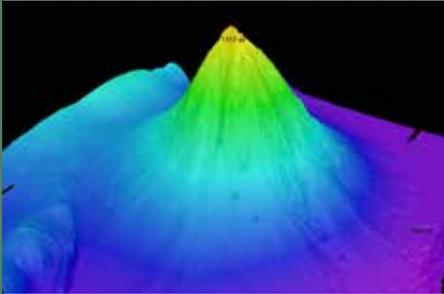## Additional Technology Activities

Okeanos Explorer's EM302 multibeam sonar mapping system produced this detailed image of the Kawio Barat seamount, which rises around 3800 meters from the seafloor. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/june26fig1_hires.jpg

Multibeam Mapping

This activity gives students first-hand experience with using sound waves to measure distance, as well as an opportunity to learn problem-solving approaches and apply processes of engineering design.

For additional information see the Telepresence section of *The Okeanos Explorer Education Materials Collection, Volume 2: How Do We Explore?* starting on page 49 (*http://oceanexplorer.noaa.gov/okeanos/edu/collection/media/hdwe-MMBkgnd.pdf*).

Multibeam Mapping: PING)))™ Sonar Simulation

Background

This activity uses ultrasonic sound waves to measure distance (this kind of measurement is known as "ranging"). "Ultrasonic" means that the frequency of the sound waves is higher than the range of normal human hearing (about 20 - 20,000 Hz). The PING)))™ sensor (Figure 1) uses ultrasonic sound waves whose frequency is 40 kHz. The sensor consists of an ultrasonic microphone, an ultrasonic speaker, and electronic circuits that
- Generate an ultrasonic pulse ("chirp"); and
- Communicate with a microcontroller.

In addition to the sensor, a typical ultrasonic ranging system includes a microcontroller that tells the sensor when to make a measurement and receives measurement data from the sensor, and a computer or calculator where the data can be displayed, stored, and analyzed.

To measure the distance between the PING)))™ sensor and another object, the microcontroller sends a signal that tells the sensor to chirp. The sensor chirps its 40 kHz pulse, and sends a signal to the microcontroller. When the sensor receives an echo with its ultrasonic microphone, it sends another signal to the microcontroller. The microcontroller measures the time between the first signal and second signal from the PING)))™ sensor, and sends this information to a computer.
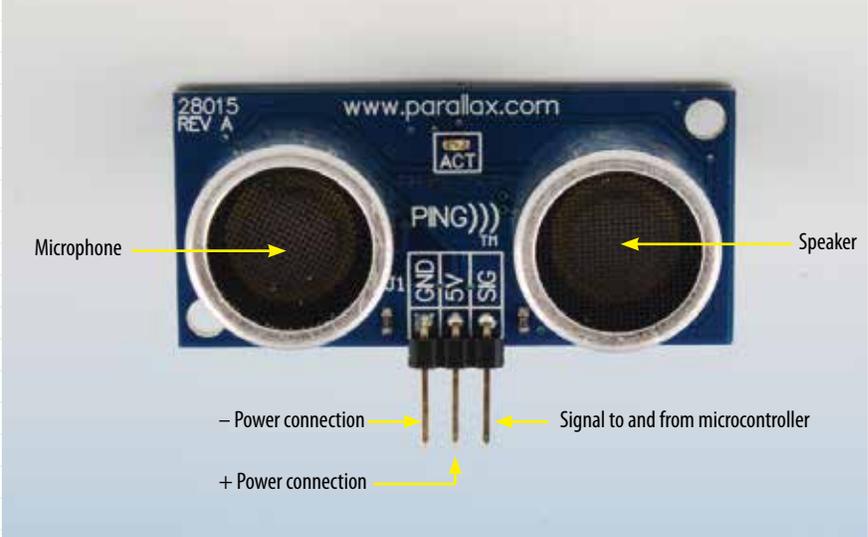
Materials
Option 1 –
- 1- PING)))™ Ultrasonic Distance Sensor
- 1 - Arduino microcontroller with a prototyping board (also called a Proto Shield)
- 1 - Computer with a USB port

Figure 1. The PING)))™ sensor

Microphone

Speaker

− Power connection

Signal to and from microcontroller

+ Power connection

Option 2 –
- 1- PING)))™ Ultrasonic Distance Sensor
- 1 - BASIC Stamp microcontroller with a prototyping board (such as Parallax Board of Education)
- 1 - Computer with a USB port

Option 3 –
- 1 - Lego® NXT Ultrasonic Sensor
- 1 - Lego® NXT Brick microcontroller
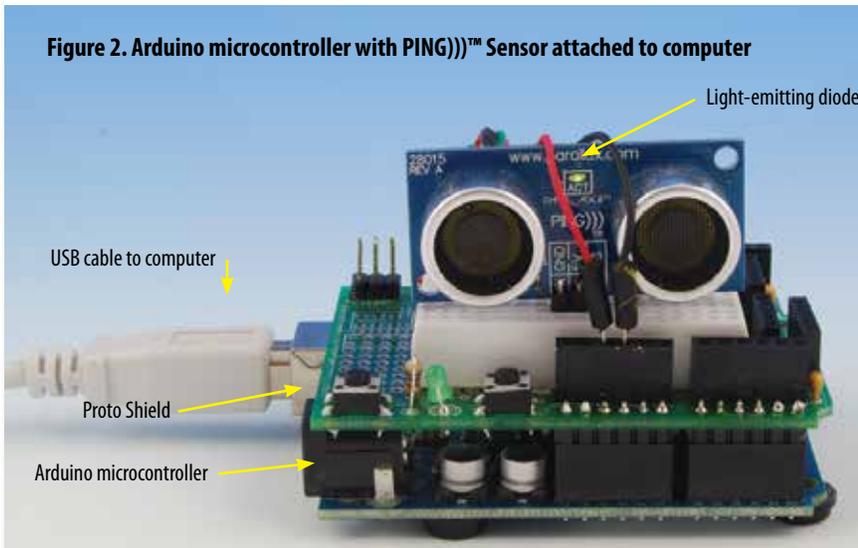- 1 - Computer with a USB port

Option 4 –
- 1 - Vernier Motion Detector
- 1 - LabQuest® or CBL 2® interface
- 1 - Computer or calculator compatible with the interface

Learning Procedure

1. To get started, be sure you know the answers to the following questions:
   a. "SONAR" is an acronym. What does it mean?
   b. What are the basic components of a sonar system?
   c. Why are transducers sometimes contained in a "towfish" that is towed behind a survey vessel?
   d. What are the advantages and disadvantages of high frequency (500 kHz and up) sonar signals compared to lower frequency (50 kHz or 100 kHz) signals?
   e. What is the difference between multibeam sonar and other types of sonar?

2. Now, set up your ultrasonic ranging system.
   - If you are using a PING)))™ sensor, connect the sensor to a microcontroller (such as Arduino, or Parallax BASIC Stamp®), and connect the microcontroller to your computer (with a USB cable or wireless connection).
   - If you are using a Lego® NXT Ultrasonic Sensor, connect the sensor to an NXT brick microcontroller, and connect the microcontroller to your computer (with a USB cable or wireless connection).
   - If you are using a Vernier Motion Detector with a LabQuest® or CBL 2® interface, connect the motion detector to the interface, and connect the interface to your computer or calculator.

Additional Technology Activities
Multibeam Mapping

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3. Load a program to run the ultrasonic sensor/microcontroller system you are using (some sources for appropriate programs are listed below). Set up the program to measure distance according to instructions in the documentation for the specific program you are using. Make a few test measurements to confirm that your system is working and providing acceptable measurements. Figure 2 shows a PING)))™ sensor attached to an Arduino microcontroller, making distance measurements (the small green light-emitting diode in the middle of the sensor flashes whenever a measurement is made; the program loaded into the microcontroller in Figure 2 causes measurements to be made about ten times per second).

Figure 2. Arduino microcontroller with PING)))™ Sensor attached to computer

Light-emitting diode

USB cable to computer

Proto Shield

Arduino microcontroller

When using a particular sensor/microcontroller system for the first time, it is always a good idea to check the accuracy of the system by obtaining several measurements of an object at known distances, and comparing the measurements with the actual distances. Graphing the results of several tests can give you a good idea about the accuracy and limits of your system.

4. You may want to try one or more of the activities provided with the program for operating your microcontroller to become more familiar with your ultrasonic ranging system.

Test Your Engineering Design Skills

Engineering Design is a process that engineers use to create solutions to problems. There are many versions of the process, but the basic steps are as follows.

- Define the problem.
- Gather relevant information.
- Brainstorm possible solutions.
- Analyze possible solutions and select the most promising.
- Test the solution.

Depending upon the results of the last step, the entire process may be repeated one or more times to improve the solution until the results are satisfactory. Sometimes, you may have to go back to a previous step because the selected solution doesn't work.

