

Research Article

The Visualization of Solutions to Electromagnetic Field Problems by Using Matlab

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Abstract: In this study, we use the superposition principle to find a particular solution to Poisson and Laplace equations. It is assumed that the field in a homogeneous dielectric is excited by space charges under a specific density distribution. Under these assumptions, the results of visualization to electrostatic field solutions are reported for two cases: i) calculation of the electrostatic field between two shielded cables and ii) calculation of the electrostatic field between the dielectric corner and a parallel long charged conductor.

In this study, we aim to initiate a discussion of the use of computer analysis and modeling as an educational tool for engineering students.

Keywords: *Electrostatics, visualization, engineering education*

Matlab Kullanarak Elektromanyetik Alan Problemlerinin Çözümlerin Görselleştirilmesi

Özet : Bu çalışmada, süperpozisyon ilkesi kullanılarak, Poisson ve Laplace denklemlerinin özel çözümleri belirlenmiştir. Homojen dielektrik bir ortamda elektriksel alanın, belirli bir yük yoğunluğu dağılımına sahip uzay hacim yükleri tarafından oluşturulduğu varsayılarak: i) iki damarlı kablo arasındaki elektrostatik alanın hesaplanması ve ii) dielektrik köşe ile paralel uzun elektrik yüklü bir iletken arasındaki elektrostatik alanın hesaplanmasına karşılık gelen çözümlerinin Matlab ortamında görselleştirilmesi sonuçları verilmiştir.

Bu çalışmada, mühendislik öğrencileri için bilgisayar analizi ve modellemenin bir eğitim aracı olarak kullanılmasının daha etkin olacağını kanıtlamak amaçlanmıştır.

Anahtar Kelimeler: *Elektrostatik, görselleştirilme, mühendislik eğitimi.*

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1. Introduction

In the theory of the electromagnetic field, some of the main problems are calculation, visualization and analysis of the electrostatic field for various configurations of interacting bodies [1-3].

Today, engineering students can benefit from the development in information technology, to perform analysis and do simulation of systems by using computers. Computer-aided design analysis tools electrical engineering students not only solve electrical circuit design problems manually, but also simulate their results.

Recently, computer tools have been widely used for education and research purposes in universities, especially in the areas of mathematics and engineering [3-5].

In-class tools and lectures are not always sufficient to fully convey the ideas to students. They often require more time and energy from the instructor to overcome the difficulties in understanding [6-8]. At this point, virtual experiment or simulation tools can help the instructor demonstrate the results visually. Visual information is easier to comprehend by students in the lectures. Such materials provided by computers can also be helpful to get and keep the attention in the classroom.

Matlab is a user-friendly programming tool supported by complex mathematical functions and effective visualization interfaces. It is designed for performing complex calculations in personnel computers and has wide range of users from engineers to scientists and students to instructors. Matlab environment can be used by people from any area of science and technology because it contains fundamental mathematical tools (operations with complex numbers, matrices, vectors, and polynomials, data processing, analysis of signals and digital filtering), which are needed for the development of more complex models and functions. Matlab developers are paying attention to graphical tools and the visualization of the various tasks to have graphical representation of the results easily. This property makes MATLAB a useful tool for educational purposes.

The main aim of this paper is not a detailed presentation of the solution to problems in the calculation of electromagnetic fields. This paper demonstrates only some Matlab features that help the concepts in the analysis of the field structures to be clear for students. We illustrate visualization of solutions to electrostatic problems by Matlab and discuss some advantages for students and instructors. We conclude that instructors and students can make use of the presented concepts to help them to solve engineering problems

2. Examples of The Analyses

A. Example 1: Analysis of two conductor shielded cable

Let us calculate the electrostatic field between two conductors shielded cable. Figure 1 shows the cross section of this cable system and the related parameters. Let us take the parameters of cable system as following: inner radius of the cable = 10 mm, the distance between core vessels $l = 10\text{ mm}$,

vessel diameter $d = 5\text{ mm}$, the relative dielectric constant of the medium between the cores (air) $\epsilon_r = 1$; and voltage between cable cores $U = 100\text{ V}$.

We will replace the cable with a system of four charged axes so that the cable sheath is an equipotential surface (see figure 2). For this, we have the following equations,

$$s - a = \frac{1}{2}l \quad \text{and} \quad s^2 = a^2 + R^2$$

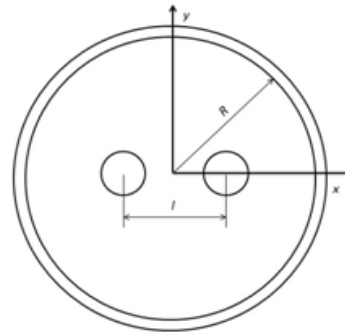


Figure 1. Cross section of two conductor shielded cable

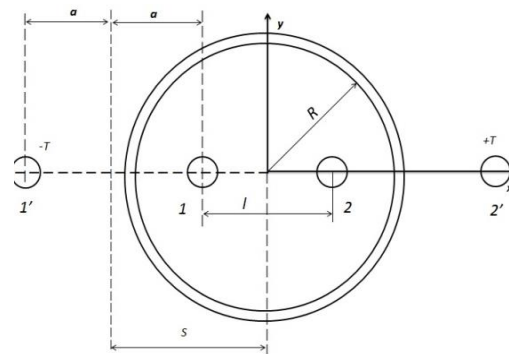


Figure 2. Cross section of two conductor shielded cable

We derive a and s as follows:

$$a = \frac{R^2}{l} - \frac{l}{4} = 7.5\text{ mm} ; \quad s = \frac{R^2}{l} + \frac{l}{4} = 12.5\text{ mm} ;$$

