Obstacle Detection and Avoidance for AUV: problem analysis and first results (Redermor)

Alain Hétet, Isabelle Quidu, Yann Dupas

Obstacle detection and avoidance for AUV: problem analysis and first results (REDERMOR)

Alain HETET[(1)], Isabelle QUIDU[(2)], Yann DUPAS[(1)]
[(1)] *Groupe d'Etudes Sous-Marines de l'Atlantique, DGA/DET/GESMA, BP 42 – 29240 Brest Armées, France, {alain.hetet,yann.dupas}@dga.defense.gouv.fr*
[(2)] *Laboratoire E^3I^2 EA3876, Ecole Nationale des Etudes et Techniques de l'Armement – 2, rue François Verny, 29806 Brest Cedex 9, France {isabelle.quidu@ensieta.fr}*

SHORT ABSTRACT:
Military Autonomous Underwater Vehicles (AUV) shall be able to execute survey missions in both known and unknown environments in order to detect a potential threat. These robots will significantly improve our exploration, analysis and intervention capability and will have a large decisional autonomy. While the primary mission of an AUV is data acquisition and collection (up to now commonly done using side scan sonar or a multibeam echosounder), another important task is to guaranty its own security. To do that, it must be able to know in advance its environment, to detect unexpected events, to analyse them, and to react. The paper occurs after the DEVITOBS'06 (Détection et EVITement d'OBStacles) experiment using two types of sensors mounted on the GESMA *Redermor* experimental AUV: the forward looking sonar *Reson Seabat 8101* with a depression angle of 15° and an echosounders network. It has been divided in three main parts: analysis of the "Obstacle Detection and Avoidance" problem for AUV, information extraction techniques assessment, and discussion about behaviour strategies and mission planning.
Keywords: *Obstacle Detection and Avoidance – AUV – Forward Looking Sonar*

RÉSUMÉ COURT:
Les robots sous-marins militaires (AUV) devront assurer des missions de surveillance de zones connues ou inconnues afin de détecter la présence d'une éventuelle menace. Ces robots élargiront considérablement nos capacités d'exploration, d'analyse, et d'intervention et ils seront dotés d'une grande autonomie décisionnelle. Comme la taille d'un robot est nécessairement limitée, il sera donc très sensible aux évènements imprévus tels que l'apparition d'un obstacle fixe ou mobile sur sa route. Si la mission principale d'un robot sous-marin est l'acquisition de données, généralement à partir de sonars latéraux ou de sondeurs multifaisceaux, une autre tâche importante est de garantir sa sécurité afin d'assurer le bon déroulement de sa mission. Pour cela, il doit être capable de connaître en avance son environnement, de détecter les évènements imprévus, les analyser, puis réagir. Cet article fait suite à la campagne d'acquisition de données DEVITOBS'06 (Détection et EVITement d'OBStacles) avec le *Redermor* (robot sous-marin d'expérimentations du GESMA), équipé d'un sonar *Reson Seabat 8101* incliné de 15 ° vers l'avant et d'un réseau d'échosondeurs. Il est divisé en trois parties principales : analyse du problème de « Détection et d'évitement d'obstacles » par robots sous-marins, évaluation des techniques d'extraction de l'information, réflexions sur les stratégies de comportement et les re-programmations de mission adaptées à nos besoins en terme de sécurité.
Mots-clés: *Détection et Evitement d'Obstacles – AUV – Sonar frontal d'imagerie*

1 INTRODUCTION

Military Autonomous Underwater Vehicles (AUV) shall be able to execute survey missions in both known (maritime approaches, harbour areas, access channels, etc…) and unknown environments in order to detect a potential threat (minefield, intrusion attempt). They also should allow to achieve Exploration and Reconnaissance missions on dedicated areas before the beginning of Navy operations (Anti Submarine Warfare, Rapid Environment Assessment, Mine Counter Measure). These robots will significantly improve our exploration, analysis and intervention capability and will be able of a large decisional autonomy.

