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Adaptive filter of seabed clutter onboard the AUVs of an active multistatic sonar network

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Adaptive filter of seabed clutter onboard the AUVs of an active multistatic sonar network

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***Abstract*—This work aims at reducing the false alarm rate of a multistatic active sonar working in coastal, shallow waters. The sonar system is implemented through a heterogeneous manned-unmanned network including autonomous underwater vehicles (AUVs) equipped with receive hydrophone arrays. According to a cognitive sonar philosophy, each AUV characterizes the environment by processing in real time the acquired acoustic data, and exploits this contextual information to optimize the sonar performance in terms of increased probability of detection and reduced false alarm rate. The paper presents an algorithm to identify areas of compact clutter on the seabed in order to filter out as false alarms the contacts falling in those areas. Promising experimental results are reported, which were obtained under different environmental conditions (during LCAS16 and DMON17 sea trials).**

Keywords—multistatic active sonar, cognitive sonar architecture, compact clutter filter, false alarm rate

I. INTRODUCTION

This work addresses the automatic, real-time exploitation of contextual information within