Underwater Positioning & Communication

“Hybrid system using both USBL and LBL for shallow waters”

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SPECIFICATIONS

PRINCIPLES

Underwater positioning
Surface positioning
USBL positioning
LBL positioning

R&D

Transmission & signal study
Treatment
Embedded electronic
Specific sensors

SEA TRIALS

Positioning accuracy
Trajectory in harbor conditions

SYSTEM COMPONENTS

Beacon
Buoy
Monitoring display unit
Acoustic recovery device
To **position** targets (divers, AUVs...) either **under the sea level or at the sea surface**

- Acoustic positioning with specific sensors
- GPS positioning

To **communicate** by sending and receiving (rescue) signals

- Acoustic communication
- Radio communication

To track in **real-time** and simultaneously up to 12 units

- State of the Art embedded Electronic
- Cutting edge Signal Processing Algorithm

In **obstructed** and shallow water zones

- Specific signals and Signal Processing Algorithm
- Ultra Short BaseLine Technologies

**Autonomous and easily deployable** even from lightweight boats

- Low power electronic
- Cutting edge Li-Ion batteries
- Compact electronic
- Entire positioning system fitting in a small buoy

**Within a large zone**

- Combination of Long BaseLine & USBL Technologies
OVERVIEW

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Underwater positioning

- **Inertial Measurement Unit (IMU)**
- **User Interface**
- **Trajectography software**
- **Acoustic emitter/ receiver**
- **Acoustic communication**
- **GPS**
- **Radio communication**

**Principles**

**BUOY**

- **GPS**
- **Time Reference**
- **Embedded Electronic**
- **Signal Processing**
- **Inertial Measurement Unit (IMU)**
- **Acoustic emitter/ receiver**

**ACOUSTIC HEAD**

- **Embedded Electronic**
- **Signal Processing**
- **Acoustic emitter/ receiver**

**BEACON**

- **GPS**
- **Time Reference**
- **Embedded Electronic**
- **Signal Processing**
- **Acoustic emitter/ receiver**

**MONITORING UNIT**
Surface positioning

**BEACON**
- GPS
  - Time Reference
  - Embedded Electronic
  - Signal Processing
  - Acoustic emitter/receiver

**BUOY**
- GPS
  - Time Reference
  - Embedded Electronic
  - Signal Processing
  - Acoustic emitter/receiver
  - Inertial Measurement Unit (IMU)
  - Acoustic emitter/receiver

**MONITORING UNIT**
- User Interface
  - Trajectography software

Radio communication

**ACOUSTIC HEAD**
Inertial Measurement Unit (IMU)
**PRINCIPLES**

**LBL positioning**

- Buoy 1 Position
- Target Immersion/Buoy 1
- TOA /Buoy 1

- Buoy 2 Position
- Target Immersion/Buoy 2
- TOA /Buoy 2

- Buoy 3 Position
- Target Immersion/Buoy 3
- TOA /Buoy 3

**MONITORING UNIT**

Terrestrial Reference Frame
- 3 Buoys Position
- Calculated Target Position

**User Interface**

Trajectography software
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➢ *Transmission & Signal study*

➢ *Signal Treatment*

➢ *Embedded Electronic*

➢ *Specific Sensors*
Study the adequate transmission mode

« Synchronous vs. Asynchronous mode »

- **Asynchronous mode**
  - ✓ 2x Acoustic path => 2x signal loss
  - ✓ 2x Acoustic reception => 2x detection uncertainty

- **Synchronous mode**
  - ✓ 1 single Acoustic path => More efficient
  - ✓ 1 single Acoustic reception => less uncertainty

Synchronization: both transmitter & receiver on GPS Clock
Time share mode for 12 targets
Study the adequate signal: **Criteria**

<table>
<thead>
<tr>
<th>Signals</th>
<th>Correlation</th>
<th>Rejection</th>
<th>Reflection</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positioning</td>
<td>+++</td>
<td>+++</td>
<td>+++</td>
<td>+</td>
</tr>
<tr>
<td>Communication</td>
<td>- - -</td>
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</tbody>
</table>

