TNA PROJECT REPORT

1. Project Information

Proposal reference number	JN_CALL_2_1
Project Acronym (ID)	EvoLUL
Title of the project	Long term Underwater localization in extreme conditions
Host Research Infrastructure	Expandable Seafloor Observatory (OBSEA)
Starting date - End date	17/10/2017 – 14/12/2018
Name of Principal Investigator **Home Laboratory** **Address** **E-mail address** **Telephone**	Dr. Sc. Konstantin Kebkal EvoLogics GmbH Ackerstraße 76 D-13355 Berlin Germany kebkal@evologics.de +49 30 4679 862-0
User group members	Konstantin Kebkal, EvoLogics GmbH, Germany Pierre-Jean Bouvet, ISEN, France Ivan Masmitja, UPC, Spain

2. Project objectives

The main idea of this project is to study the performance of range-only single-beacon localization algorithms, with which both static and moving target can be localized and tracked using autonomous underwater vehicles. These kind of methods can be used, for example, to follow a tagged animal. Moreover, it can be implemented in a fleet of autonomous vehicles to know the position between them, as a future work, if the results in terms of accuracy and feasibility are acceptable.

A long term deployment experiment will offer the possibility to ensure robustness of the range estimation at different meteorological and sea conditions, and quality of the data along time. Variability of the measurements will be studied and correlated with sea conditions since OBSEA platform is measuring waves, currents and water properties.

3. Main achievements and difficulties encountered

This project had two main goals:

a) Study the range error obtained using acoustic modems at different sea states
b) Evaluate these kinds of errors for different types of target localization algorithms

We studied the range variability due to sea conditions comparing the range obtained between two seafloor modems, and the range obtained between a seafloor and a modem in a buoy. Because tests were conducted during more than 271 days, their variability could be correlated among different sea parameters such as wave's height, buoy movement, pressure variations, etc. The results will be used to

The activity described in this report has received funding
from European Commission's H2020 Framework Programme
under JERICO-NEXT project, grant agreement No. 654410.

understand/estimate the target tracking accuracy expected vs the sea conditions presented. Moreover, different tracking tests have been conducted showing differences in algorithm's performances due to range noise and tracking paths.

Finally, some electromagnetic interferences were encountered which were propagated through the cabled observatory and the modems. This electromagnetic noise can sporadically cause acoustic communication problems between modems. These kinds of issues were observed previously in other similar scenarios, and need to be addressed using either uncoupled DC/DC power supply, EMI filters, etc. However, despite these interferences, the test has been conducted properly thanks to the robustness of the modems.

4. Dissemination of the results

Two congress publications has been carried out:

1. I. Masmitja, S. Gomariz, J. Del Rio, P. J. Bouvet, J. Aguzzi, "Underwater multi-target tracking with particle filters", **OCEANS Kobe**, 2018, Japan

2. I. Masmitja, M. Carandell, P.J. Boubet, J. Aguzzi, S. Gomariz, J. Del Rio, "Underwater acoustic slant range measurements related to weather and sea state", **IMEKO – XXII World Congress Belfast**, 2018, United Kingdom

And a third publication in a peer review paper is in progress:

3. I. Masmitja, S. Gomariz, J. Del Rio, B. Kieft, T. O'Reilly, P. J. Bouvet, J. Aguzzi "Range-Only and Single-Beacon underwater target tracking methods: from theory to practice", **IEEEAccess 2019**.

5. Technical and Scientific preliminary Outcomes

Two acoustic modems and one USBL (all from Evologics; **www.evologics.de**) were installed in December 2017. A representation of this deployment can be observed in Figure 1. The USBL (M1) and one modem (M2) 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. A second modem (M3) was installed on a buoy, in order to obtain a more challenging operative scenario for the acquisition of the range measurements. Finally, a third modem (M4) was designed to be installed on an Autonomous Underwater Vehicle (AUV) to perform the target tracking tests.