However, underwater environment is often badly known, hardly understandable, changing, even hostile. As the size of a robot is limited, it will be very sensitive to unexpected events, like the emergence of either a fixed or a moving obstacle on its way. There are several obstacle classes:

- *deep obstructions* (important bottom rising, rock plates, undersea hills, structures from industrial or manned activity, wrecks, tethered mine, chains, ropes, etc…),
- *drifting objects* in the water column (wood balls, nets, school of fish, marine mammals, seaweed, divers, and potentially submarines or other robots),
- *near surface obstacles* (buoys, surface ships, handmade objects, icebergs, etc…).

In harbour areas, similar obstacles can be encountered, with additional obstructions due to the port installations (pillars, wedges, chests, etc…). Moreover, as the traffic in a harbour is much more important than at sea, some obstacles will occur more frequently (bottom laying objects, sailing boats). And the problem is very different if we consider inspection tasks done with an AUV, working very closely to underwater structures.

While the primary mission of an AUV is data acquisition and collection (up to now commonly done using side scan sonar or a multibeam echosounder), another important task is to guaranty its security. To do that, it must be able to know in advance its environment, to detect unexpected events, to analyse them, and to react.

The paper has been divided in three main parts. Firstly, we conduct an analysis of the "Obstacle Detection and Avoidance" problem for AUV with emphasis on the imagery needs in terms of sensor and processing (signal, image, and information). This analysis has been illustrated with results obtained in 2006 during the DEVITOBS'06 (Détection et EVITement d'OBStacles) experiment using two types of sensors mounted on the GESMA *Redermor* experimental AUV: the forward looking sonar *Reson Seabat 8101* with a depression angle of 15° and an echosounders network. In a second part, information extraction techniques have been assessed, taking into account sonar images sequences. Lastly, avoidance strategies have been discussed in relation with the mission supervisor needs and capabilities.

2 ANALYSIS OF THE "OBSTACLE DETECTION AND AVOIDANCE" PROBLEM FOR AUV

2.1 Avoidance systems

The main difference between an AUV and other ships or submarines to carry out "detection and avoidance" capabilities lies in the scale of the considered vehicle. Ships, which have a great length and an important tonnage, have consequently an important inertia and a low degree of manoeuvrability compared with those of an AUV. For an avoidance operation, the obstacle must be seen at a long distance, in order for the ship to have sufficient time to change its route. Distance detection must be important (several hundred meters) and working frequency of the systems consequently lowered. In underwater robotics, AUV have a limited size and weight, and it is variable from one AUV to another. These parameters are very important for the definition of an obstacle detection and avoidance system, because they will define the payload carrying capacity and the manoeuvrability of the robot. The value of the robot must also be taken into account. It is not necessary to install a high performance and expensive detection system on a cheap AUV, whereas an AUV that carries high quality and expensive payload will need it. Several sonar technologies exist, from the simplest to the most complex: single beam echosounder, network of echosounders, single or multibeam mechanically scanned sonar, sector scan sonar (with linear, planar or cylindrical arrays), high frequency sonar with acoustic lens, multibeam forward looking sonar, Mill-Cross configured sonar, acoustic camera.

In spite of a number of efforts led in the field of underwater video imaging [1], there are still major problems with the use of optical cameras in water: limited range, non uniform lighting, low contrast. If the cameras are needed in the final phase of identification, together with sonar employed for object detection, classification and localization, their use in real time obstacle detection is inconvenient.

The use of Ahead Looking Sonar (ALS) for Obstacle Avoidance is an old idea. A number of technologies have been developed during the last decade for this purpose [2], starting from the basic echo-sounder and going until the 3D high resolution sonar using a 2D planar array. Emphasis on this problem has been pointed out during the European MAST ASIMOV project [3]. However, looking for a robust detection and avoidance capability for AUV is still a hot topic today. Indeed, the operation of an "obstacle detection and avoidance" system has to be divided in several stages, each with its associated complexity (sensor, signal and information processing, vehicle behavior). The importance of one stage can vary from one AUV to another, according to its size, its value and the use that one wants to make. Decisional autonomy is of primary importance for the definition of such a system. Is the AUV supervised or completely autonomous? In the first case a human operator controls the information processed by the AUV sensors and decides what to do. On the other hand, the AUV will have to process automatically the information extracted from the sonar images in order to decide by itself which kind of action strategies to choose. Those processing steps can be as follows:

- **Forward Imagery:** resolution capability in relation with the object size at the maximum safe distance
- **Automatic detection** : of representative echoes and/or acoustic shadows
- **Shape analysis**: echoes association and acoustic shadows characterization in order to estimate the shape or the extend of the obstacle
- **Echo tracking :** to confirm the detection on images sequence and to reduce false alarm (non consistent echoes with time)
- **Classification :** selection between hazardous obstacles (net, obstruction in the water column, unexpected and rapid seabed rising, wreck, underwater structure), or non dangerous obstacles (school of fish, seaweed)
- **Localization** : localization of obstacles (on the seabed, in the water column) in order to inform the vehicle supervisor in real time about the precise position of the hazard
- **Re-acquisition** : eventually with another sensor if a confirmation strategy has been defined
- **Avoidance** :eventually, if an avoidance strategy has been defined

2.2 Redermor 2 Architecture

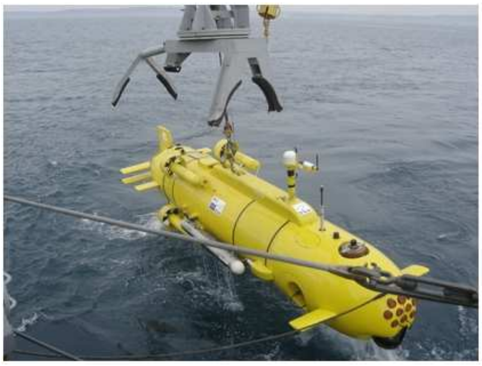


Figure 1: Redermor vehicle: on the left, front view with the 10 echosounders network (top) and the Reson 8101 Forward looking sonar (bottom) – on the right, one can see the Klein 5400 side scan sonar on the Redermor size

GESMA[4] has equipped the *Redermor* AUV with a network of 10 *Tritech* echosounders looking forward and the *Reson Seabat 8101* Forward Looking Sonar (Figure 1). The *Redermor* is the experimental platform deployed from the French Navy ship *BEGM Thetis*. It is a heavy and large AUV (3.8 tons x 6 m). Navigation is performed knowing data from a Doppler Velocity Log (DVL) and a Motion Reference Unit (MRU). A *Klein 5400* high resolution Side Scan Sonar (SSS) gives an acoustical imaging capability with a 20 cm azimuth resolution at 75 m. Each echosounder of the network, working at 200 kHz central frequency, operates over a 10° horizon (at –3 dB). The echosounders are mounted in such a way that the main lobes are joined. They can be controlled individually, sequentially or by groups. The 240 kHz *Reson Seabat 8101* Forward Looking Sonar is derived from a multibeam echosounder. Firstly selected by the NUWC "Naval Undersea Warfare Center" on the *Manta Test Vehicle* (MTV)[5], a similar design has been applied to the *Redermor* vehicle. The system integrated in the Redermor can play a beamformed image over a 15° (vertical) x 60° (horizontal) sector with a 1.5° azimuth resolution and a 5-cm range resolution. The sonar has been oriented 15° from the horizontal plane. It can be operated in image sector mode or in a bathymetric mode (in that case using a dedicated stick transmitter).

2.3 DEVITOBS'06 experiment

In order to test the capability of the *Redermor* vehicle to react when obstacles are encountered on its way, GESMA organized an experimental trial in April 2006, named DEVITOBS'06 "DETection et EVITement d'OBStacles". The aim of this campaign was to record sensor data in several modes with various obstacles. In that way, it has been possible to test, qualify and upgrade the sensor suite, to initiate an obstacle database, to start algorithm development on those obstacles and to prepare avoidance tactics and strategies to be given to robot mission supervisor.
The experiment has been conducted in the Douarnenez Bay, near Brest. Several objects have been laid: a tethered mine like object, a net and plastic chains (Figure 2). Other objects have been investigated like the shipwreck "Meuse" in the Bay of Douarnenez and schools of fish. Up to now the analysis have been mainly focussed on the Reson 8101 data.