**Signals to be analysed**

- **Phase Shift Keying (PSK)**
- **Frequency Shift Keying (FSK)**
- **Frequency Modulation (FM – Sinus type)**
Trials

Autocorrelations

Rejection & orthogonality
Trials

Tolerance against reflected signals

\[ S(t) \quad \text{Correlation} \quad S(t+\tau) \]

Reflected signal: Detection error

PSK - - -
FM + + +
FSK + + +

Main correlation peak
Amplified secondary correlation peak
Results

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<td>FSK</td>
<td>++ +</td>
<td>++ +</td>
<td>++ +</td>
<td>+</td>
</tr>
<tr>
<td>FM</td>
<td>-- --</td>
<td>++ +</td>
<td>++</td>
<td>++ +</td>
</tr>
</tbody>
</table>

- **POSITIONING: FSK**
  - Narrow main Peaks
  - Spaced secondary Peaks
  - Good tolerance against reflected signals

- **COMMUNICATION: FM**
  - Narrow main Peaks
  - Close secondary Peaks
  - Tolerance tagainst reflected signals: good detection/bad accuracy
Transmission & Signal study

**Signal Treatments**

Embedded Electronic

Specific Sensors
Develop the adequate algorithm

OBJECTIVES FOR POSITIONING

- Detect identified signal
- Measure arrival time
- Measure corresponding phase
- For numerous channels in parallel
- Easy to implement

```
Analytical Signal \( H(S(t)) = Sa(t) \) → Demodulation → Correlation

Signal \( S_1(t) \) → Time of arrival 1 Instant Phase 1

Analytical Signal \( H(S(t)) = Sa(t) \) → Demodulation → Correlation

Signal \( S_n(t) \) → Time of arrival \( n \) Instant Phase \( n \)
```
OBJECTIVES FOR COMMUNICATION

- Simultaneous detection of 12 signals
- Easy to implement
FOCUS

- Transmission & Signal study
- Signal Treatment
- **Embedded Electronic**
- Specific Sensors
Develop the adequate hardware

ADDITIONAL CONSTRAINTS

- High accuracy Time reference
- Real time acquisition/processing (FS=200kSps - 5μs)
- Low consumption electronic
- As compact as possible

ARCHITECTURE

- Positioning function
- Communication function-Rescue codes
- Communication function- Recall codes
POSITIONING FUNCTION
- 12 codes received (time share)

Hydrophone signal x4 ➔ Analogic conditioning ➔ Analogic To Digital converter ➔ FPGA ➔ DSP ➔ XYZ TOA

18cm - 7"
COMMUNICATION FUNCTION: Rescue codes -> Buoy

- 12 codes simultaneously received

Hydrophone signal x2 ➔ Analogic conditioning ➔ Analogic To Digital converter ➔ FPGA ➔ DSP ➔ Rescue code x12
COMMUNICATION FUNCTION: Recall codes -> Beacon

- 2 codes simultaneously received

Hydrophone signal \( \times 1 \) → Analogic conditioning → Analogic To Digital converter → DSP → Beacon code

Common code

- 12cm – 4.7"
- Transmission & Signal study
- Signal Treatments
- Embedded Electronic
- **Specific Sensors**
Develop the adequate equipment

Buoy Acoustic Head

- **Positioning USBL**
  - 4-hydrophone tetrahedral array
  - 1 Inertial measurement unit

- **Communication**
  - 1 emission transducer – recall codes
Beacon Acoustic Head

➢ *Transducer for Positioning USBL & Communication*
  ✓ *Position and immersion signal Emission*
  ✓ *Rescue signal Emission*
  ✓ *Recall signal Reception*
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Positioning accuracy

- Fixed point
- Multiple beacons
- Along underwater rope

Trajectory in harbor conditions
Position accuracy

Fixed point

- **Test conditions**
  - Harbor Area
  - Sea floor depth: 12m
  - Test duration: 3 hours
  - > 2000 positions
  - Beacon depth: 6m

