Invited Paper: Wireless Sensor Networks for Ecosystem Monitoring & Port Surveillance

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Abstract

Providing a wide variety of the most up-to-date innovations in sensor technology and sensor networks, our current project should achieve two major goals. The first goal covers various issues related to the public maritime transport safety and security, such as the coastal and port surveillance systems. While the second one will improve the capacity of public authorities to develop and implement smart environment policies by monitoring the shallow coastal water ecosystems. At this stage of our project, a surveillance platform has been already installed near the “Molène Island” which is a small but the largest island of an archipelago of many islands located off the West coast of Brittany in North Western France. Our final objective is to add various sensors as well as to design, develop and implement new algorithms to extend the capacity of the existing platform and reach the goals of our project.

Finally, this manuscript introduces the identified approaches as well as the second phase of the project which consists in analyzing living underwater micro-organisms (the population of Marine Micro-Organisms, i.e. MMOs such as Phytoplankton and Zooplankton micro-zooplankton, but also heterotrophic bacterioplankton) in order to predict the health conditions of the macro-environments. In addition, this communication discusses developed techniques and concepts to deal with several practical problems related to our project. Some results are given and the whole system architecture is briefly described. This manuscript will also addresses the national benefit of such projects in the case of three different countries (Australia, France and KSA).

Keywords: *Sensor Network, Complex Surveillance Systems, Immerse Platform, Underwater Ecosystem; Passive and Active Acoustics; Signal Processing, Blind Separation, Identification and Localization Problems, Data Fusion.*

1- Introduction & National Benefits

USA NOA Agency declared that oceans cover 71% of the Earth’s surface and more than 95% of underwater world remains unexplored. The World Resources Institute announced that there are 148 countries with coastlines out of 193 United Nations member states. According to the world factbook published by the Central Intelligence Agency of USA, Bosnia has the smallest coastline of 20 Km, while Canada has the largest one of 202,080 Km. It is worth mentioning that the global coastline of the world is 356,000 Km. Recent studies estimate that more than 50% (and up to 85%) of world’s oxygen is generated by ocean plants, mainly from the Phytoplankton which its study is a part of our objectives. Obviously, oceans and seas play enormous roles in sustaining life on Earth, providing food resources, providing mineral resources, supporting international traffic and developing national and international economies. Monitoring coastal marine ecosystems leads us to analyze climate changes, to study ecological parameters, and to estimate economical factors. Our project has two major targets to reach: underwater ecosystem monitoring and coast/port surveillance. Without any loss of generality, we can emphasis that our study can be extended to be representative of different marine ecosystems encountered in Europe and in temperate countries all over the world.

Our project emphasizes improved methods of monitoring coastal marine ecosystems, using signal-processing technologies to monitor marine Micro-Organisms (MO) that have a major role in those ecosystems. Because MO are affected by many parameters, including water temperature, water pollution and salinity, such monitoring will assist the modelling of coastal climate changes, the study of the marine food chain, or the analysis of the conditions of coral reefs. To illustrate the important of such project for many countries, three cases can be considered. According to the World Factbook,

1. The Kingdom of Saudi Arabia is a big country with 2640 Km of coastlines. The coastal marine ecosystems could play an important role in future KSA’s economy and sociology.
2. Metropolitan France is bordering the Bay of Biscay, the Celtic Sea and English Channel, between Belgium and Spain, southeast of the UK; and bordering the Mediterranean Sea, between Italy and Spain. With 3,427 km of coastlines in metropolitan France and 4,853 Km of total coastlines, our study can obviously be of great national interest.
3. Australia is the smallest continent and the largest island with 25,760 Km of coastlines. The surveillance of the colossal coastal marine ecosystem in Australia becomes more and more crucial for the health of the national security and the future sustainable economy of Australia.

