Control and Navigation 1
Cornerstone Electronics Technology and Robotics III

(Notes primarily from “Underwater Robotics – Science Design and Fabrication”, an excellent book for the design, fabrication, and operation of Remotely Operated Vehicles ROVs)

- **Administration:**
    - Prayer
- **Control Systems:**
    - Control System (human-made): a mechanical, optical, or electronic device, or set of devices to manage, command, direct or regulate the behavior of other devices or systems to reach a desired output.
    - Most control systems for ROV’s and AUV’s depend on electronic components since they are:
        - Modular: made up of complementary components taken from different sources
        - Relatively low cost
        - Versatile
        - Small in size
        - Easy to assemble, use, and maintain
        - Highly reliable
    - Other options for ROV control systems:
        - Mechanical
        - Pneumatic – air-driven
        - Hydraulic – liquid-driven
    - Continue to the next page.

- **Open-Loop vs. Closed-Loop Control:**
  - Both forms of control try to complete some desired response.
  - **Open-Loop Control Systems:** An open-loop control system is one in which the control action is independent of the output, that is, there is no feedback from the commanded action about its effect on the state of the system output.
    - Its performance depends heavily on well-trained, experienced operators and attentive maintenance staff to monitor, maintain, and adjust the system.
    - Its basic weakness lies in its inability to adjust the output to suit the requirements.

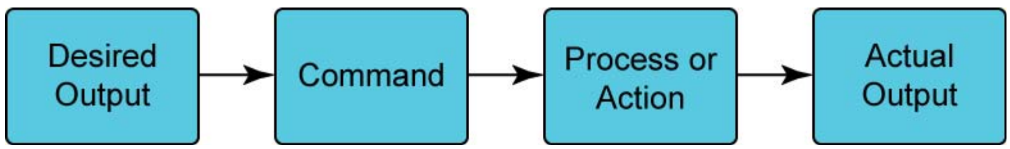


Figure 1: Block Diagram of an Open-Loop Control System

- Example of an Open-Loop Control System: The owners of a pond desire the water level to be maintained at 10'. In an open-loop control system, someone turns on the fill valve at a constant flow rate, hoping that the flow rate will compensate for evaporation and pond leakage. However, during the dry season, the flow rate does not balance the losses due to evaporation and leakage, lowering the water level to 4'.

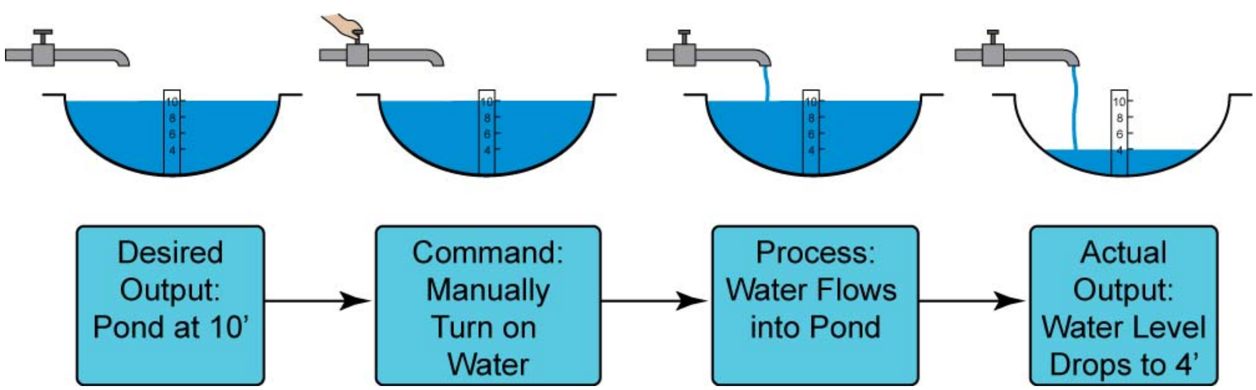


Figure 2: An Example of an Open-Loop Control System

- **Closed-Loop Control Systems:** A control system with an active feedback loop that constantly monitors the output as a system operates and the actual output is compared with the desired output. If there is any difference between the actual output and the desired output, then the process is commanded to activate in order to eliminate the difference.
  - Closed-loop control is a more accurate system of control and at the same time more expensive.
  - Closed-loop control systems are therefore capable of making decisions and adjusting their performance to suit changing output conditions.

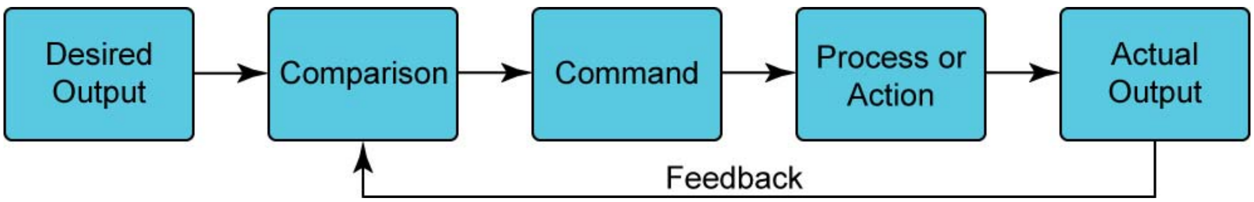


Figure 3: Block Diagram of a Closed-Loop Control System

  - Example of a Closed-Loop Control System: In this example, the owner's added a yellow float to monitor the water level and they linked the float device to an automatic control valve. If the water level falls below 10', the float opens the control valve allowing water to flow into the pond. When the water level reaches 10', the control valve is set to close and the water is stopped.

