Autonomous Underwater Vessel Sensors summary

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Artificial Intelligence & Information Analysis Lab

AUV sensors

Autonomous Underwater Vessels (AUV) are unmanned and untethered submersible vessel that can operate autonomously.

- AUVs should localize and navigate autonomously to complete their assigned mission.

Sensors typically deployed on AUVs are:

- Dead reckoning (DR)
  - Attitude Heading and Reference (AHRS) and Inertial Navigation System (INS).
  - Artificial Lateral Line System (ALLS).
- Radio Localization and Communications.

AUV sensors

- Hydroacoustics
  - Acoustic Beacons and Modems
  - Acoustic Doppler Current Profiler (ADCP)
    - Doppler Velocity Log (DVL)
  - Sonar
    - Imaging
    - Ranging / Bathymetric
- Optical Sensors
  - Led Beacons
  - Gated viewing

AUV perception

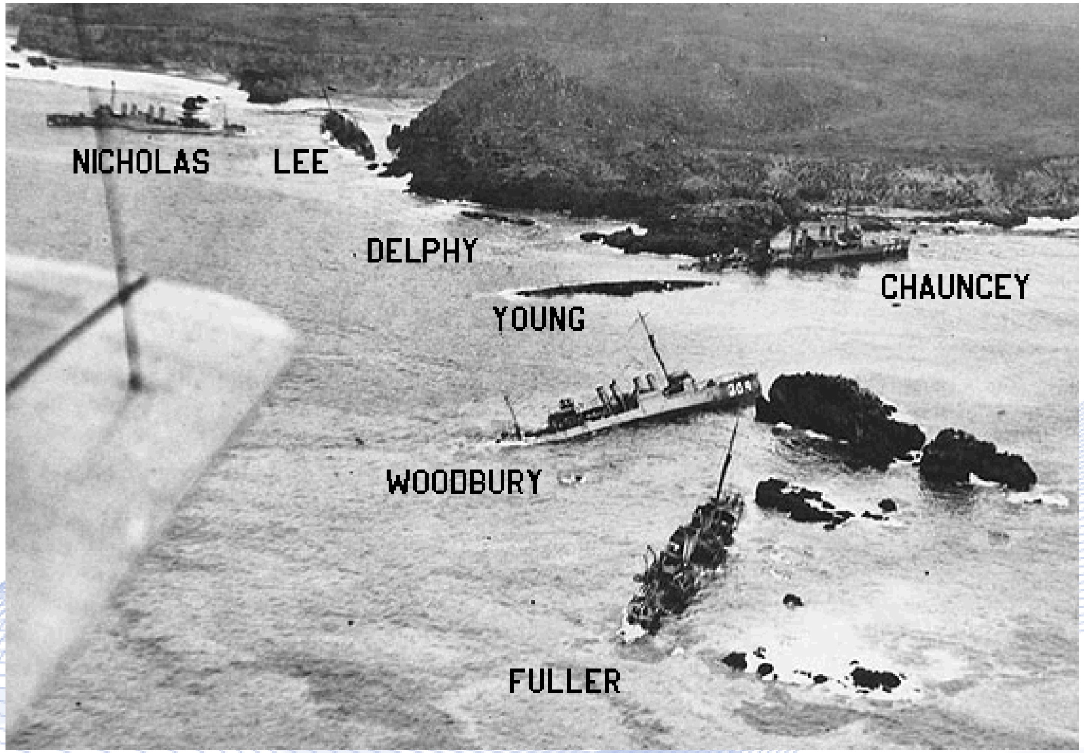
The AUV sensor data collected eventually gets processed and fused to provide a stable and redundant position estimation.

A combination of methods are used: State estimators

- Sonar Classification
  - Keypoint detection
- Simultaneous Localization and Mapping (SLAM)
- Cooperative Navigation.

