with the visualized scientific data on more sophisticated and natural ways. For that purposes, in our system, the user/observer can give commands to the visualization system and manipulate the display by changing the shape and the position of his/her hand and fingers. Each change of the position and shape using special data-glove–magnetic sensor system generates appropriate electronic impulses and passes them to the specially designed software routines inside the computer. Using these input information, observer can directly set and operate several predefined operations, such as switching the display modes between cross section and surface visualization, setting the viewpoint and the view reference point, rotation, translation and zoom inside the display domain and setting the default setup of the entire system, by simply setting several predefined shapes of his/her fingers and motions of his/her hand in the 3D space. The basic concept is the user/observer. According to only these six directions, it is possible to comparatively easy move or set the viewpoint, view reference point, cutting planes, moving objects inside the virtual space, etc. To made the commanding procedure natural and easy, for definition which movement and in which direction will results in what operation, we try to follow the peoples natural behavior and movements (see Fig. 10). As a result, we believe that the developed GUI is highly intuitive, versatile and easy for usage.

6. Conclusions

We proposed a new visualization system based on virtual reality techniques which displays interactively magnetic field distributions for an arbitrary position of an object inside the visualization space using several precomputed magnetic field distributions which bound that arbitrary position. We described the interpolation algorithm in details and give some ideas for decreasing the computation time in order to enable interactive visualization even for large 3D data sets. We also developed friendly graphic user interface utilized by the developed virtual reality visualization system in order to increase the system's versatility and robustness. In conclusions, the developed system provides highly sophisticated interactive scientific visualization efficiently and computationally cheap.

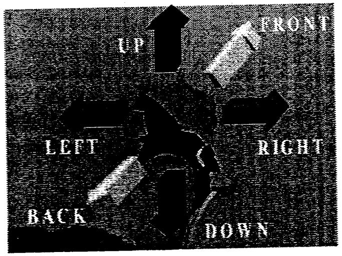
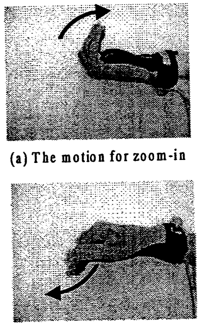


Figure 9: Data-glove as a inputting device.



(a) The motion for zoom-in

(b) The motion for zoom-out

Figure 10: Additional motions for zoom

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Instrumentation

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Abstract. In this paper the methods of teaching in the discipline "Intelligent Measurement and Instrumentation" and in particular, the laboratory exercises carrying out by the students of Faculty of Automation in Technical University of Sofia are presented.

1. The aims of the course

The main purpose in creating of the above mentioned exercises is to model the basic principles of microprocessor based measurement systems: design of primary sensors, signal conditioning elements, Analog to Digital Conversion, controllers for 8 and 16-bit microprocessors and estimation of the final results for the measured value based on inverse transfer function. The problems of processing of repeatedly-trial measurement schemes are separately considered.

One of the most important problems in realizing of these labs is to minimize the application of the commercially available software products. From one hand the utilization of this software simplifies the experiments, but from the other hand most of the modeling and processing procedures are not understandable for the students.

2. Modeling of some measurement procedures

Based on their experience the authors have created a specialized course for modeling of measurement structures. The students are supposed to create high level and assembler language subroutines for control of various measurement procedures.

The hardware used in the already mentioned laboratory exercises are modules, produced by FEEDBACK company and IBM compatible computers.

The largest part of the assignments [1] is based on the training kits: Microprocessor Applications Board MIC 960, Digital System CK 342A, Analogue Systems CK 342B, and transducers kit TK 2941/2.

This hardware and software created by the students makes possible modeling of different principles of analog to digital conversion, measurement of various electrical and non-electrical quantities, demonstration of the properties of the different measurement structures, calibration, etc.

More over, it is possible to investigate by modeling the working processes for both the operational integrators and other electronic components designed for precise measurements.

As it is well known the working (operational) process of each integrator is limited in time, but if we in advance have the information about the function of change of the output signal