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oceanexplorer.noaa.gov   **Multibeam Mapping**

The Challenge: Your ultrasonic ranging system is capable of making distance measurements over a range of about 3 cm to 250 cm. Suppose you want to make a 3-D surface plot (as in the *Mapping the Deep-ocean Floor* lesson) of the floor of a small, dry lake, roughly 12 ft in diameter, and 2 m deep at its deepest point. You can stand on the edge of the lake around its entire perimeter, but you cannot actually walk on the lake floor because your footsteps would alter the topography of the soft mud. Your challenge is to design a way to use your ultrasonic ranging system to obtain enough data points to make a 3-D surface plot that will show features that are 6 inches in diameter or larger.

Use the Engineering Design Process to develop a workable solution for this challenge. Document your solution in writing, showing how you used the Engineering Design Process to arrive at your solution.

Engineering Design Process

The Engineering Design Process is a series of steps that engineers use to create solutions to problems. There are many versions of the Process, but the basic steps include:
- Define the problem
- Gather relevant information
- Brainstorm possible solutions
- Analyze possible solutions and select the most promising
- Test the solution by building a prototype
- Revise and improve the solution
- Repeat previous steps until results are acceptable
- Report the design process and results

These steps involve several key skills:
- Obtaining, evaluating, and communicating information;
- Analyzing and interpreting data;
- Using mathematics, information and computer technology, and computational thinking; and
- Using evidence to discuss the strengths and weaknesses of ideas and designs.

Most problems will include certain constraints that may relate to cost, size, environmental conditions, or other specific requirements. Some constraints may be identified in the statement of the problem, but most problems need additional analysis to be certain that all constraints are understood. Often, constraints will force designers to make trade-offs in their solutions. For example, the strongest material may be too expensive, or too heavy to meet cost and size constraints. Identifying the solution that meets all of the constraints with the best combination of trade-offs is called optimization. Models are frequently used to help designers visualize possible solutions, and may be two-dimensional illustrations, three-dimensional physical shapes, or mathematical calculations that predict how well a potential solution will do what is necessary to solve the problem. Each step of the Engineering Design Process involves systematically examining information that is needed to move to the next step. This kind of examination is called analysis.

Additional Technology Activities
Multibeam Mapping

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Sources for operating programs and activities for ultrasonic sensors:

PING)))™ sensor, Parallax BASIC Stamp microcontroller, and Board of Education®
prototyping board – Parallax, Inc. Web site (*http://www.parallax.com*); Lindsay,
A. Smart Sensors and Applications. Parallax Inc. Rockland, CA; Lindsay, A. 2003.
What's a Microcontroller? Parallax Inc. Rockland, CA. 315 pp.

Arduino microcontroller – Arduino Web site (*http://www.arduino.cc/*); Banzi, M. 2008.
Getting Started with Arduino. O'Reilly Media, Inc. Sebastopol, CA. 118 pp.

Lego® NXT Ultrasonic Sensor and NXT brick microcontroller – Lego® Web site (*http://
www.lego.com/en-us/Default.aspx*); Kelly, J. R. 2010. Lego Mindstorms Nxt-g
Programming Guide. Apress. New York. 336 pp.

Vernier Motion Detector and LabQuest® or CBL 2® interface – Vernier Web site (*http://www.
vernier.com/*); File #19, "Mapping Ocean Floor" from the Earth Science with Vernier
activities collection (*http://www.vernier.com/cmat/cmatdnld.html*, Lab #19 under
the "Earth Science" menu)

Notes for Educators

1. This activity assumes that students have a basic understanding of sound waves
and the meaning of frequency, and that students and/or their instructor have
a basic understanding of the microcontroller system that will be used for this
activity. Additional background about waves and their properties can be found in
the *Day in the Life of an Ocean Explorer* lesson, and additional background about
microcontrollers can be found in the *Additional Technology Activities: Underwater
Robots: Getting Control*, and in the documentation provided by the manufacturer of
the microcontroller system that will be used for this activity.

2. Answers to questions in Learning Procedure, Step 1:
   a. "SONAR" is an acronym for "SOund NAvigation and Ranging"

   b. The basic components of a sonar system are:
   - A transmitter capable of emitting an acoustic signal;
   - A receiver capable of detecting echoes from the transmitted signal; and
   - A processing unit to interpret the reflected signal.
      Students may also mention:
   - A cable to connect the processor with the transmitter and receiver;
   - A transducer (which is analogous to the antenna on a radio transmitter or
      receiver); and
   - A towfish to allow the transducer(s) to be towed behind a survey vessel.

   c. Transducers are sometimes towed behind the survey vessel because:
   - Being able to tow the transducer at some depth below the surface means that
      there is less water through which the acoustic signal must travel, so there is
      less absorption and scattering of the acoustic energy, and consequently, the
      signal is stronger;
   - The transducer is less affected by the surface motion of the survey vessel
      (particularly rolling motion); and

• The transducer can be towed beneath a thermocline (the boundary between two water masses of different temperature) which can interfere with the acoustic signal.

d. Higher frequencies give better image resolution (more detail) but travel shorter distances than lower frequencies.

e. Multibeam sonar systems use multiple transducers pointing at different angles on either side of a ship to create a swath of signals. The time interval between signal transmission and return echo arrival is used to estimate depth over the area of the swath. In some systems, the intensity of the return echo is also used to infer bottom characteristics that can be used for habitat mapping. Other sonar systems typically use only one transducer and measure depth in a very narrow path along the track of the ship. Sidescan sonars also transmit a fan-shaped pattern of acoustic signals, and continuously record the strength of the return echo caused by the transmitted signal bouncing off of the sea floor or other object (in contrast to multibeam systems that estimate depth by measuring the time elapsed between transmission of a sound signal and detection of the reflected signal by the sonar's receiver).

3. The Engineering Design problem may be solved many ways. The key points for evaluating students' responses to the Challenge are:
- The students clearly show how they addressed each step in the Engineering Design Process to arrive at their solution;
- The proposed solution is plausible; and
- Students have undertaken some practical tests of their solution.

Unless a test site is available that matches the characteristics of the described lake bed, a complete test of the proposed solution may not be possible; but students should document reasonable efforts to test their ideas.

For a description of one approach to this challenge, see *http://www.vernier.com/innovate/innovativeuse86.html*.

Additional Technology Activities
Multibeam Mapping

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oceanexplorer.noaa.gov

Other Resources

Doucet M., C. Ware, R. Arsenault, T. Weber, M. Malik, L. Mayer, and L. Gee. Advanced Mid-Water Tools for 4D Marine Data Fusion and Analysis. Paper presented at OCEANS 2009, Biloxi, Mississippi, October 26-29, 2009; available online at *http://www.ivs3d.com/news/PID985675.pdf*

Gardner, J. V., M. A. Malik, and S. Walker 2009. Plume 1400 Meters High Discovered at the Seafloor off the Northern California Margin. EOS Transactions, American Geophysical Union, 90(32): 275 - 275

L-3 Communications SeaBeam Instruments [cited January 24, 2011].Multibeam Sonar Theory of Operation [Internet]. Available from: *http://www.ldeo.columbia.edu/res/pi/MB-System/sonarfunction/SeaBeamMultibeamTheoryOperation.pdf*

Lobecker, M. and E. Stuart. 2010. State of the Art Seafloor Survey [Internet]. NOAA Ocean Explorer [cited January 10, 2011]. Available from: *http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july31/july31.html*

Malik, M. E. Lobecker, E. Stuart, C. Peters, and N. Verplanck. 2010 NOAA Ship Okeanos Explorer Maps Kawio Barat [Internet]. NOAA Ocean Explorer [cited January 10, 2011]. Available from: *http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/june26/june26.html*

NOAA Office of Ocean Exploration and Research [Internet]. NOAA Ocean Explorer [cited January 17, 2011]. Sonar. Available from: *http://www.oceanexplorer.noaa.gov/technology/tools/sonar/sonar.html*

NOAA Office of Ocean Exploration and Research [cited January 14, 2011]. 2002. Magic Mountain Virtual site [Internet]. Available from: *http://oceanexplorer.noaa.gov/explorations/02fire/logs/magicmountain/welcome.html;* Links to virtual fly-throughs and panoramas of the Magic Mountain hydrothermal vent site on Explorer Ridge in the NE Pacific Ocean, where two tectonic plates are spreading apart and there is active eruption of submarine volcanoes

Peters, C. 2010. Minding the Multibeam at Midnight [Internet]. NOAA Ocean Explorer [cited January 10, 2011]. Available from: *http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/aug05/aug05.html*

University of New Hampshire [cited January 14, 2011]. [Internet]. Available from: *http://oceanexplorer.noaa.gov/okeanos/media/movies/ex_podcast_video.html;* Video simulations of Okeanos Explorer discovering a midwater plume on May 17, 2009 using multibeam sonar; video formats are provided for PC users and Macintosh users