Lesson 11: Through Robot Eyes

Focus

Image analysis

Grade Level

9-12 (Physical Science/Technology)

Focus Question

How can images obtained by underwater robots be used to assist ocean exploration aboard the *Okeanos Explorer*?

Learning Objectives

- Students will explain how robotic vehicle technology is used to extend the exploration capacity of scientific investigations aboard the *Okeanos Explorer*.
- Students will use mathematics and computational thinking to show how lasers may be used in scientific investigations to calibrate images for size and distance measurements.
- Students will analyze and interpret video data from the *Okeanos Explorer's* underwater robot to make inferences about environmental interactions of organisms in deep-sea ecosystems.

Materials

- Copies of the *Robot Imagery Investigation Guide*, one for each student group
- Copies of *ImageJ Basics*, one for each student group; see Learning Procedure, Step 1c
- Ruler, one for each student group

Audio Visual Materials

- (Optional) Video projector or other equipment to display downloaded images (see Learning Procedure, Step 1d)

Teaching Time

One or two 45-minute class periods, plus time for students to complete the *Investigation Guide*

Seating Arrangement

Groups of two to four students

Maximum Number of Students

30

The combination of the *Little Hercules* ROV (above) and the *Seirios* camera sled (below)– equipped with high definition cameras and powerful lighting systems are capable of diving to 4,000 m depth. When deployed, they will be our "eyes in the sea," providing the expedition team and audiences on shore with spectacular first looks at the deep-sea habitats. Images courtesy of NOAA *Okeanos Explorer* Program, 2011.

http://oceanexplorer.noaa.gov/okeanos/explorations/ex1104/ background/hires/plan_little_herc_hires.jpg

Key Words and Concepts

Ocean Exploration
Okeanos Explorer
Robot
Imagery
Video
ImageJ

Background Information

The site characterization component of the *Okeanos Explorer* exploration strategy depends heavily upon remotely operated vehicles (ROVs; for more information about the *Okeanos Explorer* exploration strategy, please see *Lesson 1*: *To Explore Strange New Worlds*). For additional information about ROVs used aboard the *Okeanos Explorer*, please see the *Introduction to Underwater Robots* on page 123.

This lesson introduces students to remotely operated vehicles and video imagery as they are used for ocean exploration aboard the *Okeanos Explorer*. The techniques presented in this lesson may be used to complete *Okeanos Explorer* Video Imagery Supplemental Datasheets for selected *Okeanos Explorer* cruises (e.g., *http://oceanexplorer.noaa.gov/okeanos/explorations/ex1202/background/edu/media/ex1202_sdrov1.pdf*).

Learning Procedure

1. To prepare for this lesson:
   a) Review:
   - Introductory essays for the INDEX-SATAL 2010 Expedition (*http://oceanexplorer.noaa.gov/okeanos/explorations/10index/welcome.html*); including *Little Hercules* ROV (*http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/rov/rov.html*);
   - Daily log entries for
      July 7 (*http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july07/july07.html*);
      July 24 (*http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july24/july24.html*); and
      August 6 (*http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/aug06/aug06.html*).

   You may want to assign one or more of these essays as background reading prior to beginning the rest of the lesson.
   (b) Review background information about the *Okeanos Explorer* exploration strategy and technologies.
   (c) Review procedures on the *Robot Imagery Investigation Guide*. If students will be using classroom computers, download ImageJ and the *ImageJ Basics* handout from *http://rsbweb.nih.gov/ij/download.html* and *http://rsbweb.nih.gov/ij/docs/pdfs/ImageJ.pdf*, respectively.

   Also, download the image files **EX2010.07.12_ROV_01.jpg** and **EX2010.07.12_ROV_02.jpg** from
   http://oceanexplorer.noaa.gov/okeanos/edu/resources/media/EX2010.07.12_ROV_01.jpg and *http://oceanexplorer.noaa.gov/okeanos/edu/resources/media/EX2010.07.12_ROV_02.jpg*, respectively.
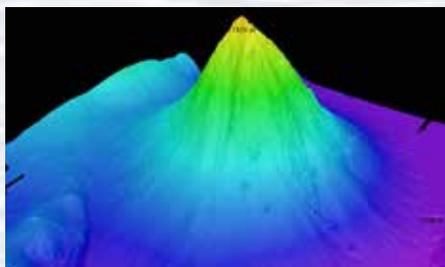

