

outside the cylinder the value of the magnetic field is expressed by Eq. (2). Thus, only the external poles of the magnets are in a magnetic field, the lines of which have the shape of concentric circles. The magnetic fields produces a torque that acts on these poles, thus rotating the rotor. As was the case for the models described previously, the direction of the rotor rotation can be reversed by reversing the current flow direction or by reversing the poles of both magnets.

## V. A UNIPOLAR MOTOR WITH A CLOSED CYLINDER AND A ROD

This motor as shown in Fig. 4 is characterized by magnets arranged parallel to the rotation axis and is constructed similarly to the motor described in the previous part of the paper. A difference is that brass rod (10) ends with a conical cavity, which constitutes the upper bearing of the rotor, and is fixed in the top cover of the cylinder. Both magnets (1) were placed into holes in the top cylinder cover and like poles were turned to the same side.

When explaining the operation principle of this motor it should be remembered that according to Ampere's law the

electric current flowing along the walls of the cylinder does not produce a magnetic field inside the cylinder. The lower poles of the magnets are not located, therefore, in the magnetic field. However, the upper poles of the magnets are located in the magnetic field produced by the electric current flowing through the rod and the cylinder. The spatial distribution of this magnetic field is similar to that of the field produced by a long rectilinear conductor with the current. Thus, the upper poles of the magnets experience a torque causing rotation of the rotor.

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<sup>1</sup>A. Isaacs, *A Dictionary of Physics* (Oxford U.P., Oxford, 1996), p. 235.

<sup>2</sup>E. M. Purcell, *Electricity and Magnetism*, Berkeley Physics Course Vol. 2 (McGraw-Hill, New York, 1965), p. 415.

<sup>3</sup>R. M. Sutton, *Demonstration Experiments in Physics* (McGraw-Hill, New York, 1938), p. 306.

<sup>4</sup>R. P. Feynman, R. B. Leighton, and M. Sand, *The Feynman Lectures on Physics* (Addison-Wesley, Reading, MA, 1963), p. 224.

<sup>5</sup>D. Halliday and R. Resnick, *Physics for Students of Science and Engineering* (Wiley, New York, 1963), p. 300.

## Simple Internet data collection for physics laboratories

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We present a surprisingly simple yet flexible method for remote data collection over the Internet. The method requires minimal development effort, has considerable hardware and software independence, and is essentially free. The basic approach is to convert a scientific measurement instrument into an Internet device to give remote computers access to the instrument. The method is compatible with most programming languages and software applications that have Internet access. It can be used with many serial port measurement instruments and allows different computers, operating systems, and instruments to be intermixed when collecting data. We give three examples of how the method has been used to enhance the undergraduate physics laboratory experience.

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### I. INTRODUCTION

Remote data collection applications range widely in cost, time, and the skills required, from high profile science such as the Hubble space telescope to more commonplace student projects. Given the low cost and wide availability of computers with Internet access and data measurement hardware, remote data collection should be simple, inexpensive, and adaptable.

What do we mean by remote data collection over the Internet? The method discussed here allows an inexpensive measurement instrument to be used as though it were an Internet device. A computer on the Internet can then collect data from the instrument as though the computer and instrument were directly connected. In the following we discuss the method in detail and give three examples of its use in an undergraduate physics laboratory setting.

### II. METHOD

What hardware and software are needed in this approach? The necessary hardware is often already available in settings where computers perform data collection and an Internet connection exists. Remote data collection hardware consists of two computers and one measurement instrument as illustrated in Fig. 1. One computer acts as a communication server to connect the instrument to the Internet. This computer is directly connected to the measurement instrument through the computer serial port and to the Internet. A second data collection computer can then access the instrument over the Internet through the communication server. The method also supports local data collection by using only one computer to act as both the communication server and the data collector. The measurement instrument can be a serial device such as those from PASCO, Pico Technology, or Vernier Software.<sup>1-3</sup>

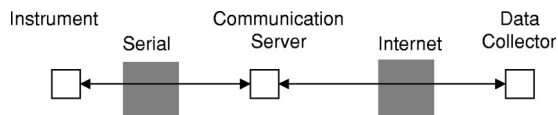


Fig. 1. A software and hardware configuration used for remote data collection over the Internet.