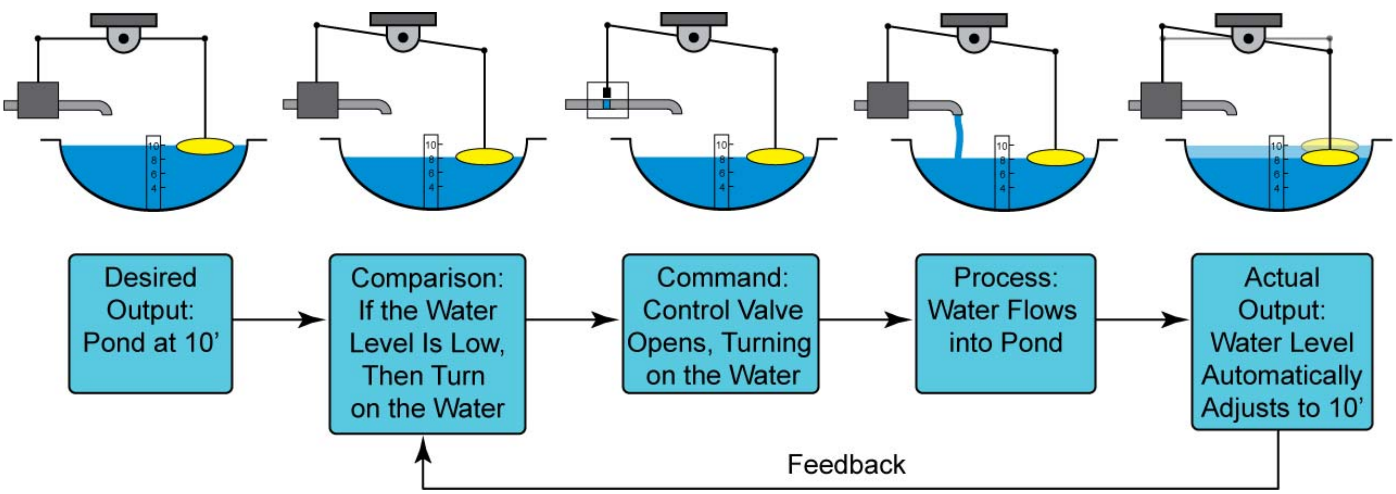
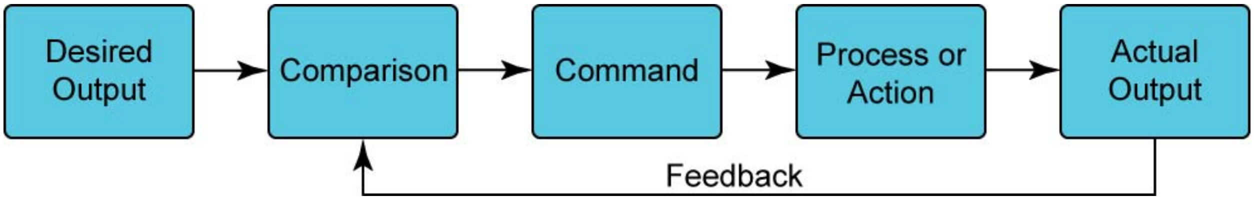


Figure 4: An Example of a Closed-Loop Control System

  - Closed-loop control systems are difficult to put into reliable service. Problems such as overheating, contamination, or poor loop tuning can create sudden and unpredictable results, leading to destructive consequences.

- **The Human Role in Vehicle Control Systems:**



- Humans are skillful at performing some of the tasks in a closed-loop control system.
- First, they define the desired output conditions.
- They also use their senses to evaluate the actual output conditions. This information is used as feedback for making comparisons.
- Humans process the feedback details and make comparisons of the actual and desired conditions.
- Based upon these comparisons, humans make decisions and give out commands to bring the actual output into alignment with the desired output.
- The range of the human role in underwater vehicle control varies from complete human control of an ROV in conditions where visibility is acceptable, to an AUV performing a complete mission autonomously.

- **Navigation:**
  - Navigation is the art or science of determining a vehicle's current position, and directing or plotting the course of the vehicle from its current position to a destination.
  - **Specifying Position or Location:**
    - Successful navigation begins with accurate and precise data about the present position of your vehicle and the location of its intended destination. The following are methods for determining an underwater position.
    - **Nearby Landmarks:** Landmarks can be used if your site is adjacent to a marker such as a buoy's mooring chain.
    - **Dead Reckoning:** Dead reckoning is a technique to determine a ship's approximate position by applying to the last established charted position a vector or series of vectors representing true courses and speed. The direction of this vector represents the ship's course, and the length represents the distance the ship travels in a given time.

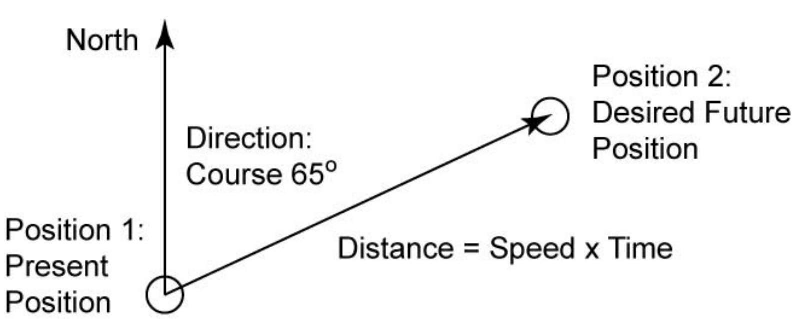


Figure 5: Dead Reckoning: Establishing a Future Position Using Distance and Direction Travelled

Dead reckoning is susceptible to errors such as currents and the errors grow larger as the distance traveled increases. If the current direction is exactly opposite to the ROV course, the ROV speed will be lower and the distance travelled will be reduced (Figure 6). If the current direction is same as the ROV course, the actual ROV speed will be higher. All other current directions push the ROV away from her course (Figure 7).