2 - Project Description

For more than twenty years, we and our colleagues have been involving in several academic as well as industrial projects related to Blind Signal Processing techniques (such as Blind Source Separation, Blind Channel Identification, Inverse Modeling, Blind Classification and Recognition Algorithms), Wireless Communication, Underwater Acoustics, Robotics, Biomedical Engineering and Electronic Warfare. In order to monitor shallow water ecosystems and achieve security and safety surveillance of coastlines, new technology and approaches should be developed. It is worth mentioning that underwater environment is a very hostile environment that offers us many challenges to overcome. The platform, “MeDON observatory”, is installed near the “Molène Island” which is located at the west coastline of the “Finistère” department in Brittany, France. Fig 1 shows a schematic view of the actual deployed surveillance system.

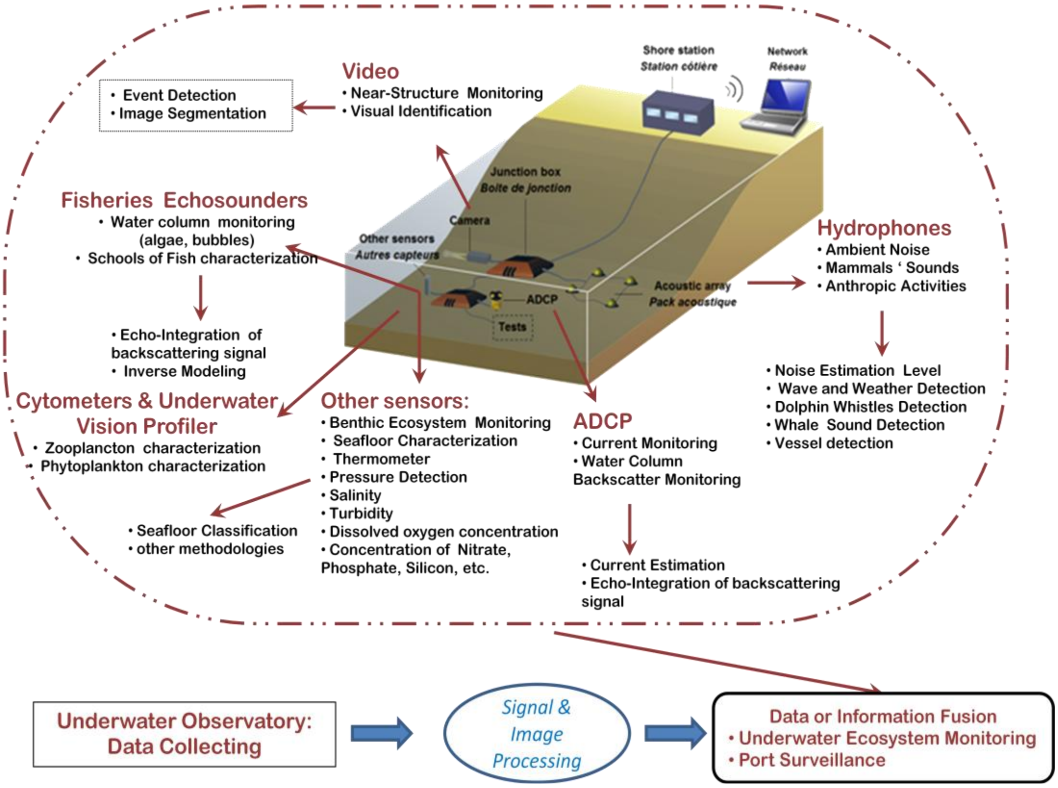


Fig. 1: A schematic of the future generation of the underwater “MeDON observatory” platform.