Video technology plays a big role in the exploration conducted on the *Okeanos Explorer*. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july24/media/randy_at_controls.html

A video engineer adjusts the images from the HD camera on the remotely operated vehicle, *Little Hercules*. Image courtesy of the NOAA *Okeanos Explorer* Program.
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1202/logs/hires/apr17-3-hires.jpg

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

A CTD is attached to a metal frame called a rosette, or carousel, along with numerous water sampling bottles and when deployed, provides information about the composition of the water column. Image courtesy of NOAA.
http://oceanexplorer.noaa.gov/technology/tools/sondectd/sondectd.html

Okeanos Explorer crew launch the vehicle during test dives off Hawaii. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/hires/launch_hires.jpg

ROV Team Lead, Commanding Officer, and Science Team Lead discuss operations at the Mid-Cayman Rise with participants located at both the Silver Spring ECC, and URI's Inner Space Center. Image courtesy of NOAA *Okeanos Explorer* Program, MCR Expedition 2011.
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1104/logs/hires/daily_updates_aug9_1_hires.jpg

If students will not be using classroom computers, ensure that they will have access to the file *oceanexplorer.noaa.gov/okeanos/edu/resources/media/EX2010.07.12_ROV_01.jpg*.

(d) Download images referenced in Step 2 and 3. You may also want to download examples of imagery from underwater robots from *http://oceanexplorer.noaa.gov/okeanos/media/slideshow/flash_slideshow.html* and *http://oceanexplorer.noaa.gov/okeanos/media/slideshow/video_playlist.html*).

2. Briefly introduce the NOAA Ship *Okeanos Explorer* and the INDEX-SATAL 2010 Expedition, and discuss why this kind of exploration is important (for background information, please see the lesson, *Earth's Ocean is 95% Unexplored: So What?*; *http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/edu/media/so_what.pdf*). Highlight the overall exploration strategy used by *Okeanos Explorer*, including the following points:
   - The overall strategy is based on finding anomalies;
   - This strategy involves
     - Underway reconnaissance;
     - Water column exploration; and
     - Site characterization;
   - This strategy relies on four key technologies:
     - Telepresence technologies that allow people to observe and interact with events at a remote location;
     - Multibeam sonar mapping system;
     - CTD and other electronic sensors to measure chemical and physical seawater properties; and
     - A Remotely Operated Vehicle (ROV) capable of obtaining high-quality imagery and samples in depths as great as 4,000 meters.

   You may want to show some or all of the images in the adjacent sidebar to accompany this review.

3. Show students images of several ROVs (see *http://oceanexplorer.noaa.gov/technology/subs/subs.html*), and briefly describe their capabilities. Conclude with one or more images of the *Little Hercules* ROV, and explain that the primary purpose of this underwater robot is to gather high quality video images as part of site characterization activities. At this point you may want to show the video clip compilation referenced in Step 1d. Lead a discussion of how ocean explorers might use these images. Students should realize that in many cases these images provide the only indication of living organisms in sites being characterized. In addition, these images can provide data about geological formations and other environmental conditions that cannot be obtained with other data gathering instruments. Students should also realize that video imagery also has limitations, including:
   - coverage is limited to a relatively small area;
   - mobile organisms may avoid the moving ROV and/or lights used for video imaging; and
   - many organisms cannot be accurately identified from photographs or videos alone.

Show the image **EX2010.07.12_ROV_02.jpg**. Call students' attention to the red dots near the center of the image, and ask for ideas about why these dots are present. Students should realize (possibly with your help) that these dots provide a scale that makes it possible to estimate the size of objects in the image.

Tell students that their assignment is to learn about some of the ways scientists use imagery from underwater robots to investigate deep-sea ecosystems. Provide each student group with:

- A copy of the *Robot Imagery Investigation Guide*;
- The image file *oceanexplorer.noaa.gov/okeanos/edu/resources/media/ EX2010.07.12_ROV_01.jpg*;
- The ImageJ Basics handout; and
- Any additional instructions about operating the ImageJ software on classroom computer systems.

Point out that the primary purpose of the *Investigation Guide* exercises is to become familiar with techniques that can be used for a wide variety of investigations and projects that use digital imagery.

4. When students have answered all questions on the *Investigation Guide*, lead a discussion of their results. The answer sheet can be found on page 161.

