

Enhancing visualization of magnetic fields in Electromagnetic Fields Course

Dr. Carl Iolani Pettiford, Liberty University

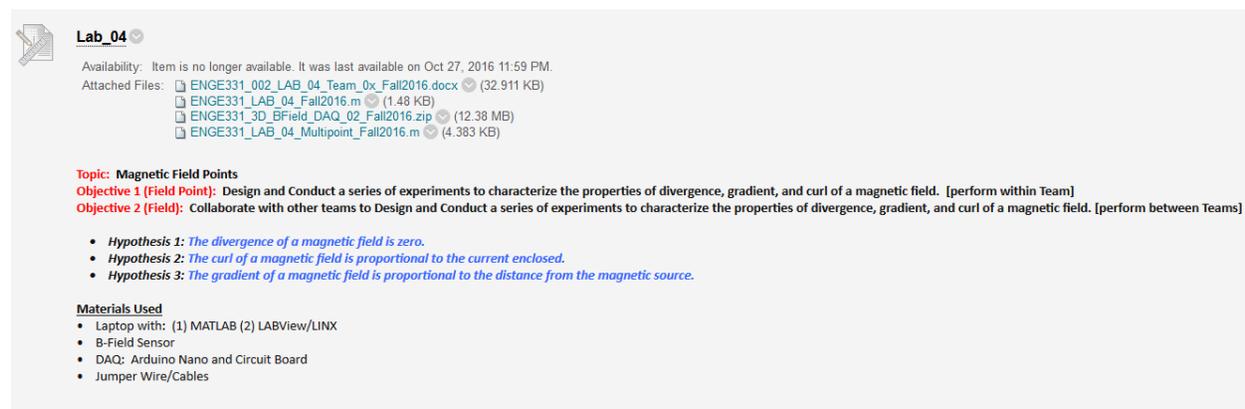
Dr. Carl Pettiford is the Chair of the Engineering Department at Liberty University. He received his B.S. in Electrical Engineering from the University of Hawaii, M.S. in Electrical Engineering from the University of Dayton, and Ph.D. in Electrical Engineering from Northeastern University. Dr. Pettiford is a senior member of IEEE.

**Enhancing Visualization of Magnetic Fields
in Electromagnetic Fields Course**

This paper describes the motivation for -- and implementation of -- a real-time, streaming, 3D map of field points used to explain the concept of a vector field in electromagnetics. The purpose of this paper is to share my experience in developing a tool to visualize streaming magnetic field data. It is my hope that readers will find this useful or inspiring in their own course development.

Students in my Electromagnetic Fields course have had difficulty grasping the concept of a mathematical vector field in relation to the electromagnetic (EM) phenomena it was being applied to. There have been many studies on assessing student learning styles such as the VARK test¹. Some of our students are visual learners and struggle with visualizing the mathematics of dynamic fields without some form of scaffolding to aid them, while others prefer to learn kinesthetically by doing hands-on practical examples. A lab was designed to enable students to visualize a mathematical vector field in real-time as well as post-processing (replay the event) for analysis and reflection. The combination of hands-on (kinesthetic), documentation (read/write), collaborative (auditory discussion), and visual results in a single lab is intended to benefit students with different learning styles. This serves to reinforce student understanding of the mathematics of vector fields in electromagnetics.

The EM Fields course is 4 credit hours and generally held in an electrical and computer engineering teaching lab. Students are grouped into teams of 2 students per lab. Lab partners are randomly assigned for each lab. Labs must be completed and submitted by the end of class. Lab reports are submitted via Blackboard (Bb). Students use a generic template to complete each written lab report. A list of materials and equipment and a set of objectives (which include at least one hypothesis) is provided. Students are instructed on how to use the equipment prior to the lab. The objective is for the students to design their own experiments within the given constraints based on a problem-solving approach². These constraints are as follows: (1) Students must utilize the supplied lab equipment and materials issued by the instructor. (2) Lab experiments must be designed and completed within the class period. (3) Lab reports must be completed using the course lab report template. (4) Lab reports must be completed by a set deadline (typically by the end of the class period on the day of the lab). Figure 1 shows the lab assignment that students see on Bb.



The screenshot shows a Blackboard interface for a lab assignment titled "Lab_04". It includes an availability notice, a list of attached files, a topic, objectives, hypotheses, and materials used.

Lab_04

Availability: Item is no longer available. It was last available on Oct 27, 2016 11:59 PM.

Attached Files:

- ENGE331_002_LAB_04_Team_0x_Fall2016.docx (32.911 KB)
- ENGE331_LAB_04_Fall2016.m (1.48 KB)
- ENGE331_3D_BField_DAO_02_Fall2016.zip (12.38 MB)
- ENGE331_LAB_04_Multipoint_Fall2016.m (4.383 KB)

Topic: Magnetic Field Points

Objective 1 (Field Point): Design and Conduct a series of experiments to characterize the properties of divergence, gradient, and curl of a magnetic field. [perform within Team]

Objective 2 (Field): Collaborate with other teams to Design and Conduct a series of experiments to characterize the properties of divergence, gradient, and curl of a magnetic field. [perform between Teams]

- Hypothesis 1:** The divergence of a magnetic field is zero.
- Hypothesis 2:** The curl of a magnetic field is proportional to the current enclosed.
- Hypothesis 3:** The gradient of a magnetic field is proportional to the distance from the magnetic source.

Materials Used

- Laptop with: (1) MATLAB (2) LABView/LINX
- B-Field Sensor
- DAQ: Arduino Nano and Circuit Board
- Jumper Wire/Cables

Figure 1: Student Lab assignment as viewed on Bb.

To design a lab that will satisfy these lab constraints, both the software and hardware tools had to be relatively easy to use and the experiments relatively quick to perform. LABVIEW with LINX add-on was chosen to serve as the control software for real-time data acquisition, while MATLAB was selected to perform an additional post-processing data analysis step. Both LABVIEW and MATLAB are pre-installed on student-owned laptop computers. Arduino Nano v3.0 was selected to serve as the primary data-acquisition hardware. The Nano is controlled via USB using the LINX add-on. Streaming-vector field data was extracted from a 3D magnetic field sensor that was through-hole mounted to an in-house designed and fabricated printed circuit board, capable of being easily mounted to a 2"x3" breadboard. The hardware interface is shown in Figure 2. The software application used for real-time data processing is a LABVIEW executable file that was created specifically for this lab (see Figure 3). The executable has the capability to store the streaming data for post-analysis. The software application for post-analysis of the vector field data is a MATLAB m-file created specifically for this lab. The combination of the two software applications allows the student teams to observe the behavior of a vector field point in real-time while measuring the magnetic field, or through replay during post-analysis. The multipoint hardware setup is shown in Figure 4.

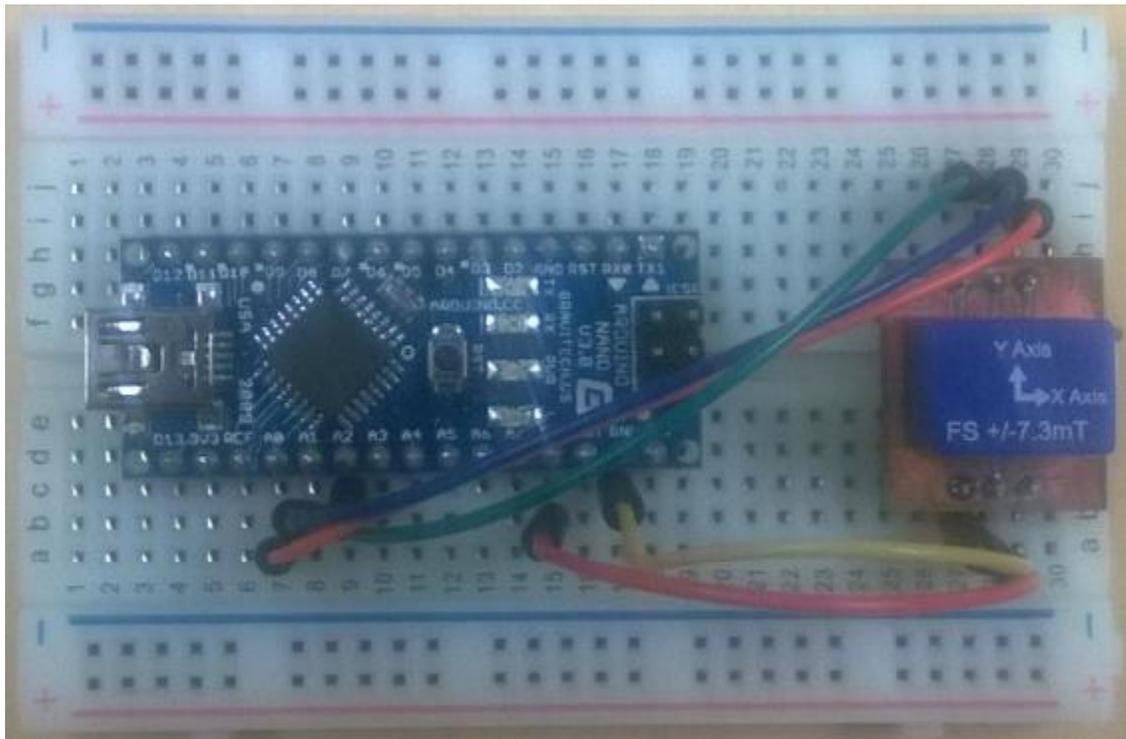


Figure 2: Hardware interface used for magnetic sensor data acquisition (USB connection to student laptop, not shown).

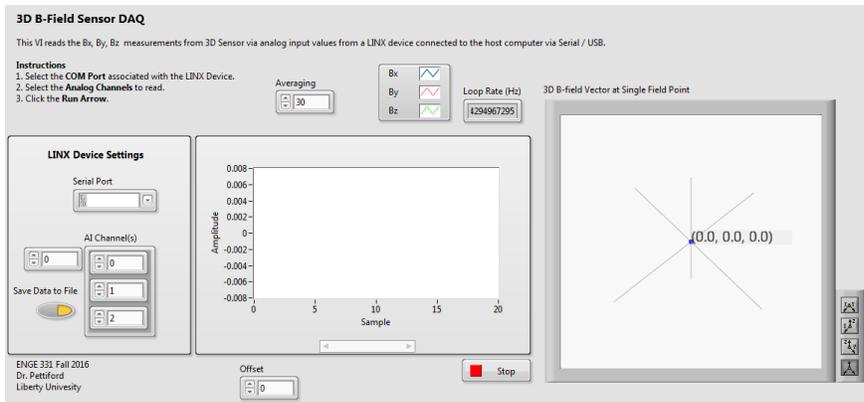


Figure 3: LABVIEW software interface for real-time sensing.

The lab tool also enables student teams to combine instruments to form a multi-point vector field array and collectively visualize the field points in unison. This enables teams to collaborate with other teams to design and conduct a series of experiments to characterize the properties of divergence, gradient, and curl of a magnetic field using multiple sensors. Each team collected readings from their own sensor unit as the magnetic source was moved about the space between the sensors. The data collected from each team was distributed so that all teams had a copy of the combined data set. A MATLAB program was used for post-processing the multipoint data so that the combined results from all the sensors could be viewed for analysis, as shown in Figure 5.

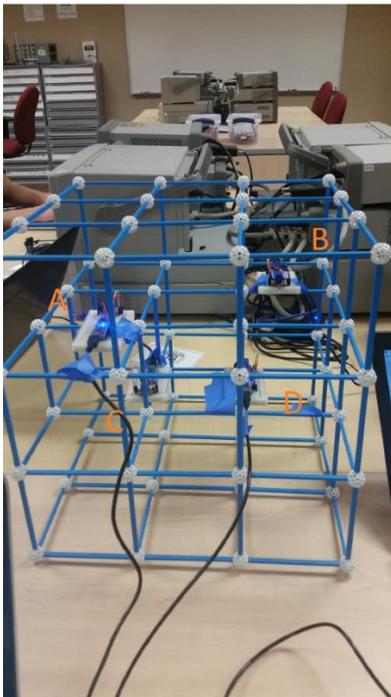


Figure 4: Student Lab Team photo of Hardware Sensor configuration for Multipoint Experiment (Sensors located at positions A, B, C, and D).

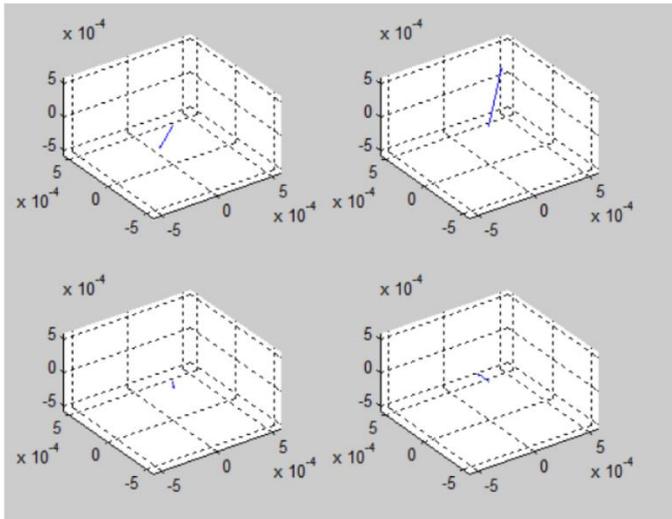


Figure 5: MATLAB software interface for Multipoint post-analysis.

The effectiveness of the lab tool was assessed from the student lab reports. Students are required to use a Lab Report template (shown in Figure 6) that requires them, for each given hypothesis, to address the following areas: Results, Experimental (Procedures), Analysis of Results, and Conclusions.

LAB 04 REPORT

PROJECT SUMMARY

REPORT DATE: September 29, 2016 LAB NAME: ENGE331_LAB_04 PREPARED BY: Team 01

RESULTS:

Describe the measured data that appears in the data tables or charts you provide:

Include all Charts, Graphs, and/or Tables of all your experiments **in this section**, and label each appropriately so they may be referenced in the other sections of this report.

Note: There should only be one **Results** section (i.e. do not create one for each experiment).

EXPERIMENTAL:

Experiment 01 (E01):

Describe the experimental setup of E01 and the test runs performed: How was the data collected? Who collected the data? Why was the data collected? What data was collected?

Experiment 02 (E02):

Describe the experimental setup of E02 and the test runs performed: How was the data collected? Who collected the data? Why was the data collected? What data was collected?

etc ...

Note: There should only be one **Experimental** section (i.e. do not create one for each experiment).

ANALYSIS OF RESULTS:

Describe the analysis methods and procedures used: How was the data analyzed? Who analyzed the data? Why the data was analyzed this way? What results did the analysis produce?

Note: There should only be one **Analysis of Results** section (i.e. do not create one for each experiment).

CONCLUSIONS:

Compare and contrast your results with expected outcomes: How did the results compare with expected outcomes? Who made these conclusions? Why did you make these conclusions? What conclusions can you make regarding your results?

Note: There should only be one **Conclusions** section (i.e. do not create one for each experiment).

DELIVERABLES:

Submit completed lab before end of class:

- Complete and submit lab worksheet to instructor
- Save lab report to a file as
 - "ENGE331_002_LAB_04_Team01_Fall2016.pdf"
 - example:
 - "ENGE331_002_LAB_04_Team_03_Fall2016.pdf"
- Assign one team member to complete and submit lab report to instructor via Bb.

End of document ■

Figure 6: Lab Report Template used by students.

Experimental (Procedures), Analysis of Results, and Conclusions reported by the lab teams were used to assess how well the lab tool enhanced student comprehension of the concepts of divergence, gradient, and curl of a magnetic field. Each concept was expressed as a hypothesis: *Hypothesis 1: The divergence of a magnetic field is zero. Hypothesis 2: The curl of a magnetic field is proportional to the current enclosed. Hypothesis 3: The gradient of a magnetic field is proportional to the distance from the magnetic source.* Each of the three sections of the report were ranked based on level of understanding: (1) Developing, (2) Competent, (3) Sophisticated. If the section demonstrated a high level of rigor and understanding that could be clearly traced to the hypothesis, then the lab report was ranked "3". If the section demonstrated a moderate level of rigor and understanding that could be traced to hypothesis, then the lab report was ranked "2". If the section demonstrated a low level of rigor, understanding, or lack of traceability to hypothesis, then the lab report was ranked "1". The results are shown in the Table 1.

Table 1: Results of Lab Report Analysis.

Team#	Lab Report Section	Hypothesis 1 (Divergence)	Hypothesis 2 (Curl)	Hypothesis 3 (Gradient)
1	Experimental Procedure	3	3	3
1	Analysis of Results	1	1	2
1	Conclusions	1	2	2
2	Experimental Procedure	2	2	3
2	Analysis of Results	2	2	2
2	Conclusions	2	2	2
3	Experimental Procedure	3	3	3
3	Analysis of Results	2	2	3
3	Conclusions	1	1	2
4	Experimental Procedure	2	2	2
4	Analysis of Results	2	2	2
4	Conclusions	2	2	2
	Average Score:	1.92	2.00	2.33

Analysis: The results in Table 1 indicate that students had a better understanding of the concept of gradient and how to develop an experiment to prove or disprove the hypothesis, than they did the concepts of divergence and curl for the single point experiment. Although the lab reports indicated the students understood there was a connection between the motion of the magnetic source and the response from the sensors in the single sensor experiment, there was no clear indication from the lab reports that the students saw a connection between the position of the magnetic source and the vector values measured from the sensors in the multipoint experiment.

Conclusion: The objective to design a lab that will satisfy the lab constraints, specified in this paper, have been achieved. Both the software and hardware tools had to be relatively easy to use, and the experiments relatively quick to perform. The single field-point sensor tool was relatively easy to use. The students picked up on how to use the tool during the lab session rather quickly, and did not require a lot of direction on how to combine the sensors for the multipoint experiment. The objective of designing a lab to enable students to visualize a mathematical vector field in real-time, as well as post-processing (replay the event) for analysis and reflection, was achieved. The multipoint experiment, however, required extra time to post-process the data for combined analysis. The effectiveness of the lab in helping students better understand the mathematical vector field concepts of divergence, curl, and gradient was assessed through student lab reports. This assessment indicates that the students had a better understanding of the concept of gradient, than they did curl and divergence. The combined multipoint experiment was designed to analyze the effect of the magnetic source on multiple points simultaneously, and thus provide a better visualization of spatial properties of the magnetic field (specifically divergence and curl) than the single point experiments. However, the multipoint experiment did not appear to be as effective as the single point experiments. The author concludes that this was due to the gap between the when the measurements were performed and when the visual results were processed for the multipoint experiment, compared to the single point experiments. The gap for the multipoint experiment was a few hours or more between teams, whereas the gap for the single point experiments was within a minute or two. This lack of real-time feedback for the multipoint experiment appears to have made it difficult for students to conceptualize the relationship between cause (the magnetic source), and effect

(the simultaneously measured response at each sensor location). To address this issue in future labs, an improved multipoint measurement lab tool was created to process the data in near real-time in LABVIEW, and post-process the data in MATLAB within minutes of performing the measurement. This tool was designed to simultaneously collect data from four sensors. Each sensor is connected via USB cable to a 4-port USB hub driven by a laptop computer. The LABVIEW interface displays the vector of each sensor in real-time. This tool will be utilized by students the next time the Electromagnetic Fields course is offered. The author plans to have this lab repeated with the improved tool to assess the next class of students and determine if the lab improves their level of understanding over this recent class using multiple assessment tools (such as pre and post lab student surveys), and to test the hypothesis that reducing the gap between data collection and analysis for the multipoint experiment will improve student understanding of divergence, curl, and gradient as reflected in the student lab reports.

References

- [1] I. W. Wait, A. P. Nichols and W. A. Zatar, "Comparison of Learning Styles for International and Domestic Undergraduate Engineering Students," in *2011 ASEE Annual Conference & Exposition*, Vancouver, BC, 2011.
- [2] C. Ciocanel and M. Elahinia, "Teaching Engineering Laboratories Based On A Problem Solving Approach," in *Proceedings of the 2008 ASEE Pacific Southwest Annual Conference*, 2008.