B101 Electromagnetic Field Visualization by Image Processing

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ABSTRACT

The image processing technique based on the field theory is applied for visualization of electromagnetic fields. The inverse color problem is formulated over the image. The color source densities have been evaluated from the color distributions of the field data set. The Generalized Vector Sampled Pattern Matching method is applied to solve an ill-posed linear system of equations. The new color distributions are generated using the obtained color source densities. With the proposed approach the quality of the images can be essentially improved. Different field characteristics are obtained during image processing of the field distribution. The current distributions are determined from the locally measured magnetic field.

Keywords: Electromagnetic field, Current Distribution, Visualization, Image processing

1. Introduction

Magnetic field distribution is very important considering many inverse electromagnetic problems – identification, NDT, ECT etc. Usually the locally measured magnetic field over the parallel surfaces for testing and inspection of the devices is used to determine the current distribution. When the field data set is insufficient or accompanied with essential noise, it is very difficult to analyze the visualized field distribution. Using the image processing techniques the quality of the images can be essentially improved. Recently, different methodologies and algorithms have been utilized for image processing [1-4]. It was found that the field theory is quite effective for image processing of the visualized information [5-8]. In this paper, the field theory is applied over the image visualizing the electromagnetic field distribution. The inverse color problem is formulated in order to process the image. The color source densities have been evaluated from the color distributions of the field data set. The color source distribution corresponds to the current distribution. Thus, convoluting and visualizing the color source distribution it is possible to visualize the current distribution. Different field characteristics can be obtained during image processing of the field distribution. The magnetic field density distribution can be obtained from visualized potential distribution. The magnetic field distributions of the most commonly used electromagnetic systems are investigated. The results obtained demonstrate the effectiveness of the approach.

2. Image color model of the field distribution

The image is considered as 2D-distribution of color components – Red, Green, and Blue (RGB). Each color component A is expressed utilizing the Green function G

$$A = \frac{1}{4\pi} \int_S \sigma G dS. \quad (1)$$

The color component source densities σ are determined solving the system of equations

$$\mathbf{C}\mathbf{X} = \mathbf{Y}, \quad (2)$$

where $\mathbf{C}$, $\mathbf{Y}$ and $\mathbf{X}$ are the n by m system matrix, n^{th} order column vector of the color component and m^{th} order column vector of unknown color source densities, respectively. For image processing the color components as well as color source densities have to be determined in the x -, y -pixels of the image. The RGB color components are separated. The systems of equations (2) are solved by Generalized Vector Sampled Pattern Matching method (GVSPM). The new visualization of the color distributions is carried out from the evaluated color source densities. During visualization of the fields when the potential field distribution is considered, the RGB color distribution of the image corresponds to the potential distribution of the field. Applying the relation between vector potential $\mathbf{A}$ and flux density $\mathbf{B}$ over the pixels of the image

$$\mathbf{B} = \nabla \times \mathbf{A} \quad (3)$$

we obtain the RGB color flux density distribution which corresponds to the flux density distribution. Also,

the components of the magnetic flux densities are determined utilizing the color source densities.

3. Application

3.1 Magnetic field distribution

The magnetic field distribution of linear sensor composed of ferromagnetic core and coil has been investigated. In Fig. 1 are given the original (a) and damaged (b) images of magnetic field distribution of the investigated core-coil sensor. The RGB source density distributions of Fig. 1(b) are shown in Fig. 2. The new visualization of the color distribution is carried out and presented in Fig.1(c). The correlation between original and refined images is calculated.

Fig. 1 Original and damaged images of magnetic field distribution of core-coil sensor

Fig. 2 Color source density distributions of core-coil sensor

Considering potential distribution of the magnetic field, shown in Fig. 1(a) we obtain the color flux density distribution presented in Fig.3. The color flux density distributions correspond to the flux density distributions of the visualized magnetic field.

Fig. 3 Color flux density distribution

Fig. 4 Circular coil

Fig.5 Magnetic field density distribution

Fig.6 Magnetic field density distribution – B_r, B_z

Fig. 7 Color component distribution of B_x

Fig. 8 Color component distribution of B_z

Fig. 9 Color source distribution of B_x

Red Green Blue
Fig. 10 Color component distribution of B_z

(a) RGB of B_x (b) RGB of B_z
Fig. 11 Color source distribution

(a) circular coil (b) current distribution
Fig. 12 Circular coil and determined current distribution

3.2 Determination of current distributions

Usually magnetic field is measured over the parallel surfaces during the testing and inspection of the devices as printed current boards (PCBs), motherboards of personal computers etc. Visualizing the obtained data set, the corresponding current distribution can be obtained by image processing. The circular coil shown in Fig. 4 has been tested. The inner and outer diameters are $d_1=0.02\text{m}$ and $d_2=0.04\text{m}$, respectively. The height is $h=0.005\text{m}$. The components of the magnetic flux density distribution over parallel surfaces at distance $d=0.01\text{m}$ are measured and visualized as shown in Fig. 5(a-c). As the system is axisymmetrical, the radial and axial components of the magnetic field are determined and presented in Fig. 6. The Red, Green and Blue color components of the images in Fig. 5 are separated and shown in Fig. 7 and Fig. 8 for the B_x and B_z components of the magnetic field densities, respectively. The color source density distributions are obtained by solving the system of equations (2) for each color

component – RGB of the both images shown in Fig. 9-11. Using convolution of color source densities the corresponding current distribution is obtained and visualized in Fig. 12.

Fig. 13 Coil system

(a) B_x (b) B_y (c) B_z
Fig. 14 Magnetic field density distribution

Fig. 15 Magnetic field density distribution – B_r , B_z

Red Green Blue
Fig. 16 Color component distribution of B_x

Red Green Blue
Fig. 17 Color component distribution of B_z

Red Green Blue
Fig. 18 Color source distribution of B_x

Red Green Blue
Fig. 19 Color source distribution of B_z

(a) RGB of B_x (b) RGB of B_z
Fig. 20 Color source distribution

(a) coil system (b) current distribution
Fig. 21. Coil system and determined current distribution

For the coil system in Fig. 13 the components B_x , B_y and B_z of the magnetic field density distribution are measured over parallel surface at distance 0.01m and are shown in Fig. 14. The diameters of the thin coil turns are $d_1=0.02\text{m}$, $d_2=0.05\text{m}$, $d_3=0.08\text{m}$. As the coil system is with axial symmetry, the radial and axial components B_r and B_z are presented in Fig. 15. The RGB color components are separated and shown in Fig.16-17 for the B_x and B_y components of the magnetic field densities, respectively. Solving the inverse color problem over the images of the B_x and B_z data set, the color source densities are obtained for each color component RGB and presented in Fig. 18-20. By using the proposed image processing approach the corresponding current density distribution is obtained and

shown in Fig. 21.

4. Conclusion

The image processing technique using field theory was successfully applied for field visualization of electromagnetic devices. From the potential distribution of magnetic field, it is possible to visualize the flux density distribution. From the locally measured magnetic field distribution with the proposed image processing approach the corresponding current distribution is determined and visualized. With the proposed inverse approach the quality of the images can be essentially improved. The results obtained reveal that the proposed approach based on the image processing and field theory can be effectively applied for visualization of electromagnetic fields and characteristics.

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