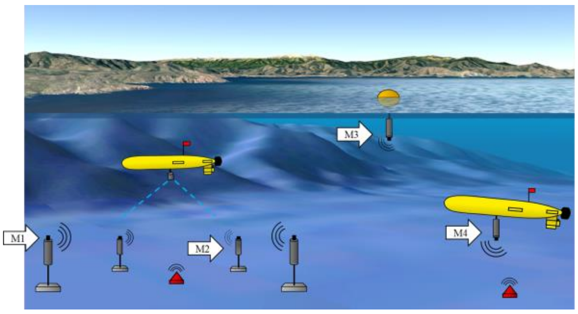

Fig. 1. *Acoustic modem deployment scenario*

The ranges among all the modems (M1 … M3) are presented in Figure 2 (middle), which were measured from December 6, 2017, to September 19, 2018, with a sampling 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. To correlate the measured range variations with the sea state a parameter called total buoy inclination was used. This parameter indicates the absolute buoy inclination respect to the normal vector of the plane X-Y, it has been calculated from the combination of the pitch and roll from the buoy and offers an estimation of the sea flatness. Then, the Standard Deviation (STD) of both range measurements and buoy inclination have been computed in groups of 1 hour to observe the influence of the sea state with the range variations, Figure 2 (bottom). The STD between M1 and M2 is much lower than the STD between M1 (or M2) and M3, as expected, because both M1 and M2 were moored on the seafloor, and M3 was in a buoy. Finally, the range variations can also be compared with the Wave Height and other parameters such as CTD measurements presented in Figure 2 (Top).

The localization experiments using range-only methods were conducted in two scenarios. Firstly, the three modems (M1 … M3) deployed in the OBSEA were localized using a forth modem (M4) installed on a boat (used as an AUV). Two methods were used to estimate the modems' position, a Least Square (LS) and a Particle Filter (PF). The main difference between the LS and PF is observed in M1's position, where the error introduced by LS is significantly greater (Figure 3). The second scenario was tracking a moving target, in this case a drifting buoy with one modem was tracked for approximately 1 hour. During this time, the ranges between both target and observer were measured and used with a PF algorithm to track the target's position (Figure 4).

Finally, a last experiment using an AUV to track two targets were conducted, the preliminary results are shown in Figure 5. Despite of some issues with AUV's compass, both targets could initially be tracked. These results will be published in a peer review journal.