The actual project can be mainly divided into three main distinctive phases:

1. In the first phase, an adequate prototype underwater sensor network platform should be validated and completely operational. This phase focuses on the analysis and classification of heterogeneous data collected using different sensors including but not limited to:
    a) Acoustic Array and Hydrophones are used as passive acoustic sensors to monitor ambient noise, mammal sounds, anthropic activities, etc.
    b) Fisheries echo sounders are deployed to accomplish water column monitoring, such schools of Fish characterization, algae analyzing, bubbles quantifying, or zooplankton quantification.
    c) Acoustic Doppler Current Profiler (ADCP) improves currents & water column backscatter monitoring.
    d) Side scan sonar (standard or interferometric side scan sonar) are widely deployed by different institutes (government agencies, navies, port authorities, research centers, etc.)
    e) Multibeam sounders can provide acoustic backscattering of the entire water column.
    f) By using low frequency acoustic waves, subbottom profilers penetrate few meters of sediments and provide an internal characterization of the structure of the seafloor.
    g) Underwater cameras monitor near-structure and make visual identification.
    h) A wide range of various sensitive sensors measure benthic ecosystem, seafloor characterization, temperature, pressure, salinity, turbidity, dissolved oxygen concentration, minerals (nitrate, phosphate, silicon, etc.) concentration, etc.
2. The 2nd phase of the project consists in analyzing living underwater micro-organisms in order to predict health conditions of the macro-environment. This monitoring method will focus on processing cytometry signals and the outputs of other sensors to assess the role of MO in these ecosystems.

3. During the final phase of the project, a network of immersed platforms should be employed to monitor a large part of France’s coastlines. Obtained results could be coupled to satellite surveillance which can achieve very large-scale monitoring. Unmanned Aircraft Systems and airborne hyperspectral remote sensing could be also deployed in monitoring reasonable areas. Finally, data fusion approaches should be developed to achieve the prediction and the decision making.

This project requires the collection and the process of huge amount of data. Many samples of marine micro-organisms should be automatically collected, processed, analyzed and classified. The analysis of various images and signals obtained from any ecosystem or bio-system is very challenging due to the complexity of the images, and the non-stationarity and sparness of the signals. Conducting underwater experiments is mostly expensive and involves complex logistics. In order to validate our approaches, techniques and algorithms, real underwater experiments should be carried out. For these reasons, we developed a simulation model of underwater acoustic transmission channels which takes into consideration the acoustic underwater propagation properties.

2.1 Heterogeneous Sensors

A major task of our works consists in reducing the total cost of the project by improving the capacity and the performance of existing sensors by developing and adapting advanced signal, image, classification, and fusion algorithms.

2.2 Active Acoustic Sensors

Acoustic signals are widely used to investigate the underwater environment in civil or military applications: hydrography, cartography, meteorology, etc. Active mono or multi-sounder beam, sidescan sonars or ADCP mainly suffer from the following problems:

a) Underwater acoustic propagation properties (refraction, attenuation, reflection, Doppler effects, etc.).
b) Reflectors present in the water column or on the seabed. They depend on the physical properties of signals, transmission medium or frequency, multiple diffusion, interferences, speckle, etc.
c) Formation of echoes or backscattering signals depends on the frequency, target shapes and materials, incidence angles, etc.
d) Interpretation of recorded signals depends on each sensor: for example, a sidescan sonar use grazing angles to insonify the seafloor when single beam sounder use normal incidence and multibeam sounder several incidences.

Fig. 2 shows two images of the same water columns, insonified with two different echosounders and frequencies (Simrad EA400 at 38 and 200 kHz): Fishes, bubbles in surface and scattering layers are more visible on the 38 kHz sounder (Fig.2 top) but isolated targets are more detectable on the 200 kHz sounder (Fig.2 down).

