A system displaying equipotential lines from electrodes in real time

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Abstract. Electric field is a fundamental quantity that is studied in the secondary and university levels. For the study, an experiment of finding equipotential lines from the charged electrodes is conducted. For the general experiment, the electric potentials are measured at various positions around the electrodes using a voltmeter. The measured data are then manually plotted to a graph to show the equipotential line. This experimental method is time-consuming (more than 1 hour in experiment). It is complicated to study of multiple electrodes using this experiment. Therefore, this research developed an experimental set that can display equipotential lines from various electrodes in real time. The developed experimental set uses a microcontroller (Arduino MEGA) to control a stepper motor to determine measuring positions of electric potential and measure electric potential at various positions around the electrodes (point of charge), automatically. The measured electric potentials and positions were plotted in contour graph to display patterns of the equipotential lines via a computer. The experimental set was tested using 2, 3 and 4 electrodes. The results showed that the developed system was able to display the equipotential lines of the electrodes within 2 minutes. The patterns of the equipotential lines were consistent with the equipotential lines generated from the theory. The correlations of the electric potential values from the experiments and the theoretical simulations for the systems of 2, 3 and 4 electrodes were 0.9452, 0.8691 and 0.9193, respectively. These results demonstrate that the presented experimental set can be used to display the equipotential lines from the electrodes effectively.

1. Introduction
Electric field is a fundamental quantity that is studied in the secondary and university levels. As electric field is nonvisible and electric field meters are not generally used therefore it is not convenient to study electric field directly. Fortunately, there is a relation between the potential difference and electric field as shown in equation (1) i.e.

\[ E = -\frac{dV}{dr} \] (1)

where \( E \) is electric field, \( V \) is electric potential and \( r \) is distance from the charge [1]. Therefore, studying of electric potential is another way to understand electric field since the electric potential can be easily measured by voltmeter. In high school and university lessons, an experiment of determining equipotential lines from the electrodes is usually conducted. For the general experiment, the electric potentials are measured at various positions around the electrodes using a voltmeter. The measured
electric potentials at various positions are then manually plotted to a graph to show the equipotential lines [2, 3, 4]. This experimental method is time-consuming (more than 1 hour in experiment). It is also complicated to study of multiple electrodes using this experiment.

Therefore, this research aimed to develop an experimental set which can display equipotential lines from various electrodes in real time.

2. Research methodology

2.1. Experimental setup and operation

The proposed experimental set for displaying equipotential lines from electrodes was designed to be easy and convenient to operate. It was aimed to be able to automatically measure electric potentials at various positions around electrodes and generate a contour graph of equipotential lines from the electrodes. It consists of a structure part and a controlling part. Its set up is shown in figure 1.

For the structure part, a 30 cm × 30 cm × 10 cm water bath made of acrylic sheets was used to contain electrolyte (water). Metal electrodes were connected to a power source to generate points of charges. The electrodes were placed under the electrolyte in the water bath. Electric potentials from the electrodes were measured by an electric potential sensor unit. This unit consists of 15 sensor pins as shown in figure 1(c). These sensor pins were connected to 15 analog inputs of a microcontroller to read the electric potential compared to the ground (0 volt) at different 15 positions. Each position of sensor pin is 2 cm apart. This electric potential sensor unit was moved over the water bath using a stepper motor and a lead screw in step of 1 cm to measure the electric potentials from the electrodes for the whole area. This electric potential sensors unit could move for 27 steps in this water bath. Therefore, the electric potentials were measured for 15 × 27 positions in this experimental set. A microcontroller (Arduino MEGA) was a main part of controlling part. It was used to control a stepper motor for determining positions where the electric potentials were measured. It was also used to measure electric potentials at various positions around the electrodes. The measured electric potentials and positions were automatically plotted into contour graphs to display patterns of the equipotential lines via a computer program created by the authors. They were automatically transferred from the Arduino program to a plotting program written on Python. The processes of this plotting program have to import Mathplot
library (matplotlib.pyplot) and Multi-dimensional image processing (scipy.ndimage) in order to use the smoothing and contour plotting functions. The raw data of the measured electric potentials and positions were smoothed using Gaussian filter (scipy.ndimage.gaussian_filter) and then plotted into contour graphs using function matplotlib.pyplot.contour.

