Autonomy for operational MCM AUVs, based on high resolution sonar

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Abstract- **The major concern of Mine Counter Measures (MCM) domain is to keep the men far from the mine threat while having a high level of confidence in the detection and classification of possible threats. The development of unmanned MCM vehicles allows to put away the crew from danger, and giving autonomy to these vehicles both improves their operational efficiency and reduces the post mission residual risk of missing a mine and post mission analysis time. This paper aims to demonstrate how autonomy is an operational need for AUVs, and how we can benefit from real time SAS processing to increase autonomy and reliability of an MCM AUV.**

I. Introduction

One of the main challenge of the next years in the field of Mine Counter Measure (MCM) is to develop autonomous MCM systems able to perform exploration and surveillance missions, keeping the men away from danger. If exploration missions have to becovert , the solution is to perform the mission with AUVs. In this case, the communications with surface and operators are very limited due to low acoustic communications rate, and a large amount of autonomy has to be given to the vehicle to keep a good level of performances and efficiency.

The first level of autonomy is to be able to perform an initially programmed mission, to record the data and go back to the centre of command to download the data, process it and analyze it. This first level is not the most efficient as the acquired data validity is not checked during the mission, leading to possible miss classification or coverage holes when the sensor performances have been poor, due to environmental conditions. Moreover, the post mission processing is time consuming and this time for data analysis has to be added to the acquisition time.

The level of autonomy developed by Thales Underwater Systems is more ambitious. Based on high resolution SAS processing, it is aiming at reducing the post mission analysis time, and **increasing the mission efficiency by embedding autonomy functions that make the vehicle behavior adaptive to its environment and to the sonar data validity**.

II. First Level of Autonomy for AUVs

A. *The Detection Classification Localization mission*

The detection classification and localization (DCL) mission objective is to find all the bottom objects that are possible mines (MILCO: mine like contacts) in a given area, with a low false alarm rate, a probability of detection and classification of 90% more, and a good localization accuracy (less than 15m). This DCL mission is followed by identification and neutralization mission, performed by another system, and the efficiency of this second mission depends strongly on the false alarm rate and the positioning accuracy of the DCL one.

B. *The minimum autonomy*

The minimum autonomy required for an AUV to perform successfully the DCL mission is to be able to follow a pre-programmed path, acquire sonar data and record it, and reach the recovery area when the full path has been covered.

Fig. 1 shows an example of mission plan, with a mission area defined in blue and forbidden areas in red. The mission plan is composed of a transit to the center of the area, 8 lines to cover the full area and a return transit.

C. *The limitations*

During the mission, the vehicle has to localize its path with a good accuracy, using an inertial navigation system. Accuracy is necessary for efficiency of the mission: if accuracy is ±20m, the overlap between sonar lines has to be more than 40 m?. An increase of the accuracy leads to lower coverage rate. Moreover, if some objects have been seen several times (in the sonar overlap for example), the different observations can be associated in one contact with a good confidence only if the positioning error is low. After DCL mission, the time spent by the identification and neutralization systems to re-locate mine like contacts is increased dramatically if the positioning error given by the DCL system is high. Thus it is important to have means to limit the INS drift during the mission.

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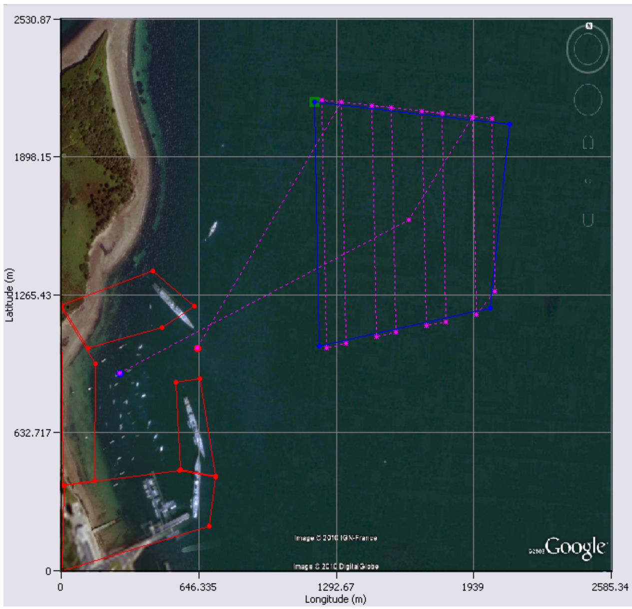

Figure 1. Initial plan for an AUV mission .