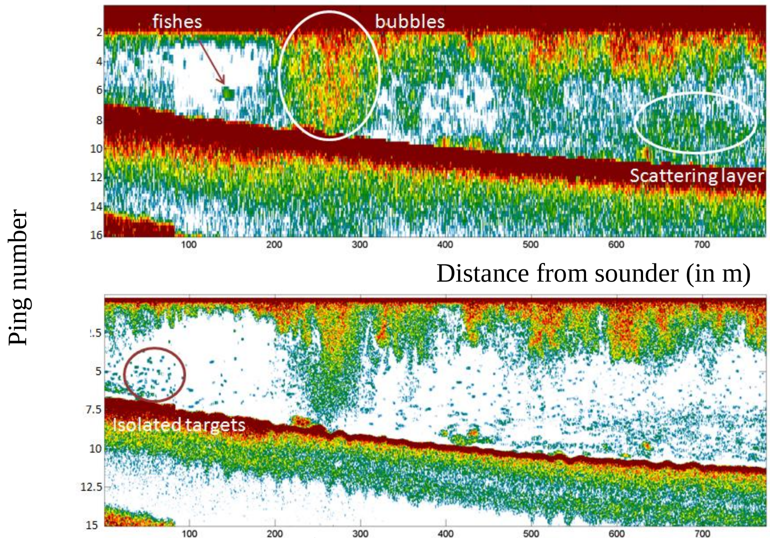


Fig. 2. Same area insonified with diverse echosounders at different frequencies

2.3 Passive Acoustic Sensors

This type of technology becomes more and more the center of attention for three main following reasons:

a) Discrete system: A vital quality for any military application.
b) Passive systems don’t require any bulky and expensive emitters.
c) Passive systems are ecological ones; as they produce no disturbance of the underwater ecosystem.

However, passive systems suffer from their dependence on the existence of natural transmitters and especially the lack of information about them. In addition, most of existing acoustic processing algorithms can only perform with a single issuer and a good SNR. In real life applications, this assumption can be hardly satisfied: A case of Multi-Sources Multi-Sensors could represent the general case. We can see the importance blind source separation algorithms to enhance existing passive acoustic.

2.4 Flow Cytometers

Scientists believe that phytoplankton contribute between 50 to 85 percent of the oxygen in Earth's atmosphere. They are the base of marine food chain. The study of Marine Micro-Organisms can help us to monitor the changes in marine ecosystem status and to detect both anthropogenic as well as long-term climate-driven changes. In fact, the plankton can adapt rapidly by changing their physiology and/or species composition, which can be monitored at high frequency with new sensors as in situ flow cytometers. To study the phytoplankton, researchers are using a combination of flow cytometry and other optical and chemical sensors deployed in situ [Olson et al. 2003, Thyssen et al. 2008, Thyssen 2011].

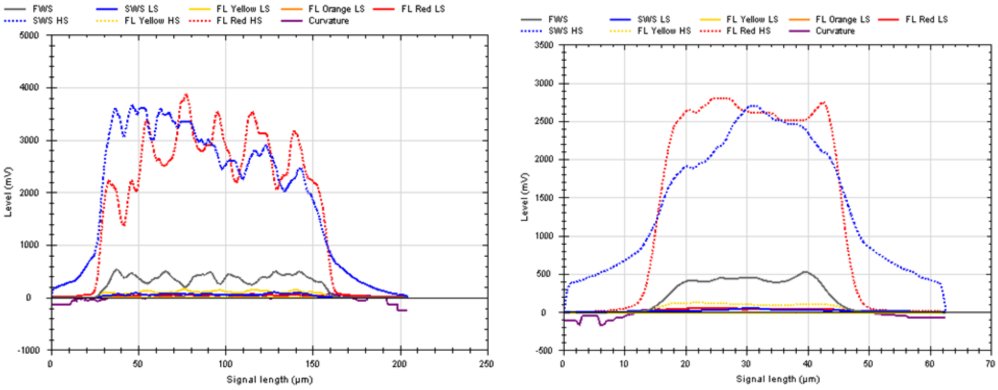


Fig 3: Electrical-fluorescent signals of a colony and a single cell of *Lauderia Annulata*.

2.5 Video Surveillance & Sensitive Cameras

CCD cameras as well as infra red camera, microscopic cameras should be used to reinforce video surveillance systems. Microscopic cameras are essential to monitor the health of micro-organisms. Underwater images suffer from many limitations: Light level, Water turbidity, Sampling and memory, image analysis problems, Data compression, Artifacts associated with sensors, movement, lighting control, etc.

Using Unmanned Aerial Vehicles equipped with stabilized camera, infrared camera, UV camera, and few other sensors to get several aerial photos of coastal regions, it can increase the efficiency of our approaches; aerial photos along with bio-signals should be processed using data fusion methods.

2.6 Multitude of Heterogeneous Auxiliary Sensors

Different sensors and data acquisition systems will be deployed, such as: Sonars, ADCP, hydrophones, cameras, sensitive microscopic digital cameras. At a final stage of our project, other sensors will be added such as: Sensitive digital cameras, satellite image data acquisition, etc. Fig. 4 shows an example of hydrophone and ADCP data recorded on the MeDON observatory at the same time. The spectrogram shows the acoustic signature of dolphins since fish schools can be shown on the ADCP echogram.

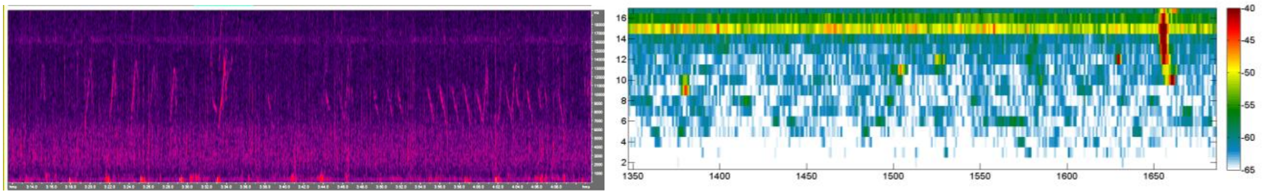


Fig.4. Spectrogram of hydrophone data and ADCP backscattering data recorded on MeDON observatory.

3 Approaches & Methodology

The analysis of various images and signals obtained from any ecosystem or bio-system is very challenging due to the complexity of the images, and the non-stationarity and sparness of the signals. Our main task will be the development of appropriate pre-processing signal and image algorithms as well as the elaboration of unsupervised classification methods.

3.1 Modeling of an Underwater Acoustic Transmission Channel

An earlier task of our project was to set a simulator and a testbed. This step should take into account the variety of natural and artificial underwater acoustic sources, their characteristic, and the specificities of an underwater transmission channel. Underwater sounds propagate through water as a continuous change in the pressure. The propagation of the acoustic wave in a stationary medium is described by Helmholtz's equation. A general solution of that equation is very difficult to obtain.

Simplified propagation models (such as: Ray theory, mode theory, parabolic model, hybrid model) are widely used. For medium and shallow deep water, a couple of meters up to a few hundred meters, the ray theory is the more appropriate propagation model. Ray trajectories and sound speed profile allow us to compute propagation times. In addition ray trajectories, water attenuation, boundaries roughness and sub-bottom properties allow us to compute the signal magnitude. The sound speed C, (m/s), in oceans is an increasing function of temperature T, (°C), salinity S, (parts per thousand, ppt), and pressure which is a function of depth D, (in meters), [Etter 1991]. From a computational view point, ray trajectory is computed by solving the 'Eikonal equation' but signal magnitude is obtained as a result of 'Transport equation' [Jensen 2000].

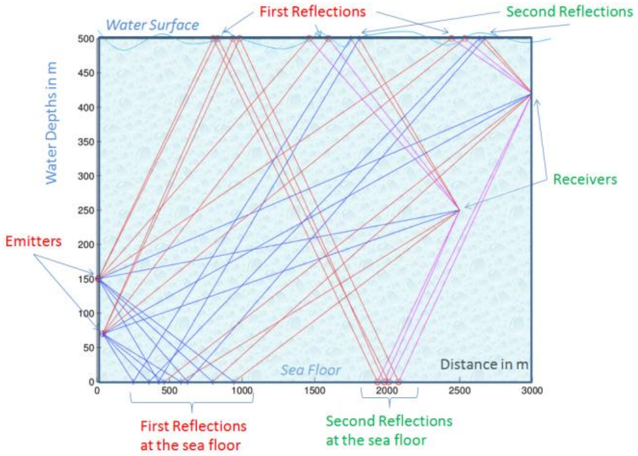


Fig. 5. Simulated underwater acoustic transmission channel.

3.2 Estimation of the Number of Active Sources:

In most cases, the number of active sources cannot be exactly evaluated (a school of small fishes or waves' noises). However, recorded acoustic signals can be practically clustered and attributed to few generic sources (a school of fish, a commercial or military boat, dolphins, etc.). In any surveillance system, a rough estimation of sources is crucial [mansour EUROSIP2013].

3.3 Source Localization

Using an array of hydrophones, Roy et al. estimate the localization of marine mammals. Using only one hydrophone, Aurbauer et al. find the distance and depth of marine mammals in particular conditions. We are aiming to develop new underwater localization algorithms which can be based on MIMO systems, modified MUSIC algorithms, High Order Statistic, Channel Equalization algorithms, Time Difference of Arrival, Triangulation, etc. These algorithms should be tested on real data recorded with the fixed cabled observatory MeDON located at 20 meter depth. This observatory contains, among other sensors three hydrophones, and localization of marine mammals should be then possible.

3.4 Estimation of High Order Statistics

High Order Statistics (HOS) are used in many localization, identification and separation algorithms. In order to exploit spatial diversity, many blind or semi blind separation; or identification algorithms uses HOS, in time or frequency domain. The estimation of cross cumulants and moments, up to the fourth order, has been investigated in our previous studies. We proposed [Martin 2004, Mansour 2013] new adaptive HOS estimators for fourth order cross-cumulants. Many simulations were conducted to elaborate our unbiased estimators and they showed that this estimator can be applied on underwater acoustic signals which are non-stationary signals.

3.5 Source Separation

Blind separation of sources (BSS) problem consists in retrieving unknown sources from only observing a mixture of them. Recently, BSS can be found in various situations: radio-communication, speech enhancement, separation of seismic signals, noise removal from biomedical signals, etc. Fig. 6 shows a proposed architecture to apply ICA algorithms on real underwater acoustic signals issued from passive acoustic sensors [Mansour 2013]. Generally, classic ICA algorithms are powerless due to the high non-stationarily, sparness and diversity of underwater acoustic signals. Therefore, pre-processing and post-processing stages are required.

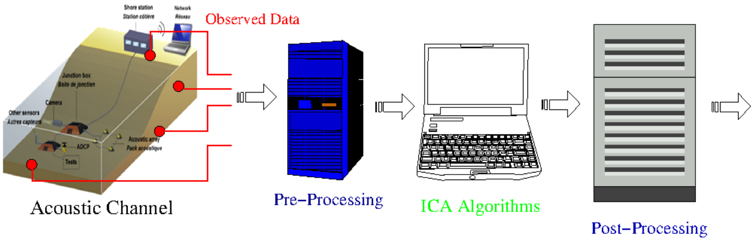


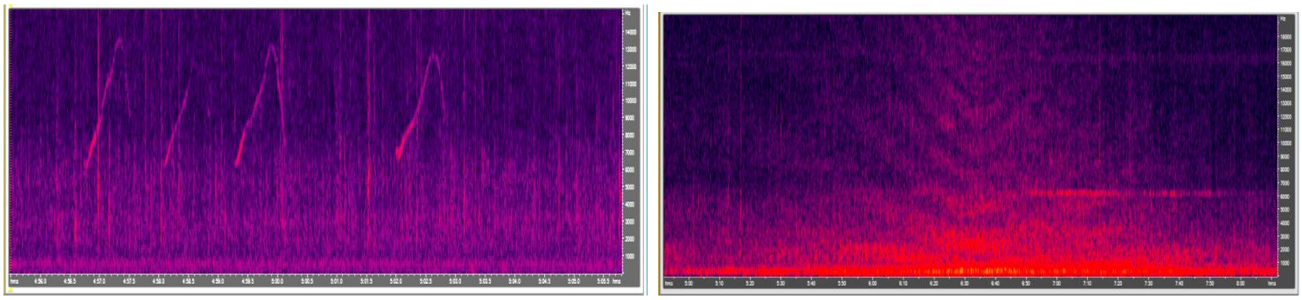
Fig. 6. An architecture to apply BSS algorithms on real underwater acoustic signals issued from passive acoustic sensors.

3.6 Performance Indexes

The classification, separation and understanding of speeches, words, as well as images or videos can be naturally and subjectively processed by our brains. However, the processing procedures depend on our personnel experiences and knowledge. Therefore, the most powerful processing systems are the ones how introduce human experts in the final decision stage. For example, we can easily distinguish between any specimen of dogs and a cat. In addition, we are able to distinguish the features of two images mixed together using a low and high pass filters. Human are able to focus on the speech of someone in a very noisy environment. The common factor among all these various information sources (speech, written words, images, etc) are their intelligibility. Underwater acoustic signals are non-intelligible. This property should be taken into account in all stages of signal treatment. This can generate a problem related to measure the performance of our algorithms. To consider non-intelligible signals, one should investigate performance indexes. We conducted a preliminary study to propose or modify various performance indexes to deal with non-intelligible signals such as boat noises or marine animals [mansour 2012].

3.7 Source Classification & Recognition

Source separation, classification and recognition are essential for any real world underwater surveillance system. While the separation step could breakdown the mixed signals and produce simple sources. The classification (for example, natural or artificial signals, fish noise, etc.) and the recognition (a specific kind of dolphins) help us to observe underwater activities. To reach our goals, we are planning to apply feature extraction, hidden Markov models, classification algorithms, etc. Fig. 7 gives an example of few indentified sources recorded with hydrophones on MeDON Observatory.



a) Dolphin whisles

b) Lloyd's Mirror coming from boat sound

Fig.7 Spectrograms computed with hydrophone data recorded on MeDON observatory

In order to obtain a better knowledge of the nature of the seafloor, we also proposed a multiscale segmentation and classification algorithm on textured sidescan sonar image, using parameters coming from a wavelet analysis. Fig.8 shows an example of the results of the sonar classification (Klein 5000, data from Gesma), the segmentation [Leblond et al. 2005] and the classification [Leblond et al. 2008].

Multiview classification and fusion were used to improve the classification of sonar images of mines. The originality of this study was consisting in the automatic choice of the additional views using a predictive tool based on the estimation of the angle of view. Fig. 9 gives a schematic view of the approach [Leblond et al. 2010].

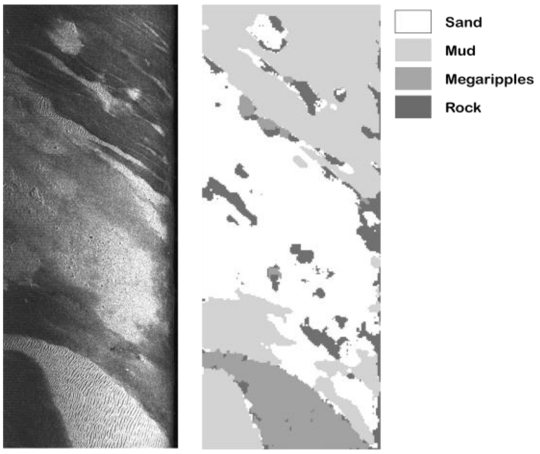


Fig. 8. Example of sidescan sonar image

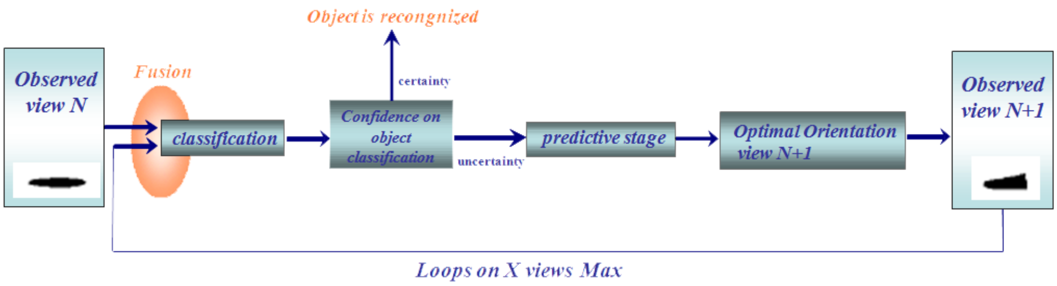


Fig.9. Schematic of the multiview classification methodology.

3.8 Inverse modeling methodologies in echosounder data

Inverse modeling is widely used in the literature to estimate the size [Leblond et al.], the abundance and in certain extent species of schools of fish. In fact, Acoustic data, which are recorded using a calibrated single or multibeam echosounder, gives echograms of volume backscattering strength (Sv in the formalism current used [MacLennan et al. 2002]) in the water column and, if they are split-beam, target strengths (TS) of isolated targets. If the concentration of targets (fishes) is not so important (i.e. the linear domain, this condition is generally satisfied), then the volume backscattering strength is related to the contribution of all the targets present in the insonified area: Fig. 8 shows an example of echogram data of bubbles seeps in Marmara Sea with an EK60 echosounder at 120 kHz. For this experiment, the EK60 insonifies horizontally.

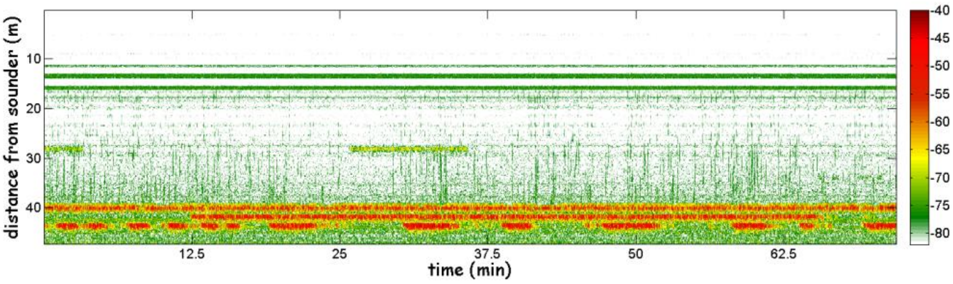


Fig.8. Echogram obtained on natural bubbles seeps.

3.9 Feature Extraction

In our project, a blind classification of micro-organisms' images and signals will be a main step to help the experts making decision. Each signal or image could be represented by a set of points in a multi-dimensional space. In this case, pertinent features of these images and signals should be firstly extracted. Later on, they should be projected in lower dimension space to reduce the computing time and efforts. To reduce the feature dimension, we will use non-linear approaches such as (Kernel PCA, ISOMAP, Locally Linear Embedding, Independent Component Analysis, etc.) and we will propose similarity criteria.

3.10 Image Processing

Video and statistic images are precious data in order to achieve our goals. Through the three stages of the project, various images should be collected and processed. It was mentioned in previous sections that images acquired with the flow cytometer and sensitive satellite images of invisible lights will be also considered to enhance the outcomes of our approach and helping us monitoring a wide area.

3.11 Data Fusion

As mentioned before, this project requires a considerable amount of complex and extensive experimentation, along with associated routine laboratory work, as well as detailed theoretical planning and interpretation. In addition, we should implement various developed approaches in real time processing algorithms and maintain the experimental equipments. We should also merge and integrate the outlines of the whole process.

4 Conclusions

In this manuscript, we described our long term project to achieve port surveillance and costal underwater ecosystems monitoring. The project consists on using a variety of sensors and underwater platforms to realize a big scale sensors networks which should be wirelessly exchange information among off-shore platforms and communicate to a processing and decision centre. Various sensors have been already deployed. Major sensors were discussed in this manuscript. In addition, once our typical platform has been carefully designed and our algorithms have been optimized, we are planning to deploy many similar platforms in sensitive and strategic places. All these immersed platforms will create a sophisticate and powerful surveillance and monitoring systems.

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