2.2. Testing of experimental set
The experiment set was tested using different forms of electrodes such as 2, 3 and 4 electrodes. Each electrode was connected to the voltage source (5 volts) or ground (0 volt). The positions of the electrodes for each form are presented in the table 1.

| Number of electrode | Voltage (volts) | Position (x, y) (cm, cm) |
|---------------------|-----------------|-------------------------|
| 2                   |                 | 5, 15 23, 14 - -        |
| 3                   |                 | 4, 16 18, 26 33, 12 - - |
| 4                   |                 | 9, 5 6, 22 19, 24 23, 12 |

The patterns of equipotential lines obtained from the experimental set were compared to patterns of equipotential lines simulated from the theory using PhET interactive simulations created by the University of Colorado Boulder [5]. The electric potential values from this interactive simulation are calculated based on the theory as equation (2) i.e.

\[
V = \frac{Q}{4\pi \varepsilon_0 r}
\]

where \(V\) is electric potential, \(Q\) is electrode charge, \(r\) is distance from the charge and \(\varepsilon_0\) is permittivity of free space. Summation of the electric potential values can be directly done in case of there are more than one electrode. This simulation, users can determine numbers and positions of the charges. The electric potentials caused by the charges can be measured directly in the simulation at any point. In this research, the simulated electric potentials were calculated from the systems of the electrodes in free space while the electric potentials from the experiments were measured in the water. The permittivity of these two media were different causing the electric potentials from the simulation and the experiment were different in values but the patterns of the equipotential lines would be the same. Therefore, the correlation method was used to demonstrate the relation between the patterns of equipotential lines from the experimental set and the theoretical simulation. For the operation, the simulated electric potential values around the electrodes were collected at the same positions where electric potentials were measured in the experiments. The correlations between the patterns of the equipotential lines from the experiments and the simulations were calculated using Microsoft Excel to validate the results from the experimental set.

3. Results and discussion
The experimental results of 2, 3 and 4 electrodes are presented in figures 2, 3 and 4, respectively. The figures 2(a), 3(a) and 4(a) are contour graphs of equipotential line obtained from the developed experimental set. The figures 2(b), 3(b) and 4(b) are graphs of equipotential lines simulated from the PhET interactive simulations.
Figure 2. Contour graphs of equipotential lines of two electrodes obtained from (a) the experimental set and (b) theoretical simulation

Figure 3. Contour graphs of equipotential lines of three electrodes obtained from (a) the experimental set and (b) theoretical simulation

Figure 4. Contour graphs of equipotential lines of four electrodes obtained from (a) the experimental set and (b) theoretical simulation
The results found that the developed experimental set was able to measure electric potentials and display the equipotential lines from the determined electrodes within 2 minutes for each form of the electrodes. From the figures 2-4, they obviously showed that the patterns of the equipotential lines measured from the experimental set were consistent with the equipotential lines generated from the PhET interactive simulation. The patterns were also related to figures of equipotential lines from the theory of electric potentials in textbooks [6-7]. The correlations between the patterns of the electric potential values from the experiments and the simulations were 0.9452, 0.8691 and 0.9193 for the systems of 2, 3 and 4 electrodes, respectively. These correlations showed that the patterns of the electric potentials obtained from the experimental set were significantly according to the patterns of the electric potentials simulated from the theory. The presented results demonstrate that the proposed experimental set can be used to display the equipotential lines from the electrodes in real time effectively.

4. Conclusion
An experimental set for real-time displaying equipotential lines from electrodes were developed in this research. This experimental set automatically measured the electric potentials around the electrodes. It used a stepper motor and a lead screw to move electric potential sensors around the area where the electrodes were set. A microcontroller (Arduino MEGA) was used to control the stepper motor to determine measuring positions of electric potentials and measure electric potentials at various positions. The measured electric potentials and positions were plotted in contour graphs to display patterns of the equipotential lines in real time via the computer. The operation of this experimental set could be processed within 2 minutes for each form of the electrode. The experimental set was tested using 2, 3 and 4 electrodes which each electrode was connected to the voltage source (5volts) or ground (0 volt). The experimental results founded that, the patterns of the equipotential lines obtained from the experimental set were consistent with the equipotential lines generated from the theoretical simulations. The correlations between the electric potential values from the experiments and the simulations of the systems of 2, 3 and 4 electrodes were 0.9452, 0.8691 and 0.9193, respectively. These results showed that the presented experimental set can be used to study the equipotential lines from various form of the electrodes as this experimental set can automatically display the equipotential lines from the electrodes in real time.

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