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Underwater acoustic slant range measurements related to weather and sea state

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Abstract. Underwater range measurements are key factor in underwater acoustic positioning, used in Long Base-Line (LBL) or Ultra Short Base-Line (USBL) computing techniques. These measurements are commonly carried out through acoustic communications between modems and their accuracy can be affected by different factors, such as sea state, weather conditions, and obstacles in the line of sight propagation. This is especially important in shallow waters areas, where others phenomena such as multi-path have to be considered. Therefore, range accuracy and the associated position estimation errors are an important area of research. Here, we addressed the relation between range measurements variability and sea state (i.e. currents or waves height) as proxy of real-world conditions, affecting acoustic positioning performances. For that purpose, a long-term deployment have been carried out in the underwater cabled observatory OBSEA, which provide different measurements of the sea and weather state.

1. Introduction

The ranges between two points are usually measured using two acoustic modems, which are typically endowed with a standard command to know their reciprocal distance, using a two-way message exchange. The range can be easily derived by knowing the Time of Flight (TOF) of the message and the sound propagation velocity (approx.1500 m/s). However, this latter is usually difficult to know, due its sensitivity in front of temperature and salinity variations. This can cause a systematic error in range measurements, and therefore, reduce the accuracy of the target estimation. Moreover, some outliers in range measurements can also be produced through the multipath effect (i.e. echoes) or other variations due the sea or weather state (i.e. wave height), which introduce a non-Gaussian error in range measurements.

Here, we studied the range measurements variability in a long-term deployment of two acoustic modems and an Ultra Short Base-Line (USBL) in the cabled observatory OBSEA (www.obsea.es), as a EMSO Testing-Site. This multiparametric platform is endowed with different biogeochemical and oceanographic sensors, with the capacity of measuring Conductivity, Temperature and Depth (by CTD). The observatory is connected to a surface buoy with a meteorological station also measuring sea conditions, including temperature and wind. All these environmental parameters could be

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correlated with the range measurements obtained through the acoustic modems in a continuous and real-time fashion.
The complexity of the water channel in communications is well known [1], which introduces different sources of errors in acoustic positioning systems, some of which already had studied in previous work [2][3][4]. A mathematical model for range error was also derived to study the range-only and single-beacon positioning methods ([5] and references therein). However, a long-term measurement are conducted in this paper, and therefore these range measurements can now be compered under different marine conditions, allowing a trustful evaluation of positioning performances in real-world scenarios.

2. Description of the method

In this section, the method used to measure both ranges and marine state are described, including the deployment and use of the two acoustic modems, a USBL, and the use of sensors installed in the OBSEA. Moreover, a short description about range-only underwater target localization, as well as its relation with the range error mathematical model, are presented.

2.1. Evologics acoustic modems deployment

Two acoustic modems and one USBL (all from Evologics; www.evologics.de) were installed on December (2017). The configuration of this deployment can be observed on Figure 1. The USBL and one modem were deployed on the seafloor. These devices were connected to a secondary cylinder, which provides both Ethernet and power supply through the OBSEA observatory. Moreover, an ODROID embedded computer was used as a main controller to perform the tests, which was also allocated inside the cylinder. Finally, a second modem was installed on a buoy, in order to obtain a challenging operative scenario for the acquisition of positioning measurements.

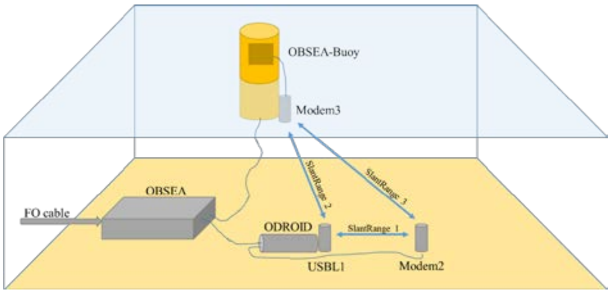

Figure 1. This figure shows the deployment configuration of the two modems and a USBL at the seafloor and on a buoy in the area of the OBSEA cabled observatory (its junction box and cable locations are also shown).

2.2. Underwater observatory OBSEA

The OBSEA observatory (www.obsea.es) is located at 4 km from the coast and at 20 m depth. This shallow water deployment area represent challenging operative scenario, to test acoustic communications measurement and their performance in the real-world. On the other hand, this observatory has installed different sensors to measure the environmental variables, such as a CTD, an Acoustic Doppler Current Profilers (ADCP), and a Buoy with a meteorological station. OBSEA and Evologics' devices deployed are shown in Figure 2.

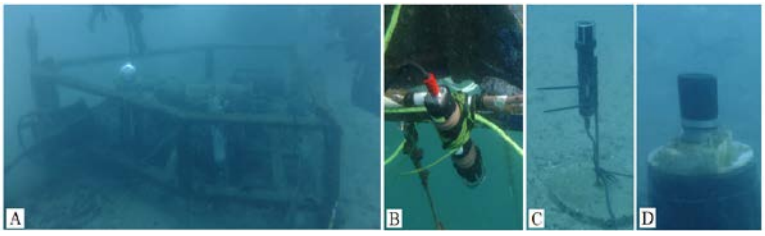

Figure 2. A) The OBSEA platform with its junction box and cable. B) Acoustic modem installed on the buoy. C) and D) are the acoustic modem and USBL, respectively, installed on the seafloor near OBSEA.