Figure 6: ROV Speed Lowered by Opposing Current

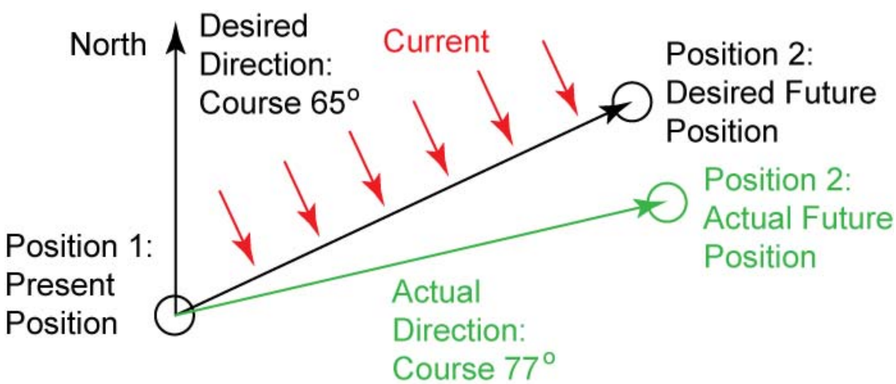


Figure 7: ROV Course Changed by a Crosscurrent

- Lesson continued below

- **Standardized Coordinate System:**
    - Latitude and Longitude Coordinate System: Latitude and longitude are angles that uniquely define points on a sphere. Together, the angles comprise a coordinate system that can locate geographic positions on the surface of the earth.

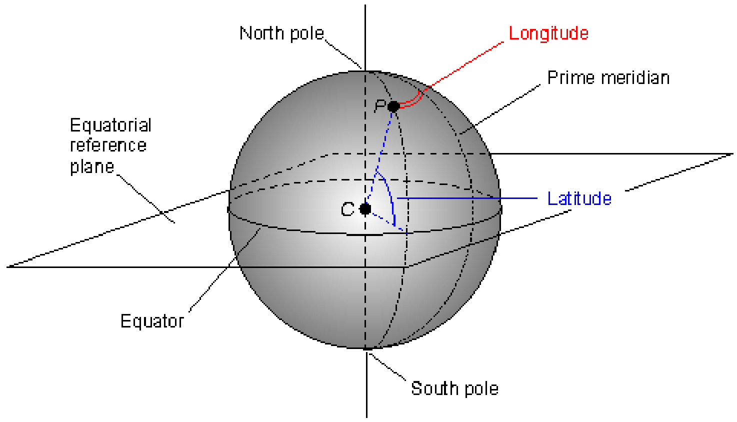


Figure 8: Locating a Point on a Sphere Using Latitude and Longitude
From http://whatis.techtarget.com/definition/0,,sid9_gci828937,00.html

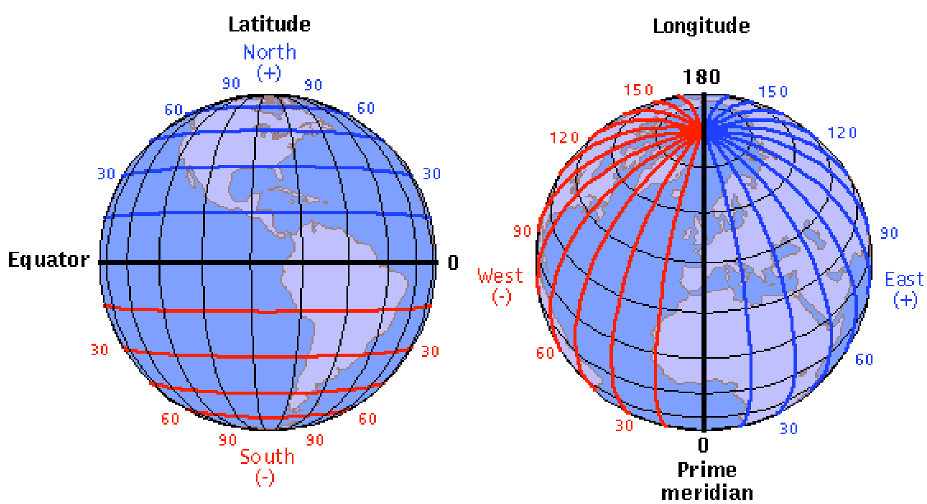


Figure 9: The Latitude and Longitude Coordinate System for the Earth
From http://meteonorm.com/support/tools/coordinates/

- **Global Positioning System (GPS):** Global Positioning System is a radio navigation system that allows land, sea, and airborne users to determine their exact location, velocity, and time 24 hours a day, in all weather conditions, anywhere in the world.
    - GPS is not useful in underwater applications because the radio signals from the GPS satellites do not propagate through water well. Some AUVs verify their location by surfacing and then use the onboard GPS to establish its position.
    - However, GPS is extremely useful to pin point ROV dive locations at the water surface.