5. Discussion of underwater robots and image technology may also include the following components of technological literacy (ITEA, 2007):
- **Core concepts of technology:** Underwater robots are composed of closely inter-related systems designed to meet specific requirements and constraints, which often involve trade-offs.
- **Relationships between technologies and other fields of study:** Underwater robotics technology is closely linked to advancements in science and mathematics, and specific information requirements in these fields drive further innovation and invention.
- **Effects of technology on the environment:** Underwater robotics technology provides new ways to monitor various aspects of the environment to provide information for decision-making.

The BRIDGE Connection

www.vims.edu/bridge/ – Scroll over "Ocean Science Topics" in the menu on the left side of the page, then "Human Activities," then "Technology" for links to resources about submersibles, ROVs, and other technologies used in underwater exploration.

The "Me" Connection

Have students write a brief essay about how robotic imagery might be of personal benefit.

Connections to Other Subjects

English Language Arts, Life Science, Mathematics, Physics

Assessment

Students' answers to *Investigation Guide* questions and class discussions provide opportunities for assessment.

Extensions

1. Visit the *Okeanos Explorer* Web page (*http://oceanexplorer.noaa.gov/okeanos/ welcome.html*) for reports, images, and other products from *Okeanos Explorer* cruises.
2. Visit *http://www.marinetech.org/rov-competition-2/* for a video from the Marine Technology Society's student ROV competition, and links to other sites about underwater robots.

3. For ideas about building your own underwater robots, see Bohm and Jensen (1998), Bohm (1997), and and the Sea Perch Program (see Other Resources).

4. For additional work with ROV video imagery, see *Okeanos Explorer* ROV Imagery Supplemental Datasheets for selected *Okeanos Explorer* cruises (e.g., *http://oceanexplorer.noaa.gov/okeanos/explorations/ex1202/background/edu/media/ex1202_sdrov1.pdf*).

Multimedia Discovery Missions

http://oceanexplorer.noaa.gov/edu/learning/welcome.html – Click on the links to Lessons 1, 5, and 6 for interactive multimedia presentations and Learning Activities on Plate Tectonics, Chemosynthesis and Hydrothermal Vent Life, and Deep-Sea Benthos.

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

Where's My 'Bot?

(from the Bonaire 2008: Exploring Coral Reef Sustainability with New Technologies Expedition)

http://oceanexplorer.noaa.gov/explorations/08bonaire/background/edu/media/wheresbot.pdf

Focus: Marine Navigation (Grades 9-12; Earth Science/Mathematics)

Students estimate geographic position based on speed and direction of travel; and integrate these calculations with GPS data to estimate the set and drift of currents.

Hydrothermal Vent Challenge

(from the Submarine Ring of Fire 2004 Expedition)

http://oceanexplorer.noaa.gov/explorations/04fire/background/edu/media/RoF.ventchall.pdf

Focus: Chemistry of hydrothermal vents (Grades 9-12; Chemistry)

Students define hydrothermal vents and explain the overall processes that lead to their formation; explain the origin of mineral-rich fluids associated with hydrothermal vents; explain how black smokers and white smokers are formed; and hypothesize how properties of hydrothermal fluids might be used to locate undiscovered hydrothermal vents.

Thar She Blows!

(from the 2002 Galapagos Rift Expedition)

http://oceanexplorer.noaa.gov/explorations/02galapagos/background/education/media/gal_gr9_12_l3.pdf

Focus: Hydrothermal vents (Grades 9-12; Chemistry/Biology)

Students demonstrate an understanding of how the processes that result in the formation of hydrothermal vents create new ocean floor, and demonstrate an understanding of how the transfer of energy affects solids and liquids.

The Tell-Tale Plume

(from the INSPIRE: Chile Margin 2010 Expedition)

http://oceanexplorer.noaa.gov/explorations/10chile/background/edu/media/plume.pdf

Focus: Hydrothermal Vent Chemistry (Grades 9-12; Chemistry/Biology)

Students describe hydrothermal vents; identify changes that they cause to the physical and chemical properties of seawater; and use oceanographic data to recognize a probable plume from hydrothermal activity.

The Roving Robotic Chemist

(from the PHAEDRA 2006 Expedition)

http://oceanexplorer.noaa.gov/explorations/06greece/background/edu/media/robot_chemist.pdf

Focus: Mass Spectrometry

Students explain the basic principles underlying mass spectrometry; discuss the advantages of in-situ mass spectrometry; explain the concept of dynamic re-tasking as it applies to an autonomous underwater vehicle; and develop and justify a sampling strategy that could be incorporated into a program to guide an AUV searching for chemical clues to specific geologic features.