Dead reckoning

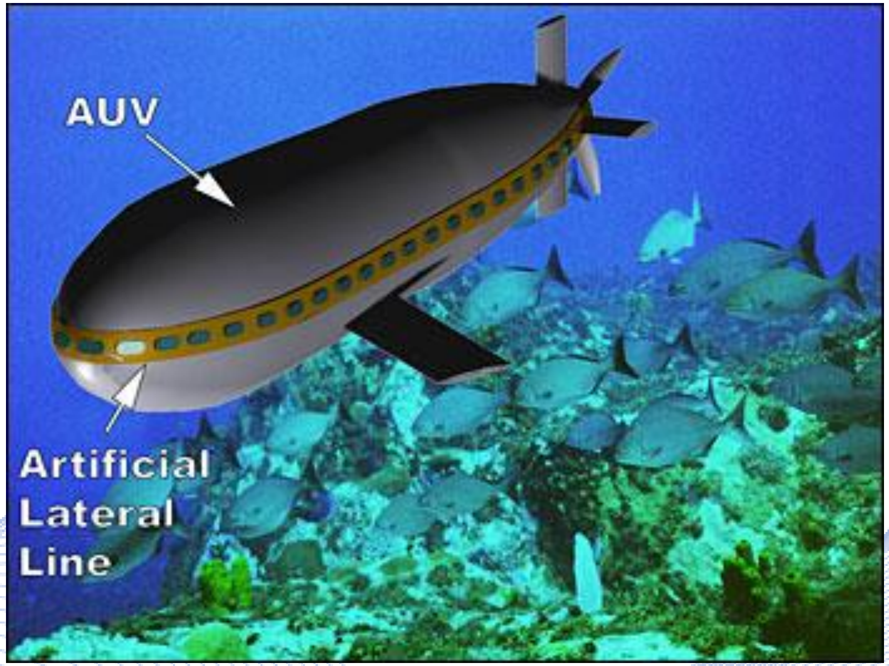
- It is acceptable only for short missions which do not require high navigational accuracy.
- It is still useful, when used together with other navigation methods.



Honda Point disaster(1923): Combined result of poor visibility, lack of trust on radio direction finding and possibly the Great Kantō earthquake [public domain].

Artificial Lateral Line

- Fish obtain hydrodynamic information about the surrounding environment through a lateral line.
- AUVs use Artificial Lateral Line systems (ALLS).
- It consists of an array of pressure sensors deployed along the horizontal plane of the vessel.
- Based on the fact that the neuromasts of fish are mainly distributed around the head area, the sensor density is also be higher around the bow of the AUV.



[PHO]

Radio Localization

- Sea water behaves like a conductor:
  - Electromagnetic signals get heavily attenuated.
  - Only signals in the MHz range are usable.
- Fresh water behaves closer to an insulator, which makes wireless communications under this environment viable.