- **Triangulation:** The fixing of an unknown point by making it one vertex of a triangle, the other two vertices being known.
    - Triangulation is based on finding an unknown location using angle measurements to two known locations. Mathematically, the two known positions define the two vertices (and length of the one side) of a triangle and the two bearing measurements define two of the angles of the triangle. These three things fix the size and orientation of the triangle; thus putting the unknown position at the third vertex of the triangle (Figure 10).

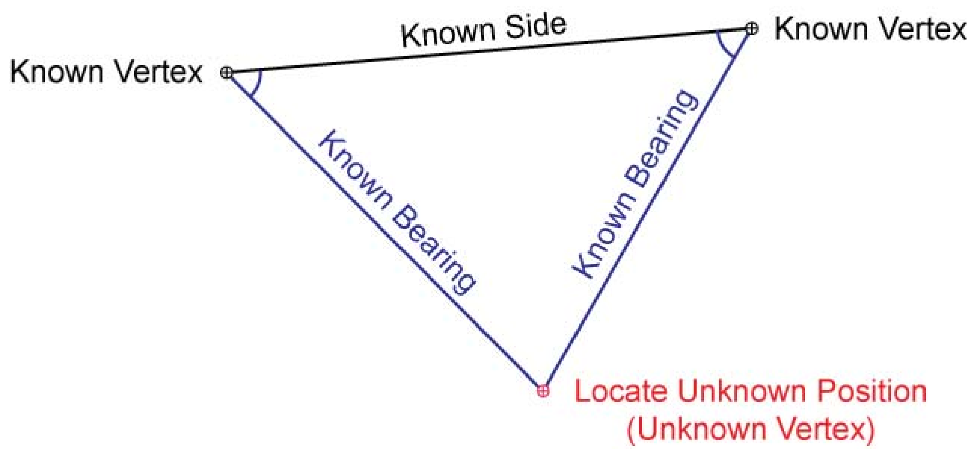


Figure 10: Locating an Unknown Position by Triangulation

- To use triangulation you need to be able to see two or more known features (the known vertices of the triangle).
- By knowing two known features and establishing lines through each of these known features (lines of position), you ascertain your position at the intersection of the two lines (Figure 11).

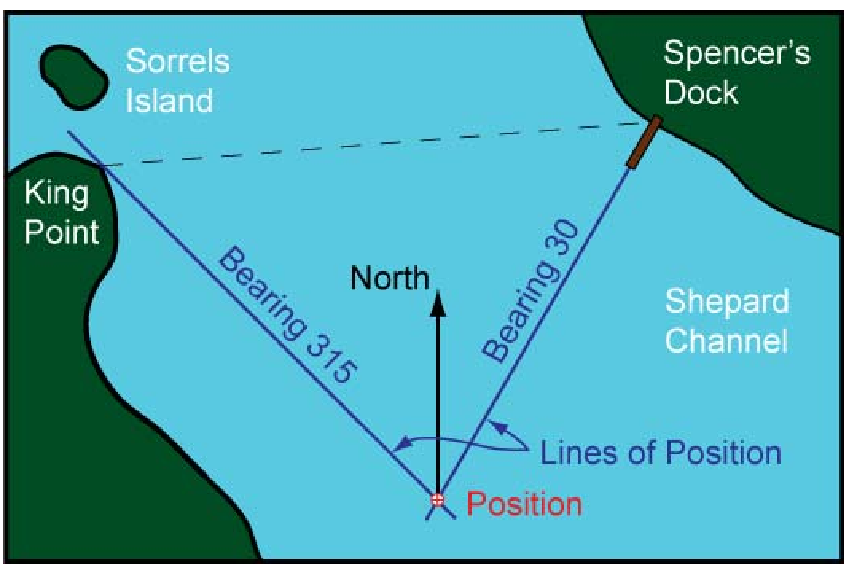


Figure 11: Triangulation on a Map

- **Navigation Instruments:**
  - Video Camera:
    - In small spatial scale (in the range of meters to centimeters), visual navigation using video cameras is valuable. The objective of this method is to maintain orientation at all times through visual contact with known subsea landmarks.
  - Compass:
    - Unlike radio signals, the earth's magnetic field penetrates water without difficulty.
    - A conventional magnetic compass that is waterproof and pressure-proof can be mounted on an ROV so that the pilot can keep track of direction by viewing the compass with an onboard camera.
    - Be aware that most compasses will give an inaccurate reading if they are not held level. A special compass called a gimbaled compass remains level despite a vehicle's pitch or roll.
    - Electronic compasses are available in several forms. One variety such as the Dinsmore 1490 digital compass outputs eight digital compass positions (N-NE-E-SE-S-SW-W-NW). Another electronic compass is the Parallax HMC5883L compass module which features 1 to 2 degree compass heading accuracy. See Control and Navigation 2 Lab 2.
    - Perform Control and Navigation 1 Lab 1 – Dinsmore 1490 Digital Compass.
  - Depth Gauge:
    - A depth gauge can serve as a navigational tool to provide clues on location for the ROV pilot.
  - Sonar:
    - Used in more advanced ROVs and AUVs.
    - Types:
      - Echosounder – Used to measure the vertical distance between the vehicle and the hard surface below.

