Underwater acoustic positioning system for the KM3NeT-IT project

Salvatore Viola
Acoustic positioning system

The acoustic positioning system is a mandatory subsystem for an underwater neutrino telescope

**Aims:**

1. Provide optical module positions during the telescope operation for muon track reconstruction
2. Give a guide during the deployment of the telescope structures and infrastructures

**Key elements:**

- Long Baseline of acoustic transceivers anchored in known and fixed positions.
- Array of acoustic sensors (hydrophones) moving with the Detection Unit mechanical structure
- Auxiliary devices: compasses, CTD, sound velocimeters, current meters
KM3NeT-Italia plan:

- 8 Detection Units in 2014
- 24 Detection Units in 2016
- A full Building Block before 2020
The acoustic positioning system for the 8 towers of KM3NeT-Italia detector will be based on the positioning system developed by NEMO-SMO teams in collaboration with ACSA for NEMO Phase-2 prototype.

NEMO – SMO positioning system design:
- 5 autonomous beacons (32 kHz – TSSC code)
- 2 acoustic sensors per floor
- Monitoring station

Time of Emission (ToE) of each beacon pulse, is obtained measuring the Time of Arrival (ToA) of this pulse at the hydrophones mounted on the base tower (monitoring station) that are anchored on the seafloor in known positions.
NEMO – SMO acoustic positioning system

14 acoustic sensors
10 SMID hydrophones: floors 1, 2, 3, 4, 6 (no F0 monitoring station)
2 FFR – SX30: floor 7 (proposed by UPV-CPPM)
2 ECAP Piezo: floor 8 (provided by ECAP)

Acoustic beacons
1 ACSA - LBL beacon on tower base
2 ACSA – LBL beacon (~400 m far from tower base)
1 UPV-CPPM beacon - time synchronized with the detector Master Clock (KM3NeT Solution)

Autonomous ACSA beacon
(not time synchronized with the apparatus)
NEMO-SMO acoustic sensors

Floor #1 + Floor #6 + Tower-base
SMID Hydrophones
+ SMID preamplifiers (gain: +38 dB)

Hydrophone + preamplifier sensitivity calibrated at NATO - URC (40 hydrophones)

Measured differences ≤ ±2 dB

Relative Hydrophone sensitivity variation with hydrostatic pressure at 20 kHz

300 Bar  400 Bar

Measured variations ≤ ±1 dB

Radiation lobe
30 kHz
50 kHz
**Additional acoustic sensors**

**Floor #7**

*FFR (Free Flooded Rings)*  
Hydrophones + SMID preamplifiers (gain: +38 dB)

**Floor #8**

*ECAP Piezo sensors + ECAP preamplifiers*

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**Sensor Technology STD**

*FFR - SX30*

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**Receiving Response of the System**

[Graph showing receiving response over frequency]
Raw data are continuously acquired underwater at 24 bit/192kHz by the acoustic sensors and transmitted to shore in AES/EBU protocol on a local internet network at the shore station.

The acoustic signals are sampled by ADC and “labeled” with absolute GPS time.
NEMO-SMO: sensors performances 1/2

Floor 6 SMID Hydro #0
Sensitivity: -172 dB re 1 V/µPa

Floor 7 FFR Hydro #0
Sensitivity: -156 dB re 1 V/µPa

Floor 8 ECAP Piezo #0
Sensitivity: -145 dB re 1 V/µPa
Acoustic signals from external beacons (about 400 m far from tower base) confirm the nominal sensitivity of SMID and FFR hydrophones. Some inconsistencies have been found for ECAP piezos installed inside the Optical Acoustic Modules.

Sensitivity has been calculated taking into account the geometrical attenuation and absorption related to the ionic relaxation of MgSO$_4$ and B(OH)$_3$. 

![Graph showing sensitivity comparison between SMID, FFR, and ECAP hydrophones and piezos.](image)
Acoustic positioning: first results

Hydrophones positioning script

Input:
- Beacons positions
- TOAs
- Distances between hydrophones in the same floor
- Sound velocity (CTD's data)

The code finds iteratively a root (zero) of a system of nonlinear equations.