Radio Localization

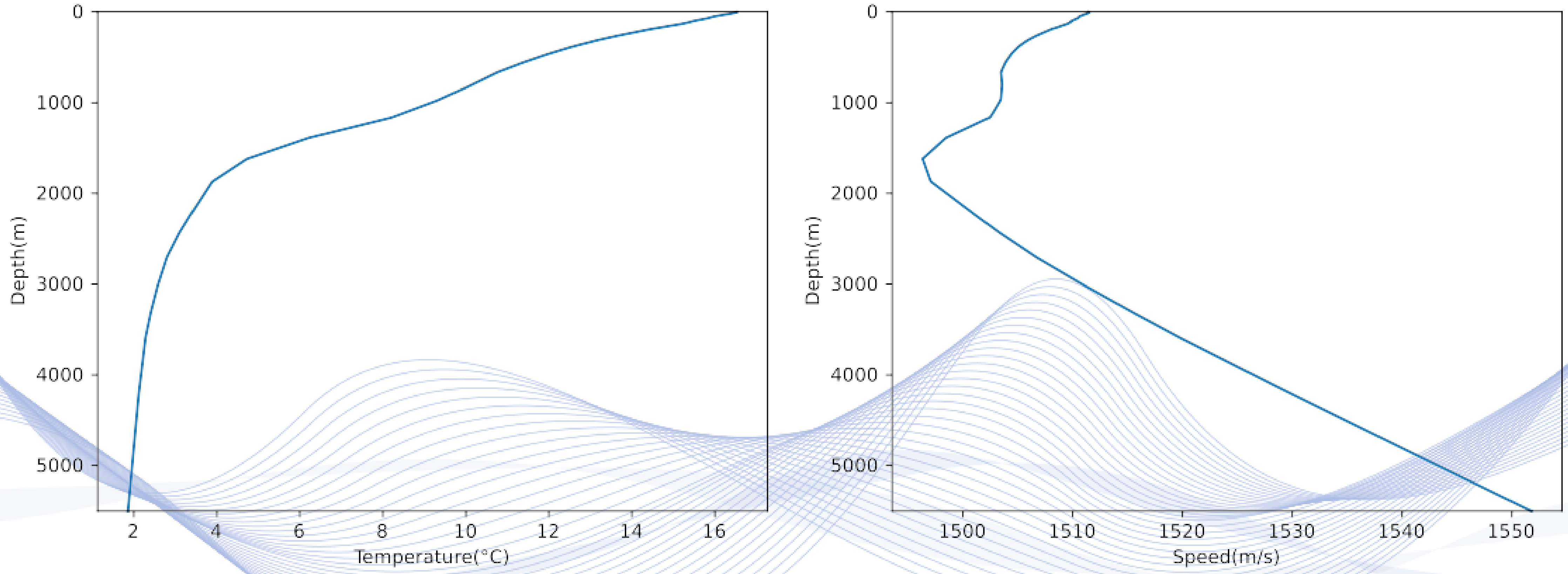
- When the vessel surfaces, or is near surface, the majority of communications are done using radio, because of the higher bandwidth, lower cost and higher reliability of air transmissions.
- Light speed is considerably lower in seawater.
- Recent studies have focused on the design of loop antennas coupled with the transfer medium (water).

Hydroacoustics

Hydroacoustics is the study of sound propagation in water.

- Hydrophone is a specialized microphone, designed for underwater operation.
- Sound waves propagate most efficiently underwater.
- However, sound waves are also the slowest, which may be unacceptable for real time AUV applications.
- The nominal speed is considered to be approximately 1500 m/s, with the exact value depending on three factors:
  - Temperature, Salinity, Depth.