The two software components required are the communication server and the data collection programs. The server program merely passes communications transparently between the Internet and serial port. Numerous Internet to serial port communication servers are available for different computer platforms (e.g., Mac, Windows, and Linux) as shareware or as freeware from the authors.<sup>4</sup> The data collection program is specific to each type of measurement instrument and typically controls the instrument by sending out the normal instrument commands and receiving data in return. As an example, the command “s{0}” is sent by the data collection program to reset a Vernier LabPro<sup>3</sup> instrument. Collection programs can be implemented in any language with Internet access including Java, Perl, Visual Basic, or applications such as Excel and MathLab. A simple strip chart can be implemented using an Excel chart and a few lines of Visual Basic code to control the measurement instrument.

### III. MOTIVATION

How is this better than other remote data collection solutions? One advantage is the low cost. The communication server software is free, nearly any computer can be used, and serial port instrumentation is relatively inexpensive. Hardware and software operation is simple and the learning curve is gentle compared to other approaches.

Alternative methods include the Common Gateway Interface (CGI) or one of several competing protocols such as Sun’s Jini, Microsoft’s UPnP, or National Instruments’ DataSocket. The CGI approach requires programming and administration of a Web server. Using one of the protocols may require learning a new programming language or learning a complex programming interface that is limited to proprietary hardware. These approaches, such as a Web server running a CGI program to control an experiment, may need at least a virtual visit to the controlling computer over the course of an experiment. The method described here instead places full

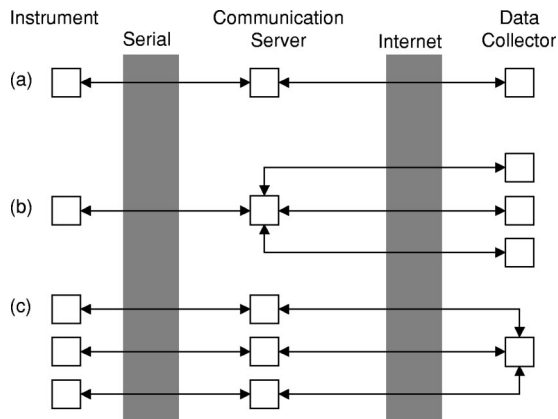


Fig. 2. Three examples of data collection topologies: (a) one instrument and one collector, (b) one instrument and multiple collectors, and (c) multiple instruments and one collector.

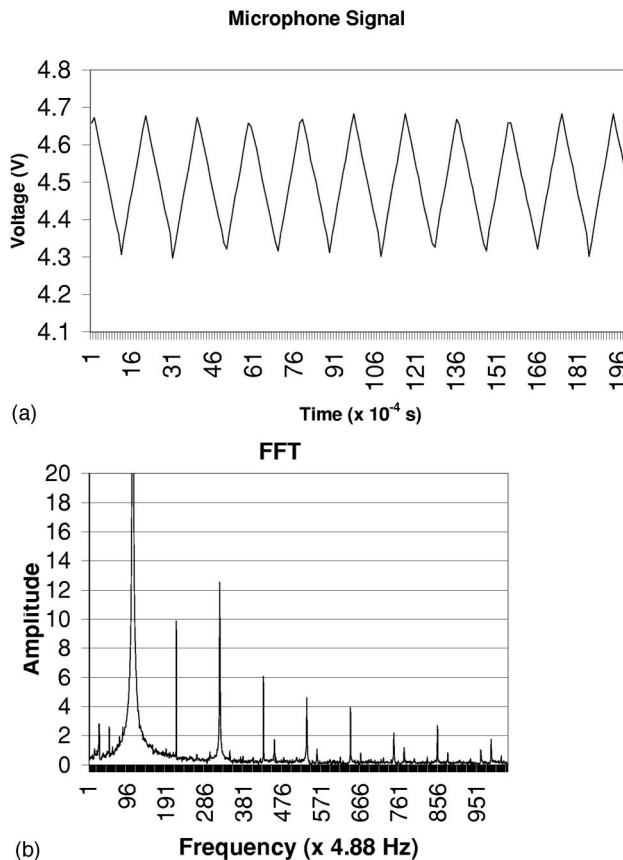


Fig. 3. In addition to known sound samples students also analyze an unknown signal, in this case a saw tooth wave (a). The spreadsheet Fourier transform function was used to create the FFT graph (b).

control of the experiment at the data collection computer. The implication is significant in that separate data collection computers can independently control the same measurement instrument for different experiments.