We calculate the potential of any point from two two-wire lines (1 and 2), assuming $\phi = 0$ at $x = 0$ as

$$\phi(x, y) = 7.9 \left[\ln \frac{(x - 0.5)^2 + y^2}{(x + 0.5)^2 + y^2} + \ln \frac{(x + 2)^2 + y^2}{(x - 2)^2 + y^2} \right] \quad (V) \quad (1)$$

By using (1), the expression for the scalar potential in the equation $\vec{E} = -grad\phi$, we obtain the following expressions for the components E_x and E_y of the electric field as follows:

$$E_x = -\frac{\partial\phi}{\partial x} = 15.8 \left[\frac{x+0.5}{(x+0.5)^2+y^2} - \frac{x-0.5}{(x+0.5)^2+y^2} + \frac{x-2}{(x-2)^2+y^2} - \frac{x+2}{(x+2)^2+y^2} \right] \left(\frac{V}{cm}\right) \tag{2}$$

$$E_y = -\frac{\partial\phi}{\partial y} = 15.8y \left[\frac{1}{(x+0.5)^2+y^2} - \frac{1}{(x+0.5)^2+y^2} + \frac{1}{(x-2)^2+y^2} - \frac{1}{(x+2)^2+y^2} \right] \left(\frac{V}{cm}\right) \tag{3}$$

Further using the boundary conditions $D_{2n} - D_{1n} = q_s$ for the charge density on the cable sheath we obtain

$$q_s = -\epsilon_0 E_r = \epsilon_0 \frac{\partial\phi}{\partial r} \Big|_{r=R} = \epsilon_0 \frac{\partial}{\partial r} (E_x \cos \alpha + E_y \sin \alpha) \Big|_{r=R}$$

If the expression for the surface charge density is rearranged to take into account the appropriate components of the electric field intensity, then

$$q_s = \frac{2.1 \cos \alpha}{1.56 - \cos^2 \alpha} \left(\frac{pC}{cm^2}\right) \tag{4}$$

The solution given by equation (1) is not easy to envisage and evaluate by students. To help students understand the physics behind (1), results of equation (1) were visualized by using Matlab graphic object in Figure 3 and 4. Figures 3 and 4 clearly show potential distribution formed by the two-conductor cable system and allow students to see and evaluate results of equation (1). They can understand the effects of the conductor position and structural parameter on the spatial field distribution easily. Such visualization also helps to improve analytical thinking skill and to understand the relation between analytical solution and its physical meaning. The Matlab code used for this example is given below in Program 1.

B. Example 2: The analysis of the electrostatic field between a dielectric corner and a parallel charged conductor

Let us calculate the electrostatic field between the dielectric corner and parallel charged conductor shown in Figure 5.

Let us take the parameters of this system as $l = h = 20 \text{ mm}$, diameter of charged cable $d = 5 \text{ mm}$ and the charge flow on the conductor $q_l = 0.2 \mu\text{C}/\text{km}$. The space is vacuum and the dielectric constant of the material corner $\epsilon_r = 20$.

By using the method of images, one obtains the field potential inside corner as,

$$\phi = -\frac{q_l}{2\pi\epsilon_r\epsilon_0} \ln \frac{r_1 r_2 r_3 r_4}{4h^4} \tag{5}$$

where,

$$r_1 = \sqrt{(x-2)^2 + (y-2)^2}$$

$$r_2 = \sqrt{(x+2)^2 + (y-2)^2}$$

$$r_3 = \sqrt{(x-2)^2 + (y+2)^2}$$

$$r_4 = \sqrt{(x+2)^2 + (y+2)^2}$$

and therefore, the electric field can be obtained from $\vec{E} = -grad\phi$ and can be written as

$$E_x - \frac{\partial\phi}{\partial x} = 0.178 \cdot \left\{ \frac{x-2}{(x-2)^2+(y-2)^2} + \frac{x+2}{(x+2)^2+(y-2)^2} + \frac{x-2}{(x-2)^2+(y-2)^2} - \frac{x+2}{(x-2)^2+(y-2)^2} \right\} \left(\frac{V}{cm}\right) \tag{6a}$$

$$E_y = -\frac{\partial\phi}{\partial y} = 0.178 \cdot \left\{ \frac{y-2}{(y-2)^2+(x-2)^2} + \frac{y-2}{(y+2)^2+(x-2)^2} + \frac{y-2}{(y-2)^2+(x+2)^2} + \frac{y-2}{(y+2)^2+(x+2)^2} \right\} \left(\frac{V}{cm}\right) \tag{6b}$$

Where E_x and E_y are the components of the field in x and y directions, respectively.