At the mission completion, the vehicle comes back to the recovery area, and the data are downloaded for analysis. With this level of autonomy, no information is available to the operators during the mission, and it is possible that sonar data are not satisfactory on the full area of the mission. For instance, if seabed is not flat, some areas can be hidden, or the presence of sand ripples can make the sonar image analysis difficult. Then the detection and classification performances will not be met, and another plan will need to be programmed to fulfill the mission and decrease the residual risk of missing mines.

Even in case of an overall good sonar performances, it is likely that some objects are very difficult to classify when seen from one single view. As there is no multiple view acquisition, the false alarm rate is very high, and another DCL mission has to be launched to specifically analyze suspicious contacts.

This first level of autonomy is an initial step for MCM AUVs, but it is not sufficient for AUVs efficiency. Thales Underwater Systems has been working for several years on embedded data processing for AUVs, to make them more efficient and robust to difficult environments.

III. AUTONOMY WITH ADAPTIVE BEHAVIOR

The key technology for AUV efficiency in MCM missions is to add adaptive behavior to the vehicle. Adaptive means that depending on its sensors data, the vehicle will modify its trajectory to optimize the mission, in terms of mission duration and residual risk. As the communications rate with the surface is low, all processing (signal processing and data processing) has to be embedded in the vehicle, and data have to be processed in real time, so that the vehicle is able to change the plan during the mission.

A. Signal processing : SAS for Autonomy

The first step for adaptive behavior is to get very high quality sonar data, so that automatic detection and classification is possible with good performances. The synthetic aperture sonar (SAS) processing is therefore essential as it gives high resolution images, and constant resolution along the sonar range.

SAS processing by allowing much better resolution reduces the ambiguity factor, so improves the classification performances. It has been shown in [1], that a real improvement on ambiguity can be obtained by decreasing beam resolution from 10 cm to 5 cm or less. A resolution of 5cm gives more than 10 independent beams on a mine like object, even at the end of the range. This give enough details on the shadows to perform automatic target recognition (ATR).

The main difficulty to perform SAS processing is to estimate and compensate for the unwanted platform motion. One way to cope with this problem relies in self-calibration or so called micro-navigation algorithms. The correlation of the bottom reverberation between two successive pings is used to estimate the along-track and along-range motion as well as the bearing shift. Different methods using ping-to-ping cross-correlation (P^2C^2) have been defined and have proved their high potential over a large number of experiments. A more detailed description of the micro-navigation methods is given in [2], [3] and [4].

On top of high resolution images, the SAS processing gives two outputs that are useful for autonomy: the estimate of array motion and the reverberation correlation.

The estimate of the array motion given by the micro-navigation is an input for the INS, in addition to a DVL. This increases the accuracy of the positioning system. The positioning accuracy is essential for efficiency of the system, so it is worth to take advantage of SAS micro-navigation for autonomy.

The reverberation correlation measurement is a good indicator of the SAS image quality. If correlation is low, the reverberation is low and the image will have less contrast. The correlation is then an input for sonar performance evaluation, which is essential for autonomy as the vehicle will be able to decide to narrow sonar lines or even to re-visit bad performances area from another point of view.

SAS processing is then an essential part for MCM AUV autonomy, giving high resolution as well as navigation and performances data.

B. Data processing

Data processing dedicated to autonomy of our AUV is composed of five main functions:

- Automatic target recognition
- Self performance evaluation
- Micro navigation
- Concurrent navigation and mapping
- Mission supervision and planning

Automatic target recognition (ATR) is based on the very high resolution SAS images. This function aims at automatically detecting and classifying mine like objects. The image processing applied performs the detection of mine like objects, and their classification by comparison of the shadow shape to a database of known mine shadows. A more detailed description of the ATR algorithms is given in [1]. If several observations of the same object exist, this function takes advantage of it: association is performed between observations, and final classification is obtained after the fusion of observations.

The output of this ATR are observations. An observation corresponds to a detected object, with an associated class (MILCO or non-MILCO), and a confidence. Confidence is essential for autonomy, as the decision will be automatically taken to re-visit some contacts depending on this confidence. If an object is non-MILCO with a high confidence in the decision, there is no need to have another observation. If the contact confidence is low, and if there is enough energy left in the vehicle, another specific trajectory close to the contact will be programmed.

Self performance evaluation: the system evaluates its sonar performances in real time, based on SAS processing and reverberation level, giving the opportunity to decide whether an area is well covered or not. A badly covered area can then be re-visited at the end of the initial mission plan. Sonar true detection range is also measured during a full sonar line, and if it is lower than expected, the initial planning of the mission can be adapted by narrowing the sonar lines.

The measured performances are mapped and transmitted through acoustic communication to the surface station. In the operational use of an AUV, this map updated continuously is an important information given to the operator during the mission. This is the only mean to effectively follow the mission execution from the surface.

Micro-navigation: the along-track and along-range motion are estimated from one ping to the next by SAS processing. These data are converted into motion in the vehicle reference frame, and sent to the INS in complement of DVL measurements. This technique gives more accuracy to the navigation of the vehicle. It has been demonstrated in [5] that an accuracy of 0.5 ‰ of the traveled distance was reachable when coupling the inertial navigation unit and the sonar displacement estimation used in SAS processing.

Concurrent navigation and mapping (or SLAM): some of the bottom objects detected along the vehicle trajectory are observed several times. They are associated and their positions are used to estimate the drift of the inertial navigation system. These landmarks are then used as reference for long term navigation. A description of this function is given in [6]. This function is also being studied by the Australian Centre for Field Robotics (ACFR) on the basis of TUS sonar data. It has not yet been tested at sea, but some post processing of sea trials data have shown that the position estimation of contacts observed during a mission is improved by this technique. A first interest of concurrent navigation and mapping appears when AUV surfacing is forbidden (under ice operations or covert operations). CNM provides a long-term navigation to reset short-term navigation. A second interest comes from its reference to terrain landmarks map. It provides relative positioning between seen objects and the AUV, and between objects. This relative positioning is independent from AUV absolute geographical position accuracy and hence from time.

Mission supervision and planning: it controls the mission events and defines actions to every situation: global mission re-planning, local re-planning, interruption of mission or emergency stop. Based on output from self performance evaluation and automatic target recognition, it decides to re-visit areas or objects at the end of the initial mission plan to increase the confidence in the detection and classification of targets. The re-planning strategy depends on the mission objectives. If mission time is of high priority, no re-visit will be performed. If residual risk of missing a mine is more important and if the vehicle energy is sufficient, most of the contacts and performance holes will be re-visited.

A performance hole, i.e. either a bad covered area or an area without sonar data, is re-visited as if it was a small mission area. If it is larger than the sonar swath, several sonar lines will be planned inside the area. For contacts, the trajectory of re-visit is computed to optimize the view for classification: range in the middle of the swath, best altitude and azimuth different from the azimuths of the previous observations.

An example of trajectories and results of re-planning is shown on Fig. 2 and Fig. 3. The path followed by the vehicle after the initial plan is going to the area where no sonar data had been initially recorded, and to several contacts to get multiple views from different azimuths. The result of this strategy is that the performance hole is filled, and at least 2 observations are recorded for suspicious contacts.

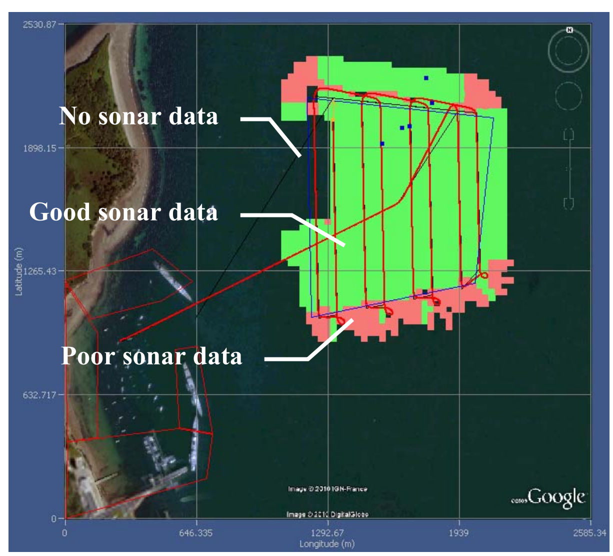

Figure 2. Performance map after initial plan.

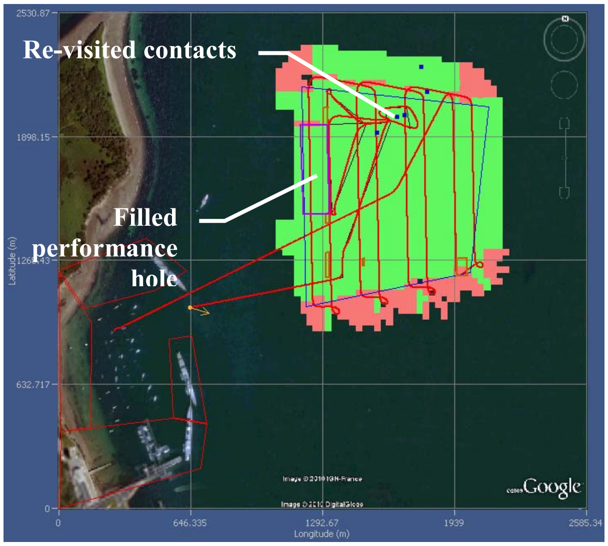

Figure 3. Performance map after re-visit.

IV. SEA TRIALS RESULTS

A. Area and trials principle

The SAS processing and the autonomy functions have been embedded in a vehicle developed by ECA in order to carry out sea trials in 2009 in the area of Brest (France).

Figure 4. AUV demonstrator at sea.

The final demonstration of these trials consisted in performing a complete MCM mission in full autonomy, with a transit of several miles from departure to the area of operations, a DCL mission and a return transit to departure position. Several exercise mines have been laid down in the area of operation, as well as several other objects of the same dimensions. The objective was to conduct the whole mission, to record sonar data on the full operation area, to detect the mines and non mines objects, localize them and perform both automatic and supervised classifications.

The supervised classification consisted in confirming or not the automatic classification given by the system, based on small images extracted from the sonar waterfalls. The system records for each contact at least one small image corresponding to each observation of this contact (Fig. 5).

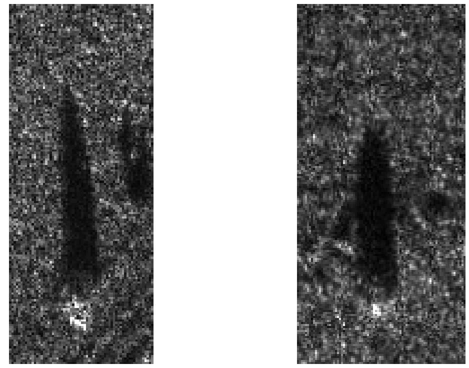

Figure 5. small images of contacts for operator analysis.

B. Results

The AUV has been able to perform the full mission, with automatic re-planning of trajectory due to shorter maximum sonar range than initially planned.

The Fig. 6 shows the mosaic of the operation area. The sonar data are mapped on the final image, using the vehicle position, and this mosaic is presented at the operator at the end of the mission, with all detections on it, and access to the full resolution images of each contact.

The performances of the system have been demonstrated. The supervised and automatic classifications have been successful, the localization accuracy of the targets was better than 10m.

After a mission of several hours, the data have been downloaded to the surface station in a few minutes, and the time spent by the operator to process the data and perform the supervised classification was much shorter than the acquisition time. Thanks to the automatic detection and classification, the operator spent time only to analyze the images of detected contacts selected by the system.

Figure 6. Mosaic of the sea trials operation area, showing different seabed textures.

V. CONCLUSIONS

The autonomy developed by TUS has been tested at sea on an AUV demonstrator. These trials have shown that MCM detection, classification and localization missions can be performed by an AUV with embedded processing and adaptive behavior. The interests of this new autonomy is to decrease the residual risk of missing a mine without increasing the global mission time, by allowing real time re-planning of the mission on low performance area and on contacts of interest. An appreciable time may be saved by avoiding a second mission on the same area. As all data are processed during the mission, the post mission analysis time is also drastically reduced. The operator only focuses on the suspicious objects detected by the system and classified as MILCO or non-MILCO with a low confidence level. Thus only one or two people are necessary to operate the AUV and to analyze the data.

The autonomous functions developed in this project can be easily adapted to any other AUV carrying a SAS sonar, as long as the sonar resolution is good enough to allow automatic detection and classification of objects.

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