2.3. Range-only and single-beacon target localization and tracking
The main architecture behind the range-only and single-beacon underwater target tracking using autonomous vehicles, is shown in Figure 3. The idea was to estimate the position of an underwater target with a known depth, using only the ranges between the target and an autonomous vehicle, which is in a known position. The autonomous vehicle can be a surface vehicle with a GPS, or an underwater vehicle with a good dead-reckoning system.

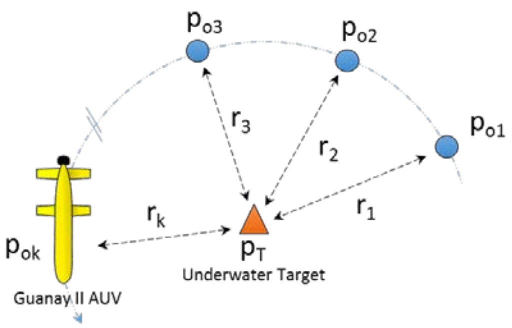

Figure 3. Representation of the AUV Guanay II (as observer) and the underwater Target.

In this scenario, the location of an underwater target using only the range measurements are

$$\bar{r}_k = \|p_T - p_{ok}\| + w_k, \quad k \in \{1,2, \dots, m\} \tag{1}$$

where $p_T = [\, x_T \;\; y_T]$ and $p_{ok} = [\, x_{ok} \;\; y_{ok}]$ are the target and the AUV positions at time step k, with some zero mean Gaussian measurement error $w_k \sim \mathcal{N}(0, \sigma^2)$, where σ^2 is its variance

3. Results and discussions
The range between the USBL and the seafloor modem are presented in Figure 4, where the slant range measured from December 6, 2017, to February 24, 2018, are reported at sample frequency of 5 min. The Received Signal Strength Indicator (RSSI) and Integrity Level of the communication between modems are also presented. These measurements are important for the evaluation of the goodness of the communication, and therefore the range measured. The range in this case is quite constant, which has a mean equal to 25.1 m and σ equal to 0.044 m. Similar result between the USBL and the modem on the buoy has been studied, in this case, the variations introduced by the sea state is significantly higher, Figure 5.
To correlate the measured range variations with the sea state a parameter called buoy inclination has used. This parameter indicates the absolute buoy inclination respect to the normal vector of the plane x-y. Then, the standard deviation (STD) of both range measurements and buoy inclination have computed in groups of 1h have computed to observe the influence of the sea state with the range variations, Figure 6.

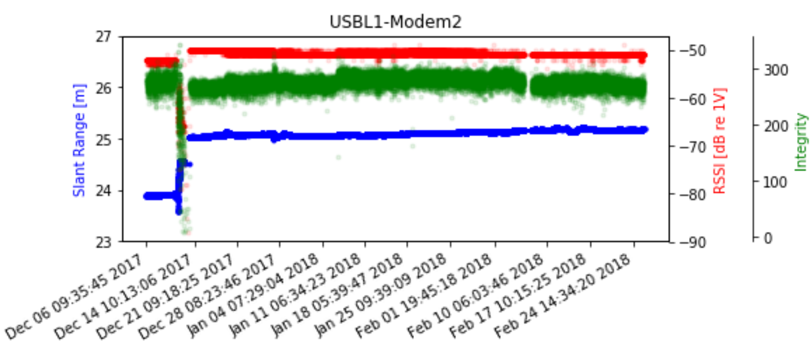

Figure 4. Range measurements obtained during 3 months. Where, we can observe a range equal to 25 m, with good RSSI and Integrity signals.

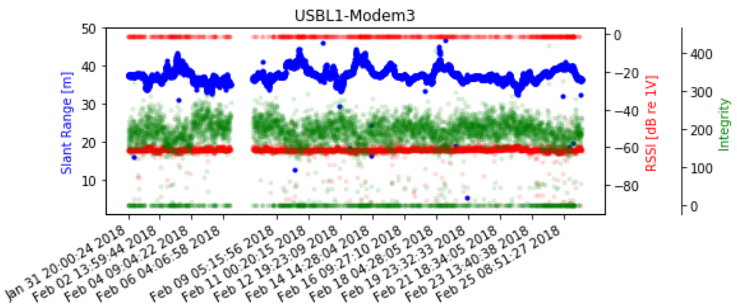

Figure 5. Range measurements between USBL, and the modem attached on the buoy, during one month, where a bigger variation than the seafloor modem is observed.

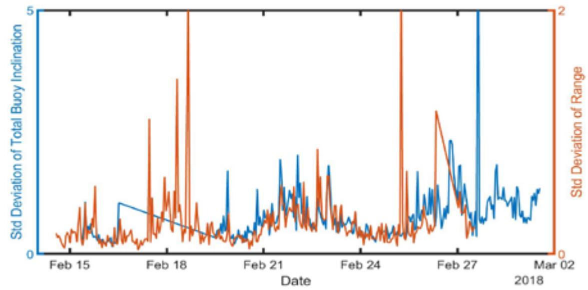

Figure 6. STD of both range measurements and buoy inclination. The range have been obtained using the surface and bottom modems. In this graphic the correlation between the sea state and range variations can be observed.

4. Conclusions

A long-term slant range measurement between acoustic modems have been carried out. These measurements can be compared to weather and sea state to find correlations between them. This study helps on the characterization of the range error, and therefore the range-only target positon estimation.

Acknowledgments

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