The fact that the communication server transparently transforms a serial measurement instrument into an Internet device is the key advantage to this method. Using the standardized Internet protocols any vendor’s serial instrument can then be accessed over a network with any computer hardware or operating system. One can intermix Mac’s with PCs running under the Windows or Linux operating system for either the communication server or the data collector computer. In addition the data collection software is typically simpler to write and more portable across different computer systems for an Internet device than for a serial port device. An instructional laboratory with mixed computers can often use the same Perl script or Excel macro for an Internet device in contrast to serial port interface code constrained to a specific operating system and computer. Debugging a remote instrument is also enhanced since a telnet session can communicate directly with the instrument.

A final benefit is the possibility of sharing experimental data as illustrated in Fig. 2. Several collection computers can simultaneously share data from a single remote instrument or several remote instruments can be controlled from one collection computer. Collection of data simultaneously from multiple remote instruments by multiple collection comput-

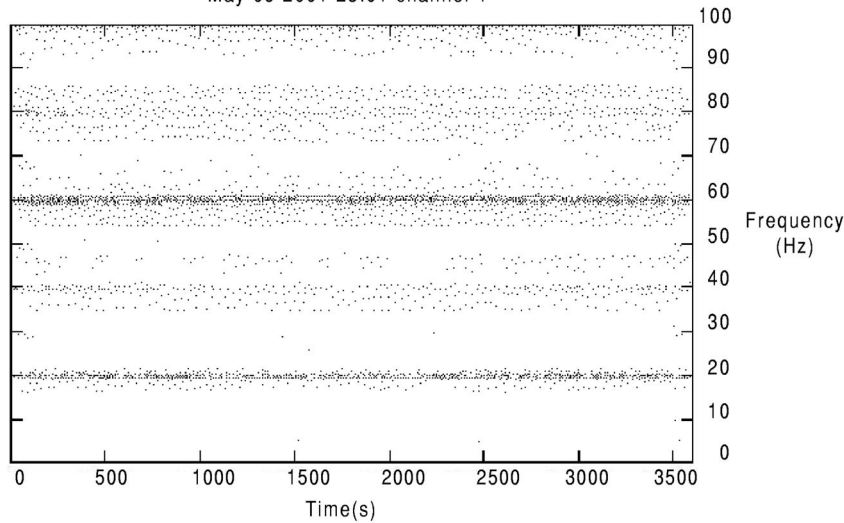


Fig. 4. A frequency versus time analysis using a Grossman–Morlet wavelet transform of very low frequency electromagnetic signals. The data represented here is collected continuously through the Internet from a remote antenna site. Several manmade signals are clearly seen including the 60 Hz power grid signal. Naturally occurring signals are not seen in this relatively short time sample.

ers is also possible. This offers the potential for collaboration among researchers sharing geographically separated instrumentation.

#### IV. APPLICATIONS IN THE PHYSICS CLASSROOM

What are some examples of use? Our original motivation for developing this remote data collection method was to support open laboratories in which students could perform experiments at school or home by accessing laboratory equipment on campus. For one experiment students determine the transmission rate and organization of a digital communications signal generated at the campus. Students employ a Java applet oscilloscope in a Web browser to analyze the signal in place of an oscilloscope on a lab bench. Because the Java applet is easily included with the laboratory instructions on a Web page, the laboratory assignment is particularly convenient for students to access and for instructors to develop and maintain. The laboratory equipment consists of a digital signal source, a serial port version of an analog to digital converter and a communication server computer. Students can use a laboratory computer or their own computer for data collection and analysis of the communications signal. Because the laboratory equipment is available to students anytime and anywhere, a single equipment setup is sufficient for the class.

