Extending the Reach of Cabled Networks: Prospects for Acoustically Linked Undersea Sensing

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NSF HAZARD SEES (1331463)
University of Pittsburgh
Northwestern University
Carnegie Mellon University
Wireless Undersea Sensing

Topics
1. Motivation for wireless
2. Other methods:
   • Buoys
   • Wave Glider
3. Observatory extensions
4. Proposed system for Indonesia
5. Field testing in Indonesia
6. Next steps and discussion

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PI: Louise Comfort, University of Pittsburgh.
Seismologist: Emile Okal, Northwestern University

With additional material from two other NSF funded projects: acoustically-linked buoy observatory (2002-2006), and acoustic link for MARS observatory project (2004-2008).
Motivation for Acoustic Connections:

- **Leverage** the investment in cables and seafloor nodes.
- **Add new sensors** without need for ROV operations.
- **Extend reach** at scales of several to tens of kilometers.

Obvious Limitations:

- Lower bandwidth.
- May require local clock.
- Cost is in energy (bits transmitted per Joule), longer range means lower efficiency.

Advantages: **increased sensor density, real-time data recovery.**
Previous Work:
An Acoustically-Linked Deep-Ocean Observatory

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Additional sensors from APL-UW and SIO.
Buoy location near Nootka Fault

Kinemetrics Q330 Data Logger

Hydrothermal Vent Sensors, ADCP and Modem

Glass floats in hard hats

Ocean Bottom Seismograph and Modem

Acoustic Release

Acoustically Linked Surface Buoy and Iridium RF Link

Iridium Link
OBS Ready for Deployment

Modem Transducer

Directional acoustic modem provided burst rates up to 5000 bps, but slower aggregate rate due to link protocol (ACKs).
OBS Data Uploaded via Acoustic Link

BDH: 20 Hz Pressure, BH1/2/Z: 20 Hz Seismometer, BH3: 40 Hz Vertical, LDH: 1 Hz Pressure (DPG), LH1/2/Z 1 Hz Seismometer
Summary: Successful operation for 7 months at 550 Kbytes/day. 5000 bps burst rate key to efficiency.
So what happened to the buoy-based acoustic observatory?

Two advancements:
- Cabled observatories (MARS, then OOI)
- Liquid Robotics Wave Glider

Note: DART buoy is an operational example of a buoy-based seafloor system – and doing well (except in Indonesia).
Fixed Sea-Floor Network: Regional Cabled Observatory

Provide drop-in instrument capability & AUV communication

Wireless extension for subsea observatories

Deep-Sea Observatory with Acoustic Communications for AUVs and Instruments
Prototype Acoustic Modem Node for MARS Observatory

Prototype Acoustic Modem Node for MARS Observatory

**Node Features**
- Two bands 10 and 25 kHz
- Embedded Micro-Modems plus data acquisition system.

**Prototype Testing**
- 2 remote systems at 2 km
- 2 remote systems at 4 km
Results at the MARS Observatory

Observations:
- 2 km: >90% success rate (to 97% for some periods)
- 4 km: varied, depending on surface wave conditions (reflections)
- Noise from occasional ROV operations impacts reception.

Link Statistics - Packet Success
Open Ocean Gateway: Wave Glider

- Wave Glider autonomous surface craft substitutes for moored buoy or ship.
- Excellent for deep-water data retrieval and monitoring.
Main Challenge: Transducer integration

Mounting Options
1. Sub-mounted modem.
2. Towed modem.

Acoustic modem on wave glider sub, but is near to mechanical noise sources. Achieved 1000 bps typical.

1. Pod integrates modem to sub, but has some noise from moving parts.
2. Tow body offers very low noise platform but requires a 3rd body.

Motion-decoupling tow cable

Directional transducer
Acoustically-Linked OBS via Wave Glider

- Wave Glider removes need for large ship to deploy and recover buoy.
- Scripps approach includes dual wave gliders to maintain one on-site continuously.

*Despite cost of Wave Glider, this may be the best approach for real-time OBS data access where no cable is available.*

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Scripps Wave Glider with WHOI Modem uploaded 1.3 MB/day from OBS in 2015.
See Poster HC4: John Orcutt, et. al.

Glider track holding demonstration, 70 days, 300 km offshore California.
Indonesia Tsunami Threats

Earthquake sources
Red patches show areas of the fault ruptures responsible for the 2004 and 2006 tsunamis.

NSF HAZARD SEES (Science, Engineering, and Education for Sustainability) Project.

Multi-disciplinary approach to near-field tsunami hazard reduction.

Source: Where the First Wave Arrives in Minutes Indonesian Lessons on Surviving Tsunamis near Their Sources. United Nations Educational, Scientific and Cultural Organization Intergovernmental Oceanographic Commission. IOC Brochure 2010-4
Sumatra Network

- Multiple threats, both offshore and within Mentawai basin.
- Need for OBS deployments to complement recent and new GPS stations on shore and islands.
- Near-field threat is focus of HAZARD SEES, but offshore important as well.

J. McGuire (WHOI) with collaborators at EOS (S. Wei, K. Sieh), LIPI, BMKG, BPPT.
Deep-Ocean DART Buoy

Far-Field Tsunamis: DART Buoy is proven technology for detection. In Indonesia many have been vandalized. Near-field buoys will be even easier targets.

Figure 18. German GITEWS Tsunami Buoy – Stolen Superstructure and Buoy Payload

Figure 20. Indonesian Tsunami Buoy Recovery
Problem: Near-shore DART buoys that detect tsunami pressure signal have been vandalized.

Solution: Replace buoys with underwater acoustic network.
Proposed Solution:
No surface buoy.
Detect tsunami sub-sea, send data via acoustics to shore.

Pressure sensor in Mentawai Basin

Send warning to shore

Detect near-field tsunami in deep water

System Overview

Padang

Siberut
Cable-Based System

- BPPT is working on cable system with pressure sensor (tsunameter).
- Plan: add **acoustic modem** to end of cable to **extend length** of cable by 20-40 km.
- Acoustic network will increase warning time with no extra cost in cable.
Remote Sensor System

Design Goals & Constraints

- Pressure sensor on bottom, well-coupled to seafloor in “lander”.
- Acoustic modem above bottom to provide for best propagation to and from remote unit.
- Use existing lander (currently at Andalas University) and acoustic modem above lander as short mooring.
- Total system height constrained by deployment method and vessel size.

Risks

- Near-bottom currents can impart very small motions to array that can couple into pressure sensor. However, signal filtering can remove this noise.
The challenge with near-field tsunamis is to detect the wave while the earthquake signals are still present because both are picked up by pressure sensor.

Not easily solved: More sophisticated instrumentation (APGs + triaxial acceleration) with in-situ processing may be the answer.

Figure 2: Tsunami of November 17, 2003, as measured at the tsunameter located at 50 N 171 W.
Nano-Resolution Depth Sensor

Figure 1 from: *Comparing the Nano-Resolution Depth Sensor to the Co-located Ocean Bottom Seismometer at MARS* by Elena Tolkova and Theo Schaad, (NorthWest Research Associates and Paroscientific, Inc.)

Pressure sensor shows very good correlation with Seismometer – as expected.

Figure 1: Records of the vertical component of the ground velocity and of the bottom pressure variations (HP filtered) upon seismic waves arrival at MARS after October 21, 2010, and March 11, 2011 earthquakes.
Near-Term Approach to Near-Field Detection: Filter and Threshold

Raw Pressure Record
- 0.5 mm resolution, $F_s=10$ Hz.
- 60 sec moving average filter
- Contamination from motion is high frequency.

Filtered Pressure Record
- Ocean tides removed
- High-pass filter.

Real-Time Detector Notes

Real-Time Detector:
- Runs continuously at 1 Hz sample rate.
- Filters for signal in tsunami band.
- Check level against threshold.
- When detection occurs: Wake-up modem and transmit filtered signal to shore.

Key points:
- Sensor does not detect tsunami, it reports pressure level over a pre-set threshold for interpretation on shore.

Example pressure data from 2012 Haida-Gwaii being used for validation

Low-power real-time processor board (ARM-based CPU).
Detector Development: Use of data from 2012 Haida Gwaii Earthquake, BC

Proposed Data Processing
- Decimate to 0.1 Hz
- Remove one hour moving mean to take out tide
- Tsunami band filter (2 to 90 minutes), adds up to 3 minutes or more of delay (red line in graph shows filtered data)
- Apply ‘event threshold’ set at 1 cm to zero-mean data
- Apply ‘tsunami threshold’ set at 3 cm, to filtered data

Haida Gwaii earthquake and tsunami signal from sensor FS20B

Processing as described in previous slide:
1. Remove mean.
2. Bandpass filter in 200-5000 second band (assumed tsunami signal band).
Total delay through filters is 3 minutes.

Example of detector processing for event with separated ground motion and pressure wave signals.

Ground motion signal is still clearly evident in waveform, though human observer can see differences between residual from motion in tsunami band, and the tsunami signal itself. Changing bandwidth could help improve difference, but still will not be unequivocal.
An alert report will go out immediately (filter delay may be present) if the ‘Tsunami threshold’ is exceeded.

The alert reports will have only 1 or two samples of post-threshold data, the rest will be past history. Alerts will continue for at least 10 minutes.

Approach for acoustically transmitted data:

1. Provide regular status to show system is functional and ‘noise’ level.
2. Provide alert when signal exceeds threshold

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The alert reports will have only 1 or two samples of post-threshold data, the rest will be past history. Alerts will continue for at least 10 minutes.
Field Testing in Indonesia – Mentawai Basin, near Padang, Sumatra
Results: Measured Temperature from CTD and Computed Sound Speed

- Warm surface water
- Shallow warm water is ‘fast’ and sound bends away from it.
- Below 1000 m the water is cold, but pressure also increases sound speed.
Acoustic Propagation In Mentawai Basin

Results: 350 bps at 27 km with high reliability.

Conclusions: Long-range bottom-bottom horizontal communications is feasible in certain environments, and may support “buoy-less” tsunami warning in Indonesia.
Siberut Island Cable Landing Site, Deployment Planned for Late 2018

Survey data by BPPT using the Baruna Jaya I

7 km distance provides for depths greater than 500 m
Future Options for Indonesia

Future Plans
- When proven, the concept for short cables (5-10 km) and wireless acoustics (25-50 km) may provide for tsunami detection outside the Mentawai Islands.
Conclusions: Back to the Feasibility of Acoustically–Linked Cabled System

What makes a low bandwidth (100 bps) connection feasible?

1. Emerging methods in automated detection.
2. Data compression, e.g. wavelet-based methods.
3. Low power processing is advancing to enable deep learning on mobile devices.

What about the energy cost?

Example: 10 minutes of 1 Hz data compressed to 1 byte/sample at 100 bps is <1 minute transmission time. In battery cost: <$1.

Automated Earthquake Detection

Wavelet Encoding for Compression

OOI Cabled Observatory: Cascadia
Acoustic Extensions at OOI Axial Site

Example Acoustic Network:
- 30 km paths
- One hop through intermediate node.
- Why not larger? Requires extra energy for routing.

Feasible? Maybe – Indonesia project may help prove practicality in a real scenario.