Hydroacoustics

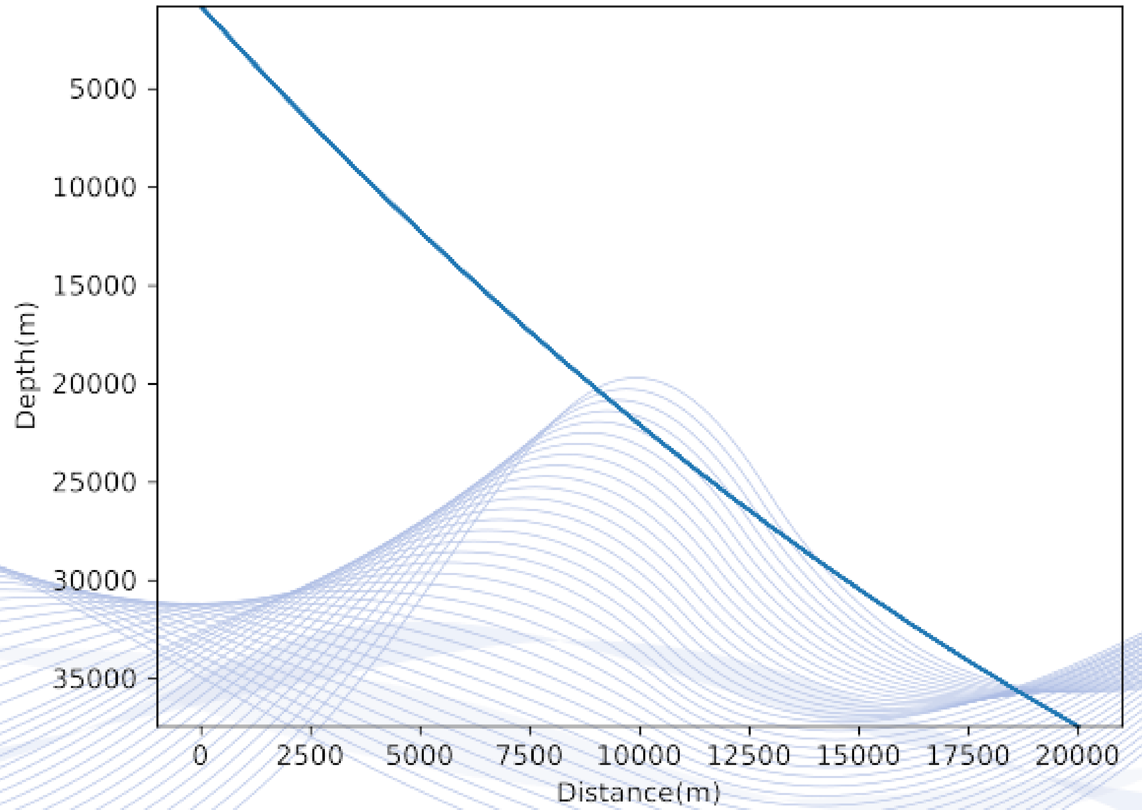


Water properties.

Hydroacoustics

Snell's Law:

$$\frac{sin(\theta_2)}{sin(\theta_1)} = \frac{c_2}{c_1}$$

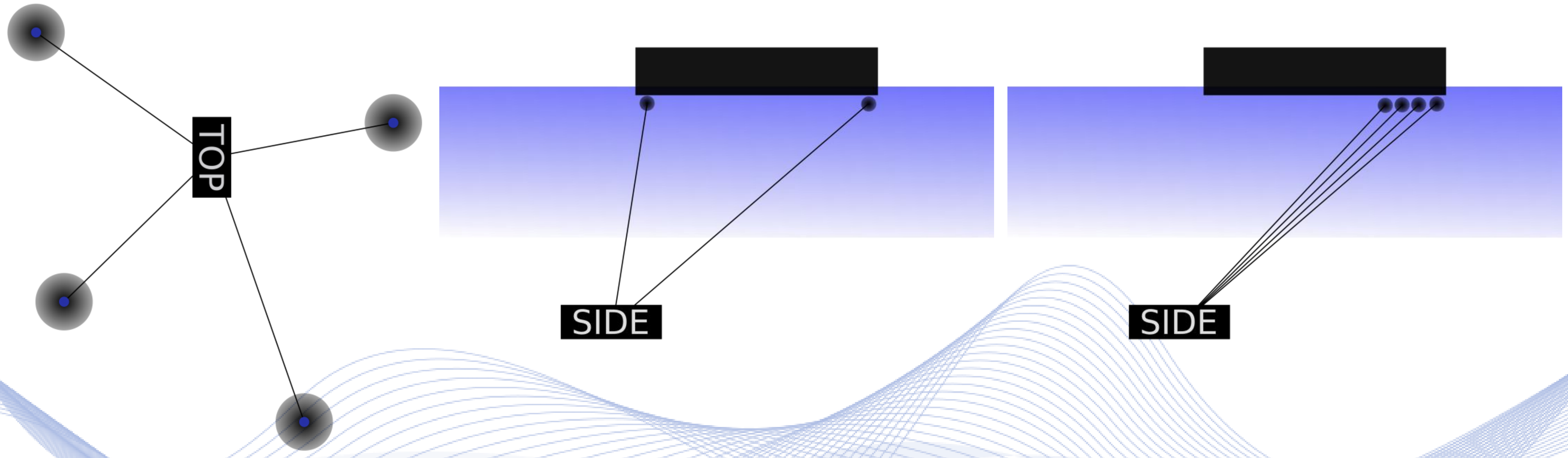


An online sound raytracer is available at http://www.arc.id.au/SonarRayTracing.html.

Acoustic Beacons

- AUV localization method consisting of communication and range measurements between at least one beacon and any number of underwater nodes.
- A minimal setup requires a transmitter on the beacon and a receiver on the AUV, although transceivers are usually used on both endpoints.
- Basic range measurement techniques used in underwater systems:
  - Time of Arrival (ToA).
  - Time Difference of Arrival (TDoA).
  - Angle-of-Arrival (AoA).

Acoustic Beacons



Long Baseline

Short Baseline

Ultra Short Baseline

Acoustic Doppler Current Profiler

- Acoustic Doppler Current Profiler (ADCP) is a category of sonar sensors specialized in measuring object speed underwater.
- ADCP operation is as follows: Acoustic pulses are transmitted and the velocity of a water column is measured by the Doppler shifted returns.

External housing of an ADCP sensor.

Sonar

Sound Navigation Ranging (SONAR) is a sensor type developed for locating objects underwater.

SONAR devices are further separated into 2 subcategories, based on output data:

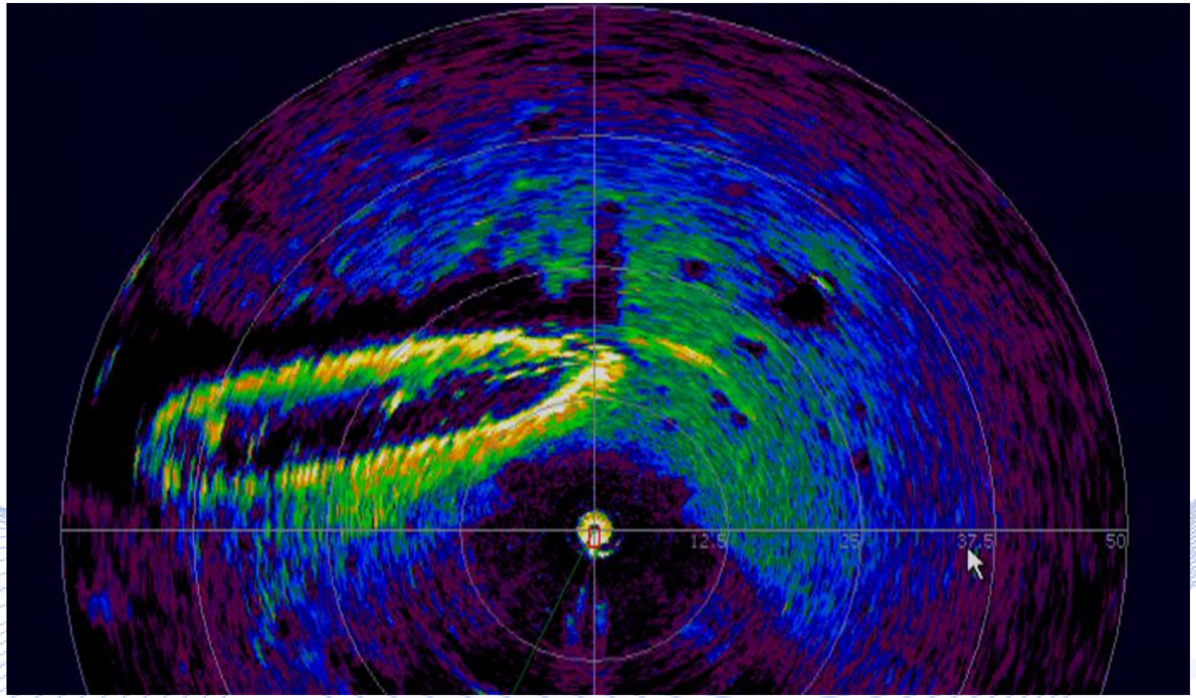
- Passive sonar locates objects based on emitted sounds.
- Because of their dependency on externals sound sources, these devices are seen as unreliable for autonomous navigation, so they are rarely used, except when necessary in military applications.

Sonar

Imaging sonar produces a 2D image, similar to a monocular camera.

Types:

- Sidescan
- Forward Look
- Synthetic Aperture
- Mechanicallly Scanned.



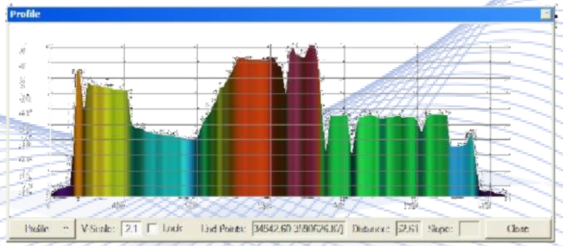
The ROV Little Hercules' scanning sonar imaged this 19th century wooden-hulled shipwreck in March 2012. Image courtesy of the NOAA Okeanos Explorer Program.

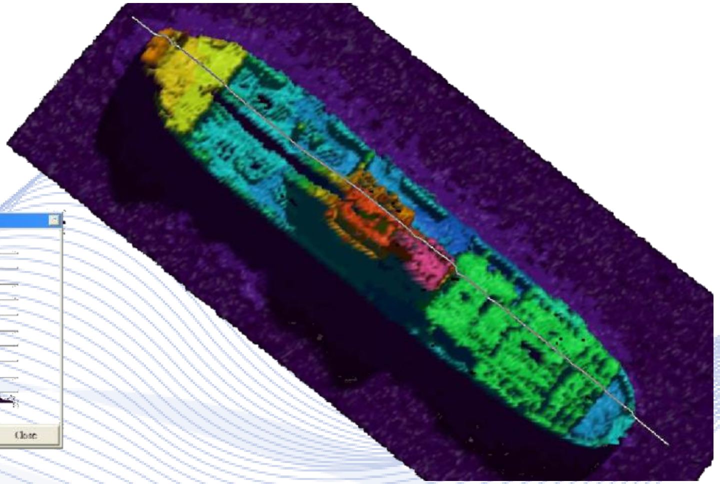
Sonar

The result of bathymetry sonar is a ’2.5D’ map, which is more similar to the output of a stereo camera.

Ranging/Bathymetric sonar types:

- Echo Sounder
- Profiler
- MultiBeam.





Multibeam image of the dredger King George that sunk in 1930 near North Rock, Bermuda.
The ship sits upright on a sand bottom in 18 m (60 ft) of water.
Image courtesy of Bermuda: Search for Deep Water Caves 2009.

Optical Sensors

Underwater optical sensors face a number of challenges:

- No natural illumination exists after photic zone (200m~1000m depth).
- Red spectral channel gets heavily attenuated.
- Special lenses (fisheye) or software-based calibration is required for correcting the distortion caused by the different refractive index of water.
- Scattering and absorption caused by floating particles in seawater.

Optical Sensors

Limitations of underwater optical systems:

- reduced range,
- susceptibility to scattering,
- inadequacy of lighting.

Nevertheless, there are occasions where optical sensors are utilized on AUVs:

- Use in tropical waters, which are clear and with good visibility.
- Use in hovering AUVs, which require centimeter localization accuracy around the target (shiphulls/shipwreck inspections), something that is not easily obtained from acoustic sensors.

Visual Odometry and SLAM

SLAM algorithms based on methods used on conventional ground robotics, have been successfully tested underwater.

Such a SLAM method [BEL2017]:

- uses HarrisZ as the feature extractor and RANSAC to eliminate wrong correspondences.
- It was tested on the New Tsukuba dataset, as it contains dimly lit scenes.
- Also experimental tests were performed at an underwater depth of 40 m.

Cooperative AUVs

- In sea trials, formations of multiple glider AUVs were used to perform adaptive ocean sampling.
- They were able to maintain their formation using only dead reckoning underwater and satellite communications when surfaced.
- The need for periodic surfacing of the AUVs can be mitigated, if methods similar to those used in underwater beacons are deployed for AUV2AUV communications.

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Q & A

Thank you very much for your attention!

More material in
http://icarus.csd.auth.gr/cvml-web-lecture-series/

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