It is not easy to evaluate potential distribution, defined by equation (5), for students. Visualization of potential distribution can be helpful for student to see and evaluate spatial distribution of the field potential. The Matlab code used for the visualization of potential distribution according to equations (5) is given below in Program 2. Figure 6 shows the resulting image by this code. This program can be written easily by students, and student can discuss graphical results in class or in a homework assignment.

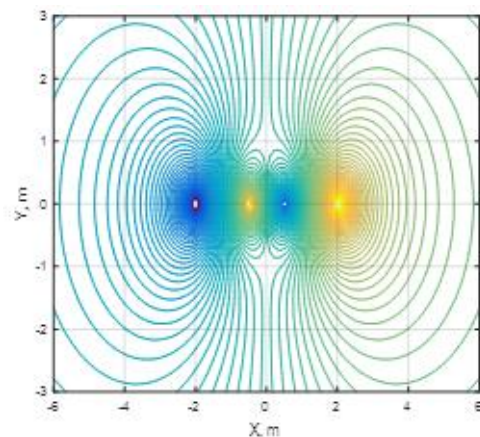


Figure 3. Potential field distribution (top view)

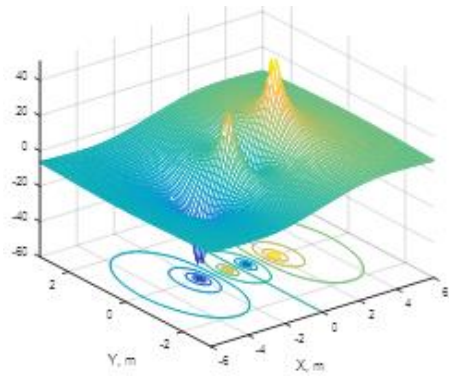


Figure 4. Potential field distribution (side view)

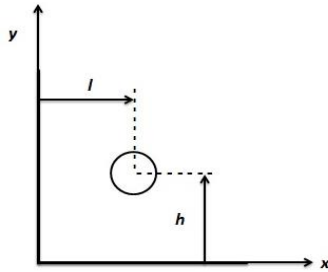


Figure 5. Cross section of dielectric corner with charged conductor.

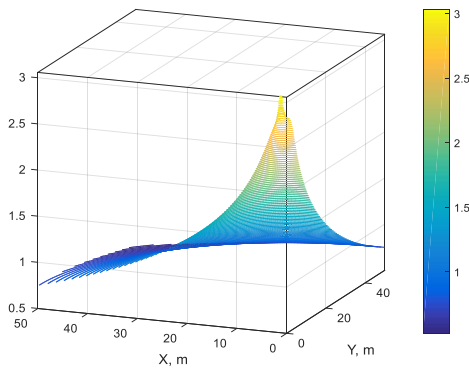


Figure 6. Potential field distribution (side view)

3. Conclusions

This study discusses some advantages of the visualization tools in MATLAB for their use in electromagnetic field theory courses. In teaching of the topic “electrostatic and electromagnetic”, visualization of resulting equations is very beneficial for developing an understanding of field distribution and related phenomenon. In addition, it is also useful to develop analytical thinking skills, and establishing relations between an analytical solution and its meaning in physical world. Due to the user-friendly interface in MATLAB, it provides various ways of visualization, and encourages discussions of the problems in a class environment. It also helps students code and have the results graphically in a short time. To conclude, instructors can prefer teaching Matlab as a programming language, and it can be used in engineering class as a computer-aided analysis and design tool.

Program 1. Visualization of equation (1).

% Visualization of results of equation (1).

```

clc
x=-6:0.1:6; % Define the coordinates
y=-3:0.1:3;
[xx,yy]=meshgrid(x,y)
% Calculate equation (1)
a=((xx-0.5).^2+yy.^2)./((xx+0.5).^2+yy.^2);
b=((xx+2).^2+yy.^2)./((xx-2).^2+yy.^2);
zx=7.9.*(log(a)+log(b));
% Draw the results
contour3(xx,yy,zx,100)
set(gca,'FontName','Arial Unicode MS','FontSize', 10)
xlabel('X, m')
ylabel('Y, m')

```

Program 2. Visualization of equation (2).

% Visualization of results of equation (2).

```

clc
x=0:0.2:50;
% Define the coordinate
y=0:0.2:50;
[xx,yy]=meshgrid(x,y);
r1=sqrt((xx-2).^2+(yy-2).^2);
% Calculate equation (1)
r2=sqrt((xx+2).^2+(yy-2).^2);
% at predetermined points
r3=sqrt((xx-2).^2+(yy+2).^2);
r4=sqrt((xx+2).^2+(yy+2).^2);
zx=-0.18.*log(r1.*r2.*r3.*r4./4.*0.01.^4);
% Draw the results
contour3(xx,yy,zx,100)
set(gca,'FontName','Arial Unicode MS','FontSize', 10);
xlabel('X, m')
ylabel('Y, m')

```

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