Next Generation Science Standards

Lesson plans developed for Volume 2 are correlated with *Ocean Literacy Essential Principles and Fundamental Concepts* as indicated in the back of this book. Additionally, a separate online document illustrates individual lesson support for the Performance Expectations and three dimensions of the Next Generation Science Standards and associated Common Core State Standards for Mathematics and for English Language Arts & Literacy. This information is provided to educators as a context or point of departure for addressing particular standards and does not necessarily mean that any lesson fully develops a particular standard, principle or concept. Please see: *http://oceanexplorer.noaa.gov/okeanos/edu/collection/hdwe_ngss.pdf*

Robot Imagery Investigation Guide

Underwater robots are our eyes into Earth's deep ocean. As digital imaging technology continues to improve, views through these robot eyes are beautiful and fascinating (see, for example, *http://oceanexplorer.noaa.gov/okeanos/media/slideshow/flash_slideshow.html* and *http://oceanexplorer.noaa.gov/okeanos/media/slideshow/video_playlist.html*). Site characterization is a key element of the *Okeanos Explorer's* strategy for making discoveries, and this characterization depends heavily upon the ability of underwater robots to obtain images that can be used to identify living organisms and geological features. The following activities are designed to acquaint you with some techniques for analyzing images obtained with underwater robots. Once you are familiar with these techniques, you will be able to use them for a wide variety of investigations about ocean organisms and ecosystems.

Many underwater robots carry digital cameras that can look ahead of the robot as well as directly below it. Often, the forward-looking camera records video while the downward-looking camera may record still or video imagery depending upon specific mission needs. For some surveys, a series of overlapping still images is obtained from the downward-looking camera. These images are spliced together to produce a mosaic image that can provide complete coverage of a large area. The essay by Liz Podowski (*http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/aug30/aug30.html*) provides more details about this technique.

One problem with most images from underwater robots is that they are two-dimensional, so it can be very difficult to accurately judge the size of organisms and ecosystem features. To overcome this problem, underwater photography systems use a system of lasers. Downward-looking cameras typically have two lasers whose beams are parallel and a known distance apart. This places two bright dots on each image that establish the scale of the image. In Figures 1 and 2, the dots on the image are 10 cm apart. Using this information, estimate:

Figure 1.
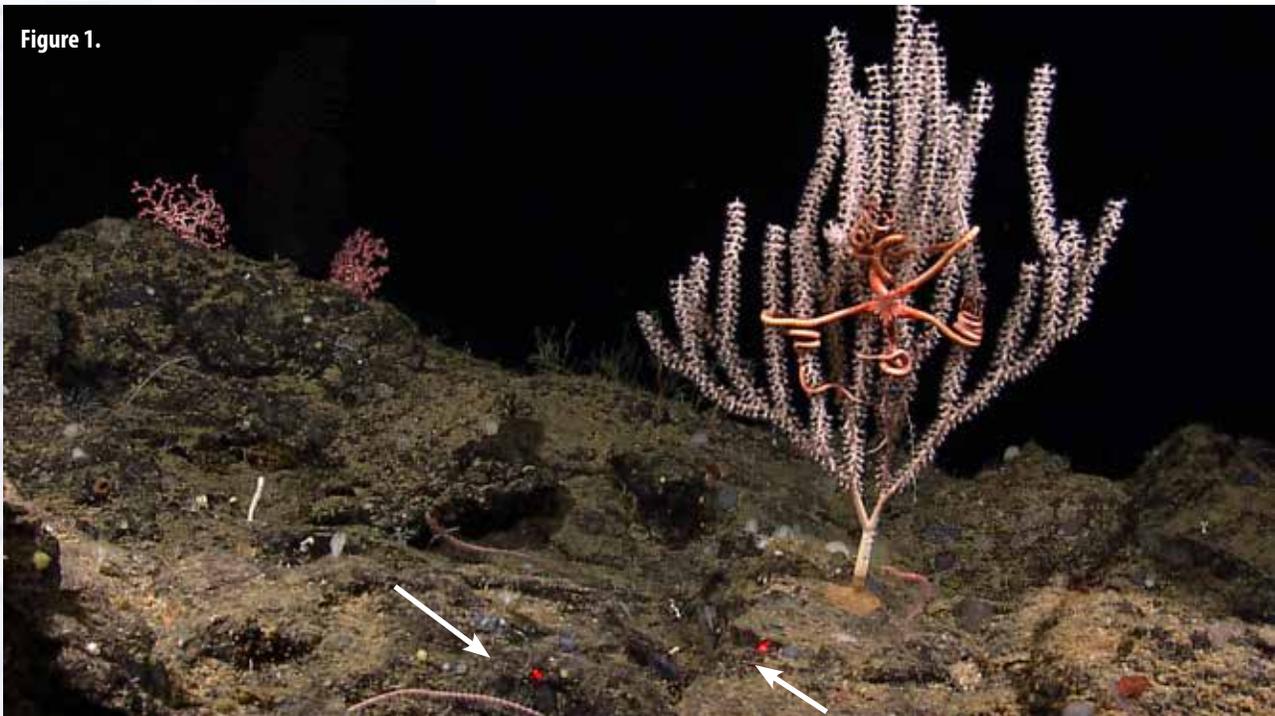
Figure 2.