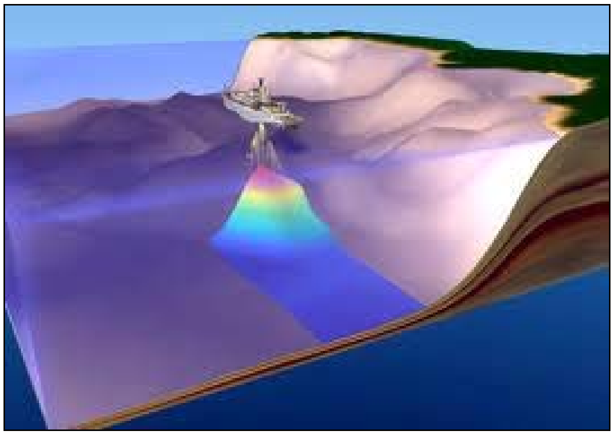
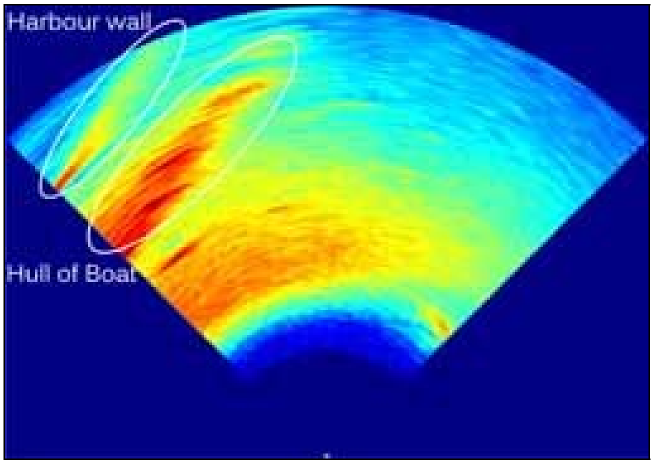


Figure 12: Echosounder Sonar

      - Sector Scanning Sonar – Commonly used on submersibles and ROV systems for a variety of tasks such as search and recovery, obstacle avoidance, tracking moving objects, and inspection. The sonar uses high frequency sound to acoustically image objects underwater, often at a much greater range than can be seen by a video camera. The sonar can operate and display data in variable sector (up to a complete circle).



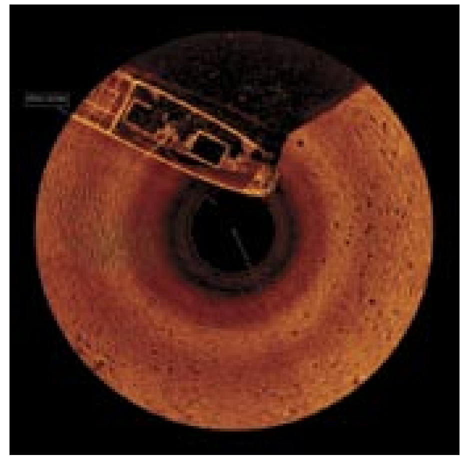


Figure 13: Images from Sector Scanning Sonar

- Acoustic Positioning System:
  - Seabed Grid Acoustic Positioning System – A system of seabed transponders where the ROV operates within the perimeter of the grid.

Figure 14: Example of Seabed Grid Acoustic Positioning System
From: http://www.imca-int.com/documents/divisions/survey/docs/IMCAS013.pdf

- Ship Mounted Acoustic Positioning System – Tracks the position of the ROV using surface vessel transponder.

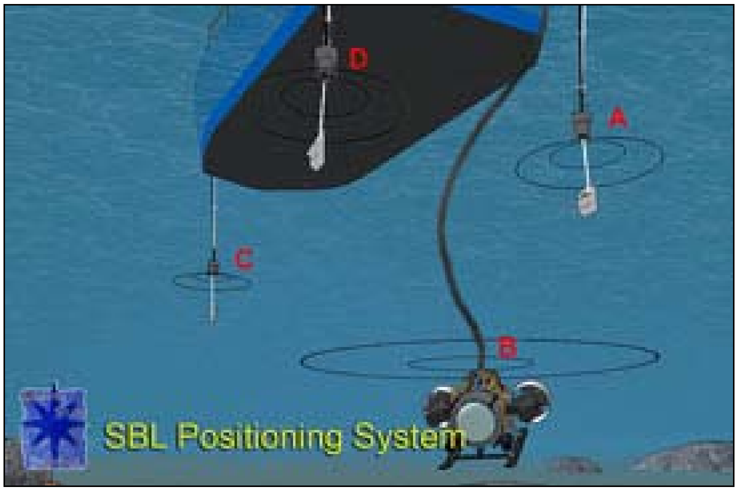


Figure 15: Ship Mounted Short Baseline Acoustic Positioning System

Surface station sonar transducer (A) sends an acoustic signal that is received by a transponder mounted on the tracked target (B). The transponder reply is received by three or more surface transducers (A, C, D). The positioning system determines distances B-A, B-C and B-D by measuring the signal run time and multiplying by the speed of sound. These distances in conjunction with depth information such as from a depth sensor on the tracked target are used to triangulate the target positions. Tracking precision depends on the spacing of the baseline (surface) transducers and the distance of the target. Wider spacing yields better precision.

From: http://www.imca-int.com/documents/divisions/survey/docs/IMCAS013.pdf

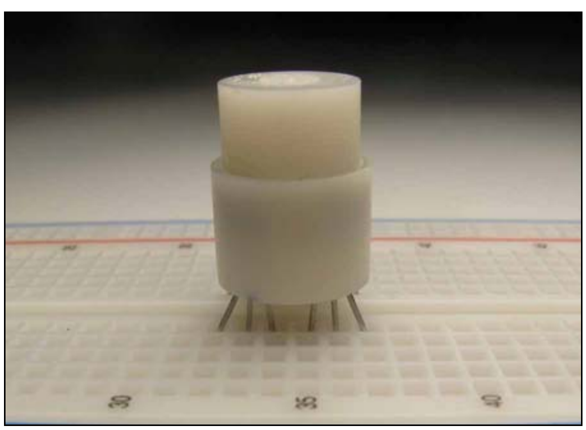
- Global Positioning System (GPS):
  - As stated previously, GPS is not useful in underwater applications. On boats however, GPS can be combined with sonar to determine the position of the underwater vehicle.

Cornerstone Electronics Technology and Robotics III
Control and Navigation 1 Lab 1 – Dinsmore 1490 Digital Compass

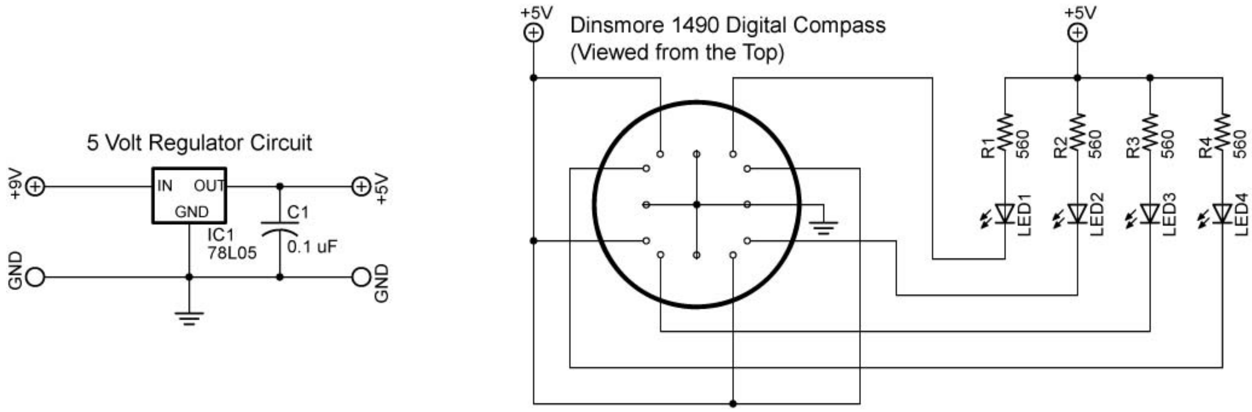
- **Purpose:** The student becomes familiar with the operation of the Dinsmore 1490 Digital Compass and how to integrate it with a PIC16F88 microcontroller.

- **Apparatus and Materials:**
  - 1 – Breadboard with a +5 Volt Power Source
  - 1 – Dinsmore 1490 Digital Compass
    - Datasheet and information:
      - http://www.cs.cmu.edu/~danieln/digital_compass.htm
      - http://www.morse-code.com/id32.htm
      - http://www.robsonco.com/Dinsmore/sensorinformation-a.pdf
      - http://www.gel.usherbrooke.ca/crj/Documentation/sensors/compasdigital1490.pdf
      - http://www.arrickrobotics.com/arobot/compass.html
      - http://www.zagrosrobotics.com/files/dens1490.pdf
    - Sources:
      - http://www.zagrosrobotics.com/shop/item.aspx?itemid=551
      - http://www.robsonco.com/Dinsmore/Untitled_7.html
  - 1 – LCD Display (Jameco Part #618003 or #1585979)
  - 1 – 20K or 25K Potentiometer
  - 4 – 560 Ohm Resistors
  - 1 – 4.7K Resistor
  - 4 – 10K Resistors
  - 1 – PIC16F88

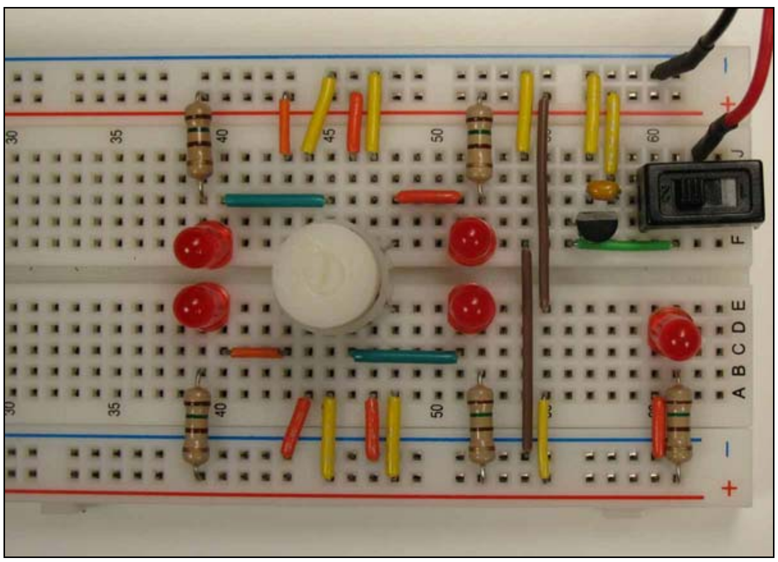
- **Procedure:**
  - For successful results, do not use a breadboard with steel base; the metal interferes with the operation of the compass.
  - Insert the Dinsmore 1490 Digital Compass into the breadboard as shown in the photograph below.



- Wire the Dinsmore2 circuit in the schematic and photograph below.

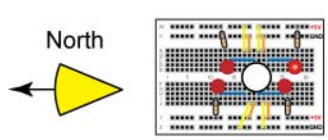


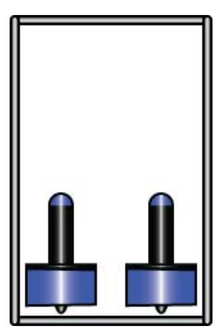
Dinsmore2



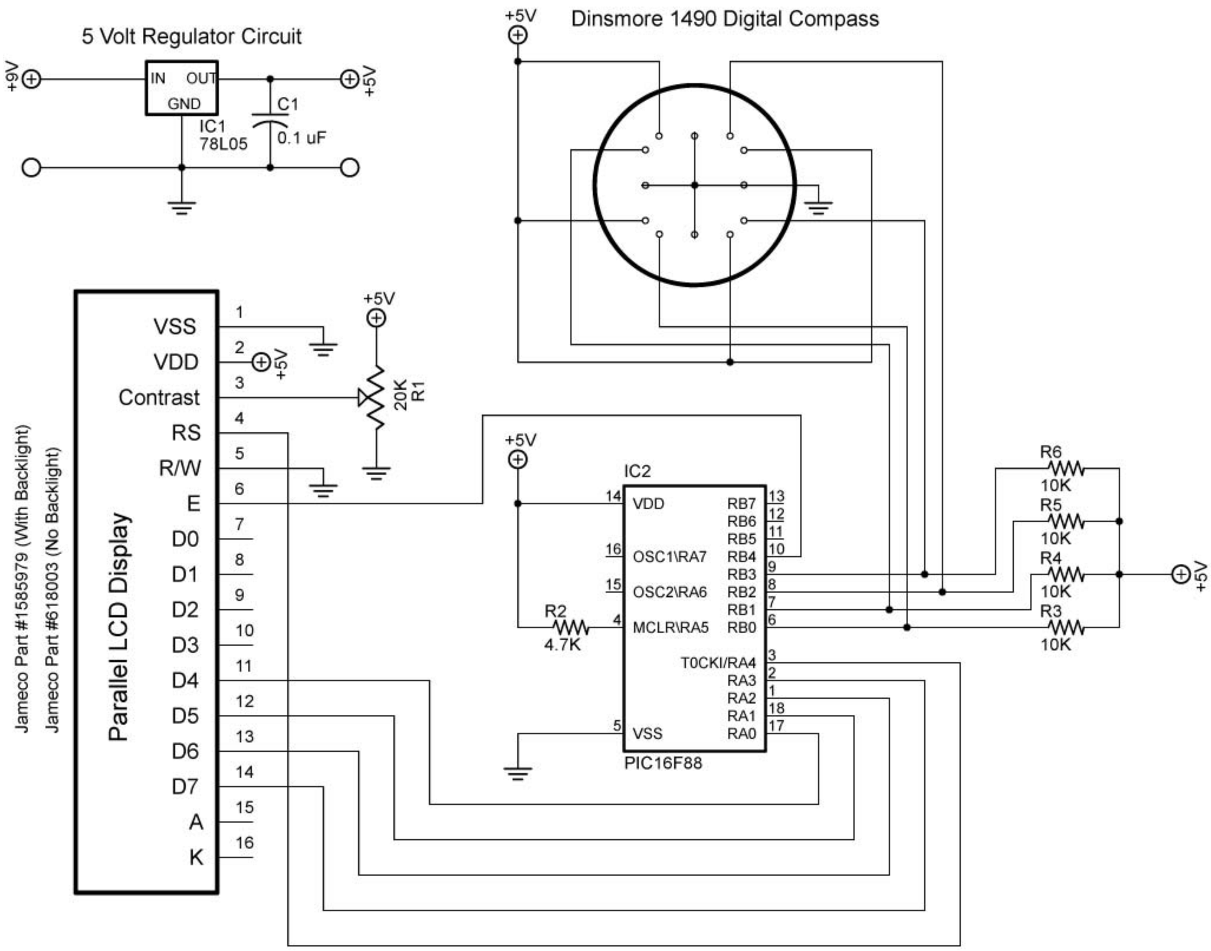
Dinsmore2 Circuit

- Rotate the breadboard to view the eight compass directions.
- Illustrate how you would mount the breadboard on an ROV to get the north reading aligned with the front of the ROV.



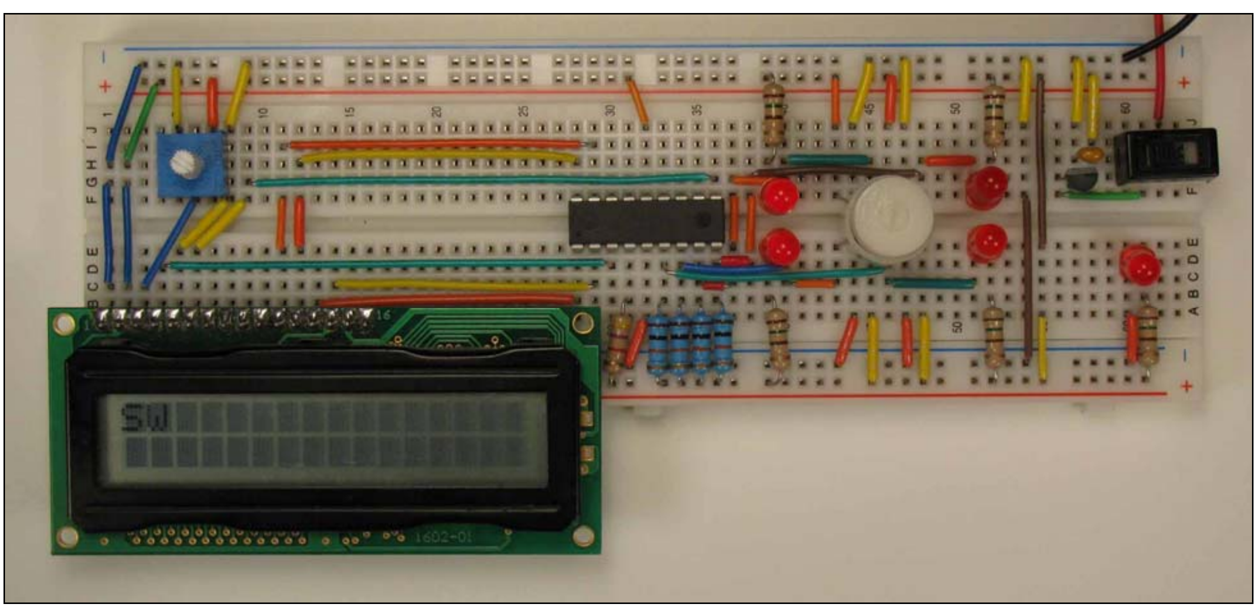


- Wire the Dinsmore1 circuit in the schematic and photograph below.



Dinsmore1

The LEDs and the 150 ohm resistors in the photo below are not shown on the schematic.



Dinsmore 1 Circuit

- PicBasic Pro Code:


```
'--------Title/--------

' File......dinsmore1.pbp
' Started....2/29/12
' Microcontroller Used:  Microchip Technology PIC16F88
'                        microchip.com
' PicBasic Pro Code: micro-Engineering Labs, Inc.
'                    melabs.com
' Compass: Dinsmore 1490 Digital Compass

'--------Program Desciption--------

' Dinsmore 1490 digital compass sends LOWs to
' PIC16F88 which displays the direction on an LCD.

'---------PIC Connections---------

'       16F88 Pin              Wiring
'       ---------            ----------
'         RA0                  DB4
'         RA1                  DB5
'         RA2                  DB6
'         RA3                  DB7
'         RA4                  RS
'         RB0                  Compass Pin 1
'         RB1                  Compass Pin 2
'         RB2                  Compass Pin 3
'         RB3                  Compass Pin 4
'         RB4                  Enable
'         RB5                  No Connection
'         RB6                  No Connection
'         RB7                  No Connection
'       See schematic for the other usual PIC connections

'---------LCD Connections---------

'        LCD Pin             Wiring
'       ---------            ----------
'          1               Ground(Vss)
'          2               + 5v(Vdd)
'          3               Center of 20K Pot(Contrast)
'          4               RA4(Register Select,RS)
'          5               Ground(Read/Write,R/W)
'          6               RB4(Enable)
'          7               No Connection(DB0)
'          8               No Connection(DB1)
'          9               No Connection(DB2)
'         10               No Connection(DB3)
'         11               RA0
'         12               RA1
'         13               RA2
'         14               RA3

'---------Constants/Defines-------
```

```
    DEFINE LCD_EREG   PORTB        'Set PORTB LCD Enable port
    DEFINE LCD_EBIT   4            'Set LCD Enable bit

'----------Initialization---------

    TRISB = %00001111              ' Set RB0 - RB3 as inputs, RB4 - RB7
                                   ' to outputs

    ANSEL = %00000000              'Sets all analog bits to digital.


    OSCCON = $60                   'Sets the internal oscillator in the
                                   '16F88 to 4 MHz

'------------Main Code------------

    PAUSE 1000                     'Pause to allow LCD to setup

start:

    IF PORTB.0 = 0 AND PORTB.1 = 1 AND PORTB.2 = 1 AND PORTB.3 = 1 THEN
LCDOUT $FE,1,"N"
    IF PORTB.0 = 0 AND PORTB.1 = 0 AND PORTB.2 = 1 AND PORTB.3 = 1 THEN
LCDOUT $FE,1,"NW"
    IF PORTB.0 = 1 AND PORTB.1 = 0 AND PORTB.2 = 1 AND PORTB.3 = 1 THEN
LCDOUT $FE,1,"W"
    IF PORTB.0 = 1 AND PORTB.1 = 0 AND PORTB.2 = 0 AND PORTB.3 = 1 THEN
LCDOUT $FE,1,"SW"
    IF PORTB.0 = 1 AND PORTB.1 = 1 AND PORTB.2 = 0 AND PORTB.3 = 1 THEN
LCDOUT $FE,1,"S"
    IF PORTB.0 = 1 AND PORTB.1 = 1 AND PORTB.2 = 0 AND PORTB.3 = 0 THEN
LCDOUT $FE,1,"SE"
    IF PORTB.0 = 1 AND PORTB.1 = 1 AND PORTB.2 = 1 AND PORTB.3 = 0 THEN
LCDOUT $FE,1,"E"
    IF PORTB.0 = 0 AND PORTB.1 = 1 AND PORTB.2 = 1 AND PORTB.3 = 0 THEN
LCDOUT $FE,1,"NE"
    PAUSE 100
    GOTO start
    END
```

Note: The **LCDOUT** $FE,1,... statement must be on the same line as the **IF..THEN** statement in the PicBasic Pro code.