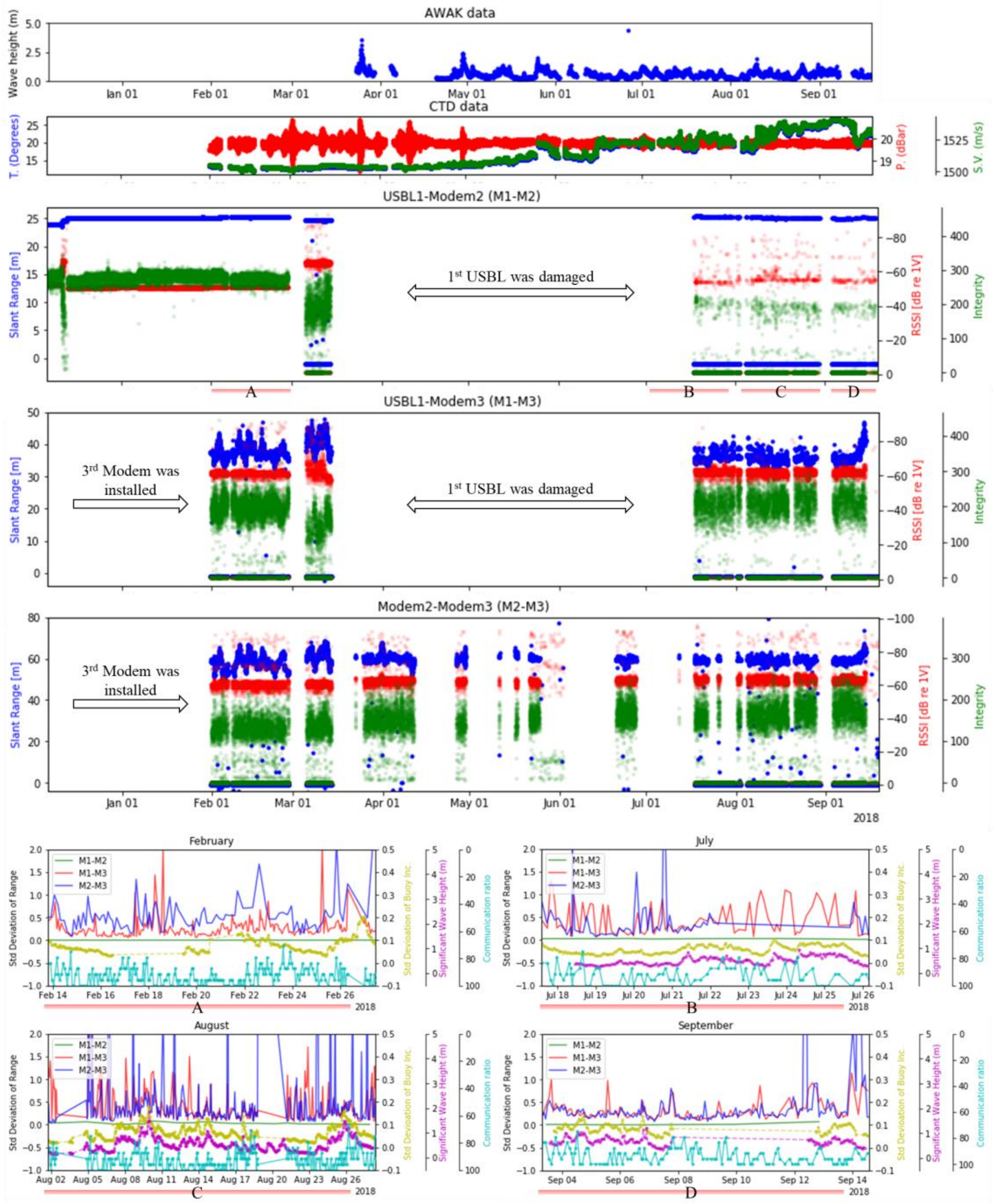

__Fig. 2. Long term deployment:__ Slant Range vs RSSI and Integrity among the modems deployed at OBSEA (top); Range measurement's STD vs Total Buoy Inclination's STD, Wave Height, and Communication ratio, for 4th different time periods (bottom).

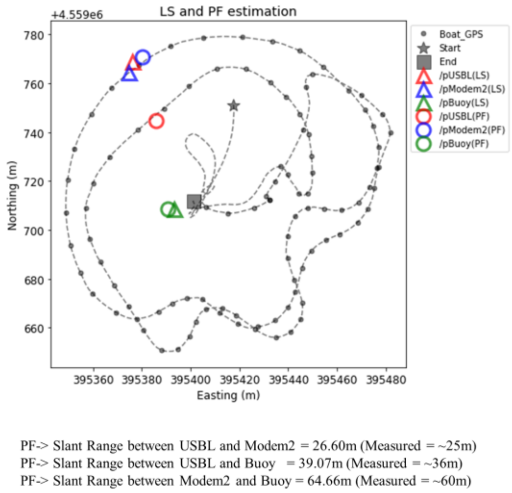

***Fig. 3. Static target localization**: Test conducted to localize the modems deployed in the OBSEA, using LS (triangles) and PF (circles) algorithms, and their ranges from an observer (grey dots). The slant range obtained using PF and the ones measured with the modems are also represented (bottom).*

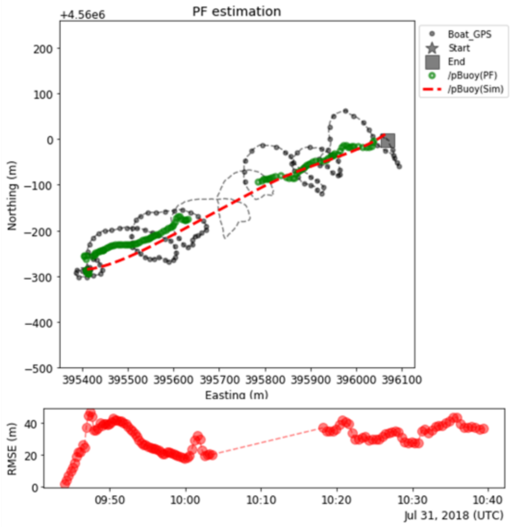

***Fig. 4. Moving target tracking:** Test carried out to track a drifting buoy equipped with a modem. The x-y position of the observer (grey), the target (red), and the target's estimation (green) are represented on the top figure. The Root Mean Square Error (RMSE) is represented in the bottom figure.*

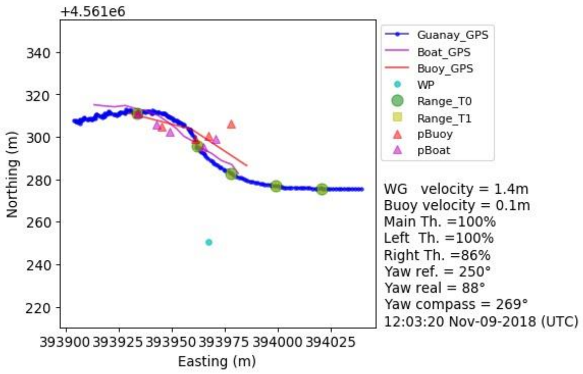

***Fig. 5. Moving multi target tracking**: Test conducted to track a drifting buoy (red-triangles) and a boat (purple-triangles). Using an AUV (blue line).*

Fig. 2 shows some of the results obtained during the long-term deployment. The different plots indicate (top to bottom): the wave height in meters obtained with an Acoustic Doppler Current Profiler (ADCP); the Conductivity, Temperature, and Depth (CTD) measured; the slant range between two modems, as well as their signal Integrity and Received Signal Strength Indicator (RSSI), which is can be used to know the communication's quality; finally, a comparative result between range variability and sea state condition from 4 different periods of time are presented in the bottom.

On the other hand, Fig. 3 shows an x-y plot of the tests conducted to localize three modems deployed in the OBSEA. One attached in a buoy at 5 m depth (green color), and two deployed in the seafloor at 20 m depth (red and blue color). Triangle dots represent their positions estimated using the LS algorithm, whereas circle dots are their positions estimated using PF.

Fig. 4 shows the dynamic test conducted, where the path conducted (grey dots) to track a drifting buoy (red line) can be observed. The error between the target's prediction and its "true" position is shown in the bottom. However, the drifter's GPS position was not available during this test, and its "true" position was derived using its deployment and recovery positions. Therefore, the constant error value shown (around 40 m) can be a circumstance of real target instead of PF performance.

To conclude, a long-term test with slant range measurements (more than 90.000) among different acoustic modems has been carried out under extreme conditions. These measurements could 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 knowledge in target position's estimation.

For example, Fig. 2 (bottom) shows the result obtained in four different periods of time (February, July, August, and September), where the variation in range measurement is compared with the sea state. In the August plot, the range measurement's STD (blue and red lines) follows the same behavior of the total buoy inclination's STD (yellow line) and the wave height (purple line), which are the main indicators of the sea state. In other words, more variability in range measurements is obtained when the weather is worst. This performance is important in range-only tracking/localization algorithms, which helps to know the accuracy achievable. On the other hand, the communication ratio which is the number of successful communications divided by the total number of attempts (green-blue line) shows also that when the sea state is worst, less successful communications are obtained between modems. However, due to the communication protocol used by Evologics modems, this problem have a minor impact.

Finally, three tests have been conducted using range-only methods to localize and track different targets under different scenarios. These methods were the LS and PF, where they good capabilities have studied.

For example, the slant range measured acoustically by modems can be compared with the slant range computed using their estimated position obtained through PF algorithm as follows:

PF-> Slant Range between USBL and Modem2 = 26.60m (Measured acoustically = ~25m)

PF-> Slant Range between USBL and Buoy = 39.07m (Measured acoustically = ~36m)

PF-> Slant Range between Modem2 and Buoy = 64.66m (Measured acoustically = ~60m)

In this case, the greatest error is obtained between Modem2 and Buoy which is 4.7 m, where the lowest error is 1.6 m. In both cases the error is < 5 m which indicates the PF's performance for target localization.

Summary and photos:

Kick off meeting on **17th/10/2017**: meeting minutes:
https://www.dropbox.com/s/0g6fsmdx4zruc34/EvoLUL%201st%20meeting.docx?dl=0

Group photo kickoff:
https://photos.app.goo.gl/7vefG7G4sd8NUS7W2

Modems received at Obsea photo during the set up on the laboratory:
https://photos.app.goo.gl/dIfqI6cwHrJLBPU32 and **https://photos.app.goo.gl/c9vDciragq2W23wa2**

1st deployment: **5th/12/2017** (usbl and modems seafloor)
2nd deployment: **31st/1/2018** (modem at sea surface buoy)
photos: **https://photos.app.goo.gl/r7mcPEKD9ZqoIQfC3**

On 8th May 2018: preparing last EvoLuL deployment: new USBL and a new Acoustic modem for experiment on moving devices. Equipment received 1st week of May 2018
https://photos.app.goo.gl/Pca32XmHUgk1YsBs6

3rd Deployment (**July 2018)** parts received in May 2018. Dynamic tests performed week 37th.

Officially the access is finished on the Friday 14th September
10-14 September: performed the dynamic tests and finished the Evolul deployment.

Project close meeting in December 14th 2018. more photos about free moving target with evologics modems
https://photos.app.goo.gl/vU71QWxEFUMeGNzr6 /
https://twitter.com/OBSEAsarti/status/1060951921366843394

SUBMITTED, 20 DECEMBER 2018; REVISED, 25 JANUARY 2019