1. The approximate height of the portion of the large branching soft coral that is visible in Figure 1:

   _____

2. The span of the two brittle star arms that are closest to horizontal, not including the portions that are twisted around the coral in Figure 1:

   _____

3. The approximate length of the shrimp in the lower left of Figure 2:

   _____

4. The approximate length of the violet sea cucumber in the upper center of Figure 2:

   _____

Note: the sea cucumber may be somewhat larger than this, since it is farther away than the substrate where the laser dots are located.

A similar system can be used in forward-looking video, but it is often important to be able to estimate distance as well. To provide this capability, a third laser is added to the system, in between the two parallel lasers. This additional laser is angled so that it converges with one of the parallel laser beams at a known distance in front of the robot (see Figure 3).

Suppose a video system using the lasers diagrammed in Figure 3 shows the image in Figure 4:
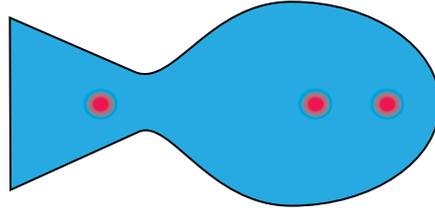
Figure 4.

Figure 3.

20 cm

6.0 m

ROBOT
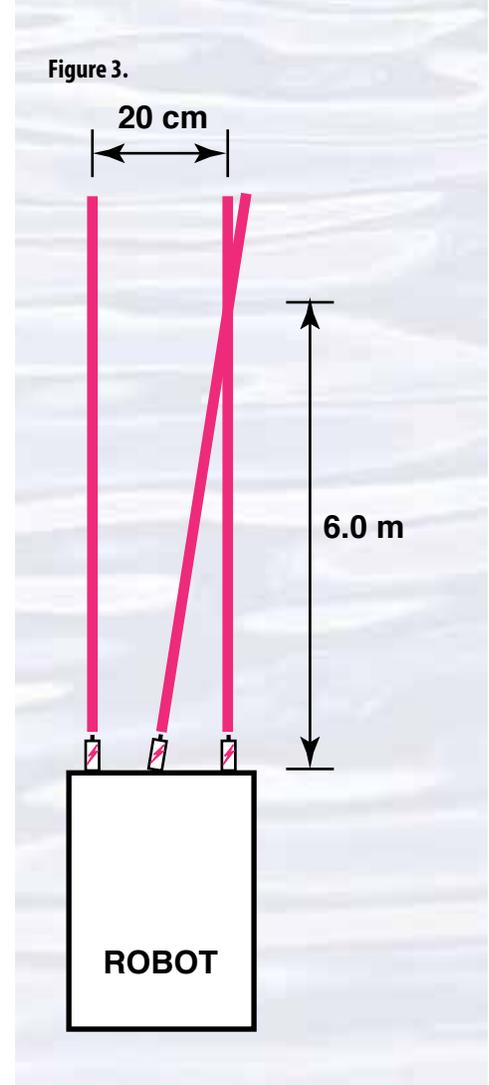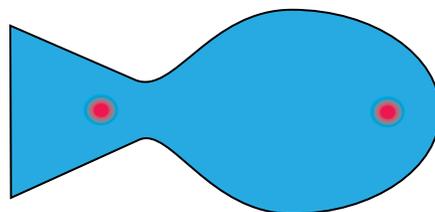
5. How far away is the fish?