07/05/2013
00:00 UTC

Not longer bar! Just different sensors position (piezo).
- Beacons installed on each tower base close to hydrophones (autocalibrating LBL)

- Autonomous beacons: help to triangulate in the first stages of the installation

- Beacons on Junction boxes
KM3NeT-Italia new approach

- Auto-calibrating LBL (beacon + receiver)

- Timing:
  - Master Clock beacon
  - Time stamped receiver

- Programmable acoustic emission signal (frequency, amplitude and waveform) through RS-232 link

- FCM emission trigger signal reception (LVDS link)

- Max emission level 190 dB re 1 μPa @ 1 m

- Acoustic beacons equipped with pressure gauge
KM3NeT-Italia: acoustic sensors

In KM3NeT-Italia “Digital Hydrophones (DH)” solution will be employed
Preamplifier, ADC and DIT on board, molded in the cable connecting the hydrophone to the FCM

- **Bandwidth:** 100 Hz - 70 kHz
- **Frequency sampling:** 192 kHz
- **Resolution:** 24 bit
- **Communication with FCM:** AES/EBU standard

2 types of hydrophones

**High Sensitivity Digital Hydrophones (HS-DH)**
Sensitivity: -190 dB re 1 V/μPa w/o preamplifier
Floors: 13, 14 (2 x HS-DH) /floor

**Low Sensitivity Digital Hydrophones (LS-DH)**
Sensitivity: -200 dB re 1 V/μPa w/o preamplifier
Floors: 1÷12 (2 x LS-DH) /floor & tower base (1 x LS-DH)
The real time monitoring of yaw, pitch and roll of each floor is provided by an Attitude Heading Reference System (AHRS) board, developed by INFN, placed inside each FCM vessel.

- Perform measurements of absolute orientation of the FCM vessel
- Provide information on the acceleration (during opening and during operation) of the floor

It consists of MEMS gyroscopes, accelerometers and magnetometers on all three axes. The yaw, pitch and roll are calculated by means of a 9th order extended Kalman filter with a dynamic angular resolution of 0.01°.
Conclusions

- NEMO-SMO acoustic array fully functional since deployment

- All hydrophones working with the expected performances

- Acoustic beacon’s signals can be easily disentangled from the underwater background acoustic noise.

- Positioning code ready

Multidisciplinary approach successful
- Automatic codes for acoustic sperm whale detection and evaluation of their size
- First sperm whale detection after 3 days of data acquisition

Beacon pulses (32 kHz)  
Sperm whale clicks  
March 27, 2013
Perspectives

- Digital hydrophones to improve S/N ratio and detector integration
- Autocalibrating LBL
- The largest acoustic array in the Mediterranean Sea
- Acoustic correlations with data from EMSO cabled acoustic arrays in Catania site (2000 m depth)

HIGH ENERGY PHYSICS PERSPECTIVES

Long term and real-time monitoring of high frequency acoustic background at different depths.

Input for simulations of large scale acoustic detector in Capo Passero Site

- Test of sensors and electronics for a future deep sea acoustic neutrino detector
- Test of DSP techniques to improve acoustic signal detection
- Detection of neutrino-like signals produced by calibrated sources
Thank you for your attention
BACKUP
Auxiliary devices: sound velocity measurement

Standard oceanographic sensors will be displaced the towers 2001-2002-2003 on-board tower base and dedicated instrumented floors.

<table>
<thead>
<tr>
<th>TOWER 2001</th>
<th>TOWER 2002</th>
<th>TOWER 2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor 14 → CTD</td>
<td>Floor 14 → DCS</td>
<td>Floor 14 → Sound Velocimeter</td>
</tr>
<tr>
<td>(CTDs Microcat SBE 37)</td>
<td>(Aanderaa Zpulse 4520-DW )</td>
<td>(miniSVS Valeport)</td>
</tr>
<tr>
<td>Floor 7 → DCS</td>
<td>Floor 7 → CTD</td>
<td>Floor 7 → Oxigen Sensor</td>
</tr>
<tr>
<td>(Aanderaa Zpulse 4520-DW )</td>
<td>(CTDs Microcat SBE 37)</td>
<td>(AanderaOptode 4831-DW)</td>
</tr>
<tr>
<td>Floor 1 → CTD</td>
<td>Floor 1 → DCS</td>
<td>Floor 1 → Sound Velocimeter</td>
</tr>
<tr>
<td>(CTDs Microcat SBE 37)</td>
<td>(Aanderaa Zpulse 4520-DW )</td>
<td>(miniSVS Valeport)</td>
</tr>
<tr>
<td>TB → Pressure gauge</td>
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<tr>
<td>(Paroscientific 8BT4000-I)</td>
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This allows sufficient vertical sampling of the water column for calibration and oceanographic purposes.