- **Results**
  - Raw positions in 7,5m radius circle
  - Accuracy (Std Deviation)
    - Radius=1,42m
    - X=1,28m
    - Y=1,95m
Position accuracy

Multiple Beacons

➢ Test conditions
  ✓ 12 beacons tracted by boat
  ✓ 4 buoys
  ✓ Reference GPS on boat
  ✓ Sea floor depth: 15m
  ✓ Beacon depth: 6m
  ✓ test duration: 25mn
  ✓ > 300 positions

2 groups of 6 Beacons
Position accuracy

Multiple Beacons

Results
Position accuracy

Multiple Beacons

Results: **High accuracy positionning**—within 1m
Position accuracy

Along underwater rope

- **Test conditions**
  - Harbor Area
  - Sea floor depth: 6m<d<15m
  - Reference underwater rope
  - Acoustic masking by vessels
  - 2 divers with beacon
  - 4 buoys
  - Diver depth: 5m
  - 5mn test duration
  - > 60 positions
Position accuracy

Along underwater rope

- **Results**
  - High accuracy positioning
  - Positions accuracy < 3m
  - Detection loss: none

[Diagram showing underwater rope and diver paths]
Trajectory in Harbor conditions

- **Test conditions**
  - Harbor area
  - 4h test duration
  - Sea floor depth: $2m < d < 12m$
  - Long stretched zone
  - Sea State: 3
  - Night dive

- **Exercice zone with 1 beacon and 1 GPS trajectory**

- **14 buoys**
- **6 divers with beacon**
- **Reference GPS on boat**
- **Diver between 1m to 6m depth**
- **> 2800 positions**
Trajectory in Harbor conditions

Results

- **Path:** very well followed
- **2.5km x 0.5km zone** accurately covered
- **High accuracy positioning**

*Exercise zone with 1 beacon and 1 GPS trajectory*
Trajectory in Harbor conditions

- Results
  - High accuracy positioning (<5m)
  - Very narrow area
  - Vessels acoustic masking
  - Reflections on concrete and steel pier

First Trajectory details

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USBL Mode Only

USBL and LBL Mode (hybrid)
SEA TRIALS

Trajectory in Harbor conditions

➢ Results
  ✓ High accuracy positionning (<5m)
  ✓ Very narrow area
  ✓ Vessels acoustic masking
  ✓ Reflections on concrete and steel pier

Second Trajectory details
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Develop the adequate equipment

Beacon

- **Transducer for Acoustic Positioning & Communication**
- **Radio antenna & modem for all surface transmission**
- **GPS Antenna for time synchronization and surface positioning**
- **Embedded intelligence & time reference**
- **Flashing light for automatic alarms**
- **Li-Ion batteries**
**Buoy**

- **Acoustic Head for communication, USBL & LBL positioning**
- **GPS Antenna for time synchronization and surface positioning**
- **Radio antenna & modem for all signals transmission**
- **Embedded intelligence & time reference**
- **Flashing light for signalization**
- **Li-Ion batteries**
SYSTEM COMPONENTS

Monitoring and trajectography Display Unit

- Radio antenna & modem for all signals transmission
- Computer with User Interface & Trajectography softwares
- Li-Ion batteries
- GPS Antenna
Acoustic Recovery Device

- 2-hydrophone array to localize targets: range & bearing
- Embedded intelligence & time reference
- Li-Ion batteries
OSEAN SAS
(simplified joint stock company)

Founded in 2003

2013 Turnover : 1,5M€

18 employees

10 research engineers

6 technicians (electronics, mechanical, acoustics & signal processing)

Located in Southern France,

by TOULON French navy harbor
COMPANY

OSEAN Building
(450 sqm)

Electronics laboratory (100 sqm)

Acoustic test tank
THANK YOU
FOR YOUR ATTENTION