_____

6. What is the total length of the fish?

_____

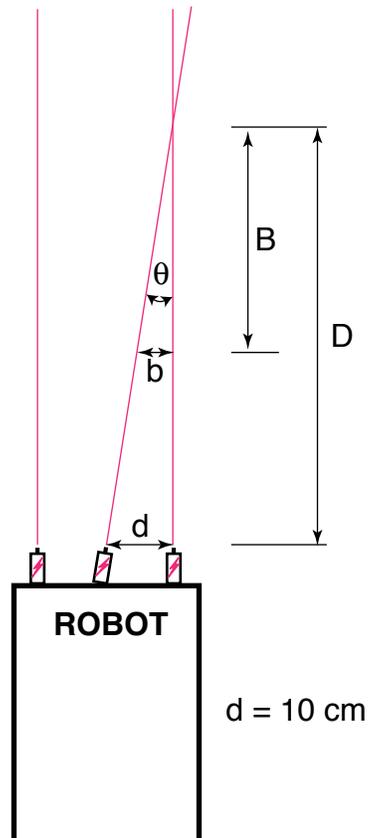Now suppose the same video system shows the image in Figure 5:

Figure 5.

7. How far away is the fish?

_____

8. What is the total length of the fish?

_____

HINT:

Figure 6.

d = 10 cm

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Volume 2: How Do We Explore?
Underwater Robots – Through Robot Eyes (9-12)

Fishes are a conspicuous part of many marine ecosystems, and ocean explorers often have questions about what kinds of fish inhabit certain areas, and how many fishes are there. Koenig (2001) describes a way to obtain this information that involves navigating an underwater robot along a series of transects (a transect is a path along which data are collected) while recording video from a forward-looking camera. When the transects are completed, the video recording is reviewed and imaged fishes are identified and counted. The total counts for each species are divided by the total area of the transect to obtain an estimate of the density of each species. For example, if 50 fish belonging to a single species were counted in a video transect that covered 100 square meters, the density of that species would be 50 fish / 100 square meters = 0.5 fish/square meter.

9. What might be some errors involved with surveying fishes in this way?

_____

To find the area of a transect, we need to know the width (W) and length (L) of the transect (Figure 7). The width of the transect can be calculated from:
• The effective distance for identifying fish species (D); and
• The video camera's horizontal angle of view (A)

The effective distance for identifying fish species (D) is the limit at which the fish can be identified with a high degree of certainty. Koenig (2001) used a distance of 5 m. The horizontal angle of view (A) depends on the camera used and the position of the zoom.

10. Suppose we have a camera whose horizontal angle of view is 90 degrees. Using 5 m as the effective distance, what is the width (W) of a video transect?

_____

Figure 7.
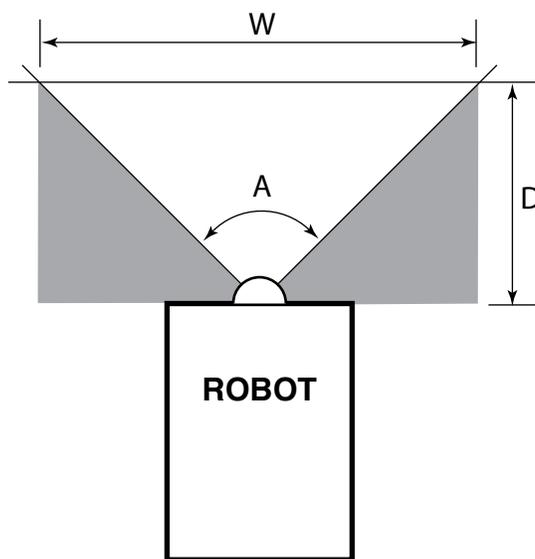
The length of a transect (L) can be calculated from the geographic coordinates of the robot at the beginning and end points of the transect. The distance between two points whose latitude and longitude are known can be calculated using the spherical law of cosines formula:

$$d = acos\ (sin(lat1) \bullet sin(lat2) + cos(lat1) \bullet cos(lat2) \bullet cos(long2 - long1)) \bullet R$$

where lat1, long1, lat2, and long2 are the latitude and longitude of points 1 and 2, respectively in radians, d is the distance between the points in km, and R is Earth's mean radius (6,371 km); latitude and longitude measurements in degrees may be converted to radians by dividing by 180.