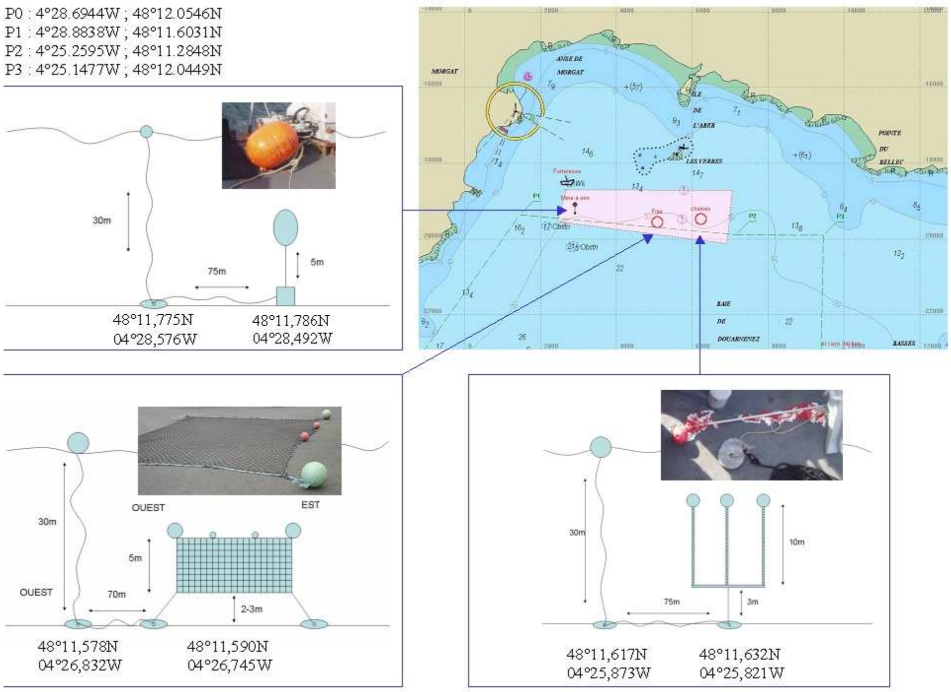


Figure 2: objects laid in The Bay of Douarnenez for the DEVITOBS'06 trial

3 INFORMATION EXTRACTION

As we said in the introduction, there are several obstacle classes but we consider here three classes of objects: a tethered mine like object, a wreck and a school of fish. Indeed, they present different properties in terms of echoes or shadows shapes and levels we have to deal with.
The main problem here is related to the bad-contrasted image we cope with. Another point concerns the resolution cell, which is 5cm in range and 1.5° in azimuth. So for a range from 20 to 100m, the resolution cell goes from about 20cm to 2.5m in length according to the sector formed.

3.1 Proposed tools

We aim at detecting suspicious information in order to decide if the vehicle has to change its trajectory or not. It is of high importance to ensure its security. So the first condition is to provide robust algorithms in order to avoid any obstacle. Another constraint is to implement low computable algorithms. We tackle these problems on two simultaneous fronts: echo detection and acoustic shadow extraction. A Human Machine Interface (HMI) has been developed to simultaneously visualize each resulting image provided by the following processing (see Figure 3).

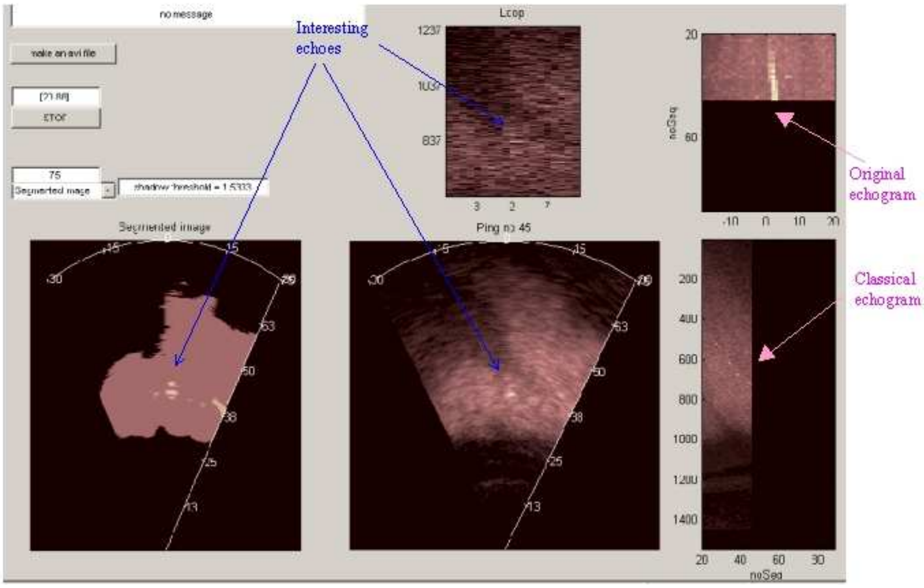


Figure 3: HMI in a case of a tethered mine

We first provide a <u>segmented image</u> of four classes on a sector Plan Position Indicator (PPI) display. Each class is related to a specific area: strong echo area, medium echo area, and background or shadow area, from the stronger level to the lower level. In order to keep any potential alarm, strong echo detection simply consists in thresholding the sonar image. The threshold value is equal to a portion of the maximum pixel value of the image, typically 75%. This level is essential to keep spherical mine echoes.

The two following thresholdings are applied to the low-pass filtered image. This is an average filtering but with a mask size which takes into account sonar image resolution: finer in range than in azimuth. It is of high importance to ensure an isotropic filtering within the meaning of ground truth. As a consequence the mask size is minimal along the azimuth axis in order to preserve details and much larger along the range axis (according to the range to azimuth resolution sizes ratio) in order to smooth and then to filter noise and to lower false alarm rate. Shadows extraction is then performed by a thresholding computed from the estimation of the reverberation mean [6]. For our bad condition contrasted images, threshold value equals to the estimated reverberation mean minus 3dB. Finally, medium echoes detection is performed as done previously for strong echoes, but based on the filtered image this once.

Two other images are designed to allow echo tracking both in range and in azimuth. The first one is the <u>classical echogram</u> used by sonar operators in mine warfare: at each ping, we only keep the maximum pixel level along each line of the sonar image. We do the same along the other axis to form the second image: namely the <u>original echogram</u>. Combining the information from each image we can then do a simple tracking: when a track remains in both images, we extract locally the relative part of the image in the <u>zoom image</u>. By default or when no echo remains, this last image is a zoom of the central part of the sonar image.

3.2 Results

In the previous paragraph, we gave a print-screen of our HMI in the case of a rising mine. We give here some results for two larger targets: a wreck and a school of fish.

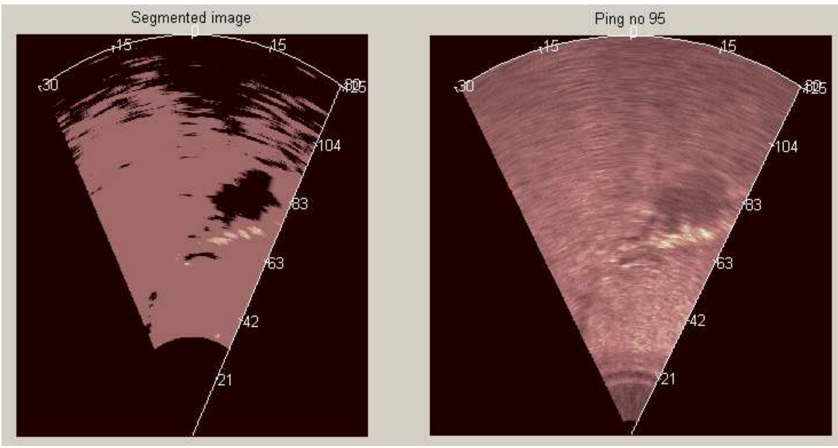


Figure 4: sonar image of the wreck "Meuse" on the right and corresponding segmented image on the left

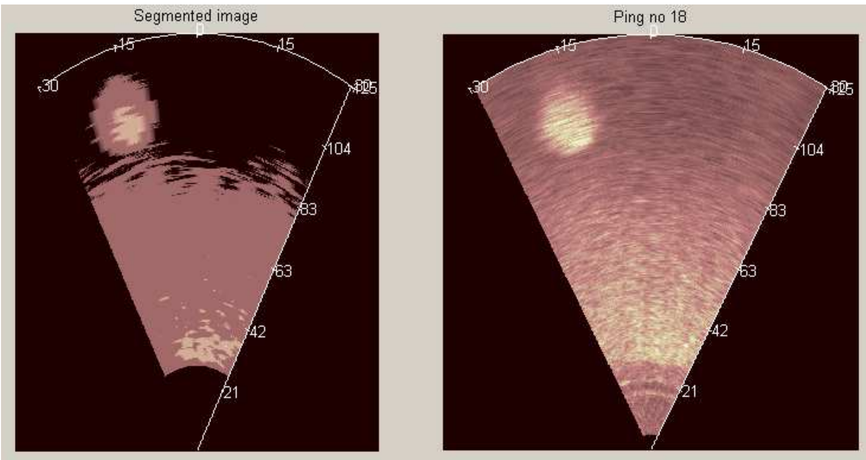


Figure 5: sonar image of the school of fish on the right and corresponding segmented image on the left

4 AVOIDANCE STRATEGIES

Robot avoidance manoeuvres, following obstacle detection, have been largely explored in both ground and aerial mobile robotics. The problem is commonly set as a path planning issue in 2D or 3D environments, from a start point to a goal point, with some static or mobile obstacles. The vehicle must automatically avoid these obstacles in order to reach the goal point with the maximum security and the minimum of time. Consequently, a large panel of algorithms has been developed to solve this problem, from the simplest to the most complex. In general, an equivalent approach is chosen by the underwater community to examine the problem of obstacle avoidance in underwater robotics, with some adjustment due to the specificity of the environment, like current, or the mobility of an AUV[7][8][9]. Algorithms developed in this context can either be based on a local or global map refreshed with the new contacts encountered in the sonar images.

In Navy operations, we have to consider the fact that some obstacles can be severe hazards and can present a major risk for the robot own safety and the global mission achievement. So, it is not desirable to travel through a minefield (except for dedicated missions), a protected area with nets or other defence equipment, or to navigate across a hard broken bathymetry.

Moreover the use of a forward looking sonar does not allow to assure that one detected echo presents a risk or not. For instance, one can be confused imaging a school of fish or a real solid dangerous obstacle of the same dimensions. As our approach is to ensure the maximum security of the vehicle a lot of echoes might be viewed as a risk. We will not consider as a good option to follow a complex trajectory across such an obstacle map. Underwater space is wide enough to allow working in more hospitable areas if the nature of the mission allows it. The main objective is to clarify if we face an obstacle or not. So the problem is just like the classification problem in Mine Countermeasures. After detection, the AUV needs to track the obstacle in order to confirm the hazard and to start a classification process, interrupting the mission for a while if necessary. If the obstacle is detected too lately (too close for the AUV) it will be considered as dangerous and a quick reactive method (emergency) should be chosen.

To prepare the AUV obstacle avoidance tactic, we propose to fuse the information from the Forward looking sonar (FLS) and the sidescan sonar (SSS). Indeed, MCM (Mine countermeasures) or REA (Rapid Environmental Assessment) will be equipped with high resolution sidescan sonar. We have to take profit of the whole payload to take a decision. A forward-looking sonar shall be used for detection, echo tracking and localisation while a SSS shall be used for target classification. Figure 6 illustrates the related manoeuvres on two examples: one point like target (tethered minelike target) and a wreck representing an extended hazard (barrier type).

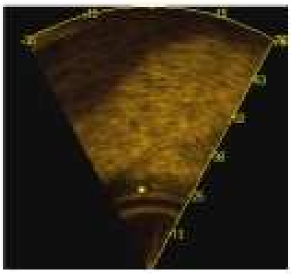
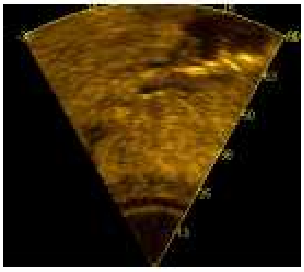
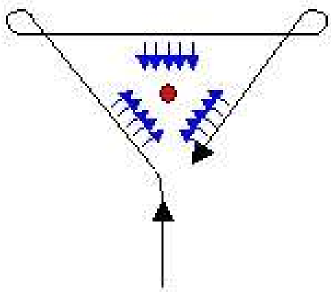
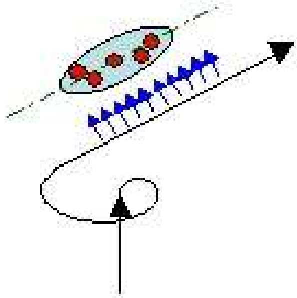
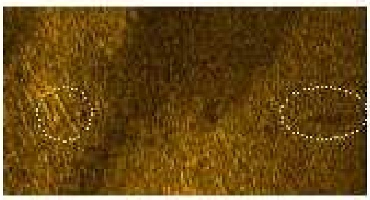
	Point-shaped static obstacle (tethered mine)	Barrier shaped static obstacle (wreck)
Reson Seabat 8101		
AUV behavior		
Klein 5400		

Figure 6: hazardous targets reacquisition with high resolution SSS after FLS target detection for AUV obstacle avoidance tactic preparation. Images with the Seabat 8101 (on top). Same targets seen with the KLEIN 5400 (bottom). One can see that in the case of a point shaped static obstacle, the AUV can start a multiaspect analysis with its SSS. If we face a barrier shaped target this kind of analysis will not be possible or risky. Here, the decision shall be taken after a more secure echo and shadow shape analysis.

5 CONCLUSION

The DEVITOBS'06 trial and the results we obtained are the first step of our studies on obstacle avoidance based on sonar image analysis acquired from an AUV. First processing works have consisted in automatic detection and echo tracking. Encouraging results can be obtained on three strongly different obstacles: a tethered mine with the echoes corresponding to the mine and anchor, a wreck with a large shadow area, a school of fish with a large medium echoes area. Future works will consist in performing image pre-processing (such as contrast enhancement) before shadow extraction and by reinforcing tracking procedure.

We have also presented the principles we will follow in our works for the vehicle behaviour (FLS & SSS data fusion, classification, decision, avoidance) of the AUV after the detection of a potential danger during the execution of a mission.

6 REFERENCES

[1] JAFFE J.S., McLEAN J., STRAND M.P., MOORE K.D., *Underwater Optical Imaging: status and prospects*, Oceanography, Vol.14, N°3, pp. 66-75, 2001

[2] LOGGINS C.D., *A comparison of forward-looking sonar design alternatives*, Proc. of MTS/IEEE Oceans'0*1*, pp. 1536-1545, Honolulu, Hawaii, USA, 2001.

[3] PASCOAL et al*, Robotic Ocean vehicle for marine Science applications: the European ASIMOV Project*, Proc. of MTS/IEEE Oceans'00, pp. 409-415, Providence, RI, USA, 2000.

[4] TOUMELIN N., LEMAIRE J.*, New capabilities of the REDERMOR Unmanned Underwater Vehicle*, Proc. of MTS/IEEE Oceans' 01, pp. 380-389, Honolulu, Hawaii, USA, 2001.

[5] CARPENTER R.N., MEDEIROS M.R., *Concurrent mapping and localisation and Map Matching on Autonomous underwater vehicles*, Proc. of MTS/IEEE Oceans' 01, pp. 380-389, Honolulu, Hawaii, USA, 2001.

[6] JAN, D, *Traitement d'images numérique appliqué aux sonars à haute résolution*, Proc. of GRETSI 87, Nice, France, 1987.

[7] PETRES C., PAILHAS Y., PETILLOT Y., LANE D., *Underwater Path Panning Using Fast Marching Algorithms*, Proc. of Oceans'05, Brest, France, 2005.

[8] MOITIÉ R., SEUBE N., *Guidance Algorithms for UUVs Obstacle Avoidance Systems*, Proc. of Oceans 2000, Proc. of MTS/IEEE Oceans'00, Providence, RI, USA, 2000

[9] PETILLOT Y., RUIZ I.T., LANE D., *Underwater Vehicle Obstacle Avoidance and Path Planning Using a Multi Beam Forward Looking Sonar*, IEEE Journal of Oceanic Engineering, Vol. 26, n°2, pp.240-251, April 2001,