A second example is from an introductory physics laboratory exercise where the fast Fourier transform (FFT) of a sound sample is examined. The experiment is conducted in a traditional laboratory course setting where the instructor, students and equipment are all at the same location at a scheduled time. Each laboratory station consists of a single computer that acts as communication server and data collector, an analog to digital converter with an attached microphone, and several musical sound sources. An Excel spreadsheet with a small Visual Basic macro is provided to collect data, perform the FFT, and graph the results. In addition to known musical sounds made by the students an unknown sound source located in a remote room is provided for students to analyze. Students can collect the unknown sound data by changing a cell in the spreadsheet from the Internet address of their laboratory computer to the address of the remote source.<sup>5</sup> Determining the frequency of the unknown sound

requires students to experiment with the measurement instrument sample rate and the number of data points collected. As part of the laboratory report students must explain the accuracy and error inherent in the measurements. This requires an understanding of measurement instrument limitations, experimental design, and the tools used to analyze the data. The familiar spreadsheet model provides the students with data collection and analysis tools that support the necessary experimental inquiry. The unknown sound source data graph and the FFT graph from the Excel spreadsheet are shown in Fig. 3.

In a third project junior level physics laboratory classes operate a listening post for electromagnetic signals in the ULF range (i.e., under 100 Hz) using three coil antennas.<sup>6,7</sup> To avoid unwanted electrical activity the antennas are buried in an open field at the edge of the campus making on-site data collection less than convenient. For safety reasons student access to the remote equipment is limited to occasional maintenance visits with faculty. These factors combine to make remote data collection an essential feature of the project. The project equipment consists of an analog to digital converter connected to the three antennas, one communication server computer, and several data collector computers. The analog to digital converter is connected through two short haul modems and by a long length of buried phone wire to the communication server running on an old Linux computer located in a corner of a university maintenance building loading dock. Data collection and analysis can be done on campus or at the student's home over the Internet. Continuous data collection has been achieved for periods of up to 2 weeks.<sup>8</sup> A wavelet analysis of 1 hour of data is given in Fig. 4.

#### V. CONCLUSION

A potential pitfall of many undergraduate science research projects or laboratory exercises is that complex data collection and analysis tools can encourage students to lose sight of the research purpose. Issues of cost and complexity can make some laboratory exercises unattractive to instructors as well. The three examples above illustrate a simple yet flexible approach in which students can concentrate on the physics of the experiment rather than struggling with complex

instrumentation. The familiar spreadsheet presents the student with a simple data collection and analysis package that they can readily master. In the ULF project multiple students can collect and analyze data from the same measurement instrument at the same time even as long-term data collection to an archival computer is ongoing. This flexibility allows students to explore, test, and develop their understanding of the research project and its requisite methodology. Because the method is simple and can be used across different platforms, time and cost investment for development is also minimized.

<sup>1</sup>PASCO Scientific, 10101 Foothills Blvd., Roseville, CA 95678-9011.

<sup>2</sup>Pico Technology Limited, The Mill House, Cambridge Street, St. Neots, Cambridgeshire PE19 1QB, United Kingdom.

<sup>3</sup>Vernier Software, 13979 SW Millikan Way, Beaverton, OR 97005-2886.

<sup>4</sup>Sample software including the communication server which passes Inter-

net TCP/IP protocol to the serial port and an Excel spreadsheet with a VB macro to control a LabPro can be downloaded from <http://Physics.ius.edu/~kyle/K/DataCollect/LabPro.html>

<sup>5</sup>Lab procedures for this experiment can be viewed at <http://Physics.ius.edu/~kyle/P222/FFTlab.html>

<sup>6</sup>This project was based on a suggestion by Shawn Carlson; *The Amateur Scientist* [Sci. Am. (1996), p. 98].

<sup>7</sup>Naturally occurring low frequency electromagnetic radiation is known to originate at 8 Hz (and multiples) as resonance (the so-called Schumann resonance) in the earth-ionosphere cavity due to global thunderstorm activity. There may also be other electromagnetic signals occurring in this frequency range as indicators of other natural events. For example, there is a possibility that earthquakes may give off signals in the range below 4 Hz. [See George Stavrakakis and the reply by Panayiotis Varotsos, Nicholas Sarlis, and Mary Lazaridou in *Phys. Today* **51**, 15 (1998) for additional references.]

<sup>8</sup>Continuous data streaming as well as archived data will become available at a future date at [http://Physics.ius.edu/~ELF/VLF\\_ULF.html](http://Physics.ius.edu/~ELF/VLF_ULF.html)