11. If our transect began at 2.523456° North latitude, 125.069212° East longitude, and ended at 2.525255 North latitude, 125.069146° East longitude, what was the length (L) of the transect (Hint: 1. Be sure to use a calculator or spreadsheet program accurate to at least six decimal places.)

_____

12. Now that you know the width (W) and length (L) of the transect, how much area did the transect include? (Hint: be sure to allow for the space that is outside the camera's horizontal field of view.)

_____

Basic analyses of video and single-frame images can be done by identifying and counting individual organisms, and by using laser scale dots to estimate the area covered by the image. Much more sophisticated analyses can be done using image analysis software. ImageJ is a very powerful image analysis program developed by the National Institutes of Health, and is free to the public. Links for downloading, tutorials, and full documentation are available at: *http://rsbweb. nih.gov/ij/index.html*.

Launch the ImageJ program, and open the file provided by your teacher. Review the *ImageJ Basics* handout, then try the following:

• Draw a line between the two laser dots, and set the measurement scale as described in the handout (remember the dots are 10 cm apart).

13. A decapod crustacean is clearly visible near the bottom center of the image. Measure the distance between the eyes, and the length of the longest segment in the first right cheliped (the leg with a claw near the front of the crab), and record your results. (Hint: Use the magnifying glass to enlarge the image for greater accuracy.)

_____

14. What is the approximate area occupied by the large white sponge in the lower left of the image?

_____

15. Notice the branching coral in the upper right of the image. What is the approximate area of this coral? (Outline the entire coral shape, not the individual branches.)

_____

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Volume 2: How Do We Explore?
Underwater Robots – Through Robot Eyes (9-12)

Robot Imagery Investigation Guide
Answer Sheet

1. The approximate height of the portion of the soft coral visible in Figure 1 is 25.4 cm.

2. The span of the two brittle star arms that are closest to horizontal is about 10 cm.

3. The approximate length of the shrimp in the lower left of Figure 2 is 9.2 cm.

4. The approximate length of the violet sea cucumber in the upper center of Figure 2 is 10.9 cm; the sea cucumber may be somewhat larger than this, since it is farther away than the substrate where the laser dots are located.

5. The fish in Figure 4 is 6 meters from the robot, since the beam from the third laser converges with the beam from the parallel laser on the right, giving the appearance of only two dots on the fish.

6. The total length of the fish in Figure 4 is approximately 30 cm.

7. The fish in Figure 5 is 3 meters from the robot, since the beam from the third laser forms a dot that is 5.0 cm from the dot formed by the parallel laser on the right. The hint in Figure 6 is that that the angle θ is constant, so the tangent of θ is constant and equal to d / D, and also equal to b / B.

8. The total length of the fish in Figure 5 is approximately 30 cm.

9. Errors involved with video fish surveys include avoidance of the robot by some fish species, attraction to the robot by other species which may also circle the robot and be counted more than once, and the exclusion of cryptic species that hide in crevices that are out of the camera's view. In some cases, particularly when areas are being explored for the first time, it may not be possible to accurately identify every fish seen. This problem may arise when the characteristics used for identification require close inspection (such as the number of rays in a fin). Accurate identification also depends upon the experience of scientists watching the video; but occasionally, no one can identify a strange organism because it is a species new to science and has never been seen before!

10. The width (W) of a video transect made with a camera whose horizontal angle of view (A) is 90 degrees and an effective distance (D) of 5 m is:

$W = 2 \bullet (\tan (0.5 \bullet A)) \bullet D = 2 \bullet (\tan 45) \bullet 5 = 2 \bullet 1 \bullet 5 = 10$ m

11. The length of a transect that begins at 2.523456° North latitude, 125.069212° East longitude, and ends at 2.525255 North latitude, 125.069146 East longitude is 0.2002 km.

12. Using values from questions 8 and 9, the area of the transect is

10 m $\bullet$ 200.2 m = 2002 square meters

To correct for the space that is outside the camera's field of view, it is necessary to subtract

$0.5 \bullet (W \bullet D) = 25$ square meters

which is the shaded area shown in Figure 6.

13. The distance between the eyes of the crustacean is about 2.15 cm; the length of the longest segment in the first right cheliped is about 7.80 cm.

14. The area occupied by the large white sponge in the lower left of the image is about 353 cm^2.

15. The area of the branching coral in the upper right of the image is about 253 cm^2.

Note that students' results will vary depending upon how precisely they outline objects whose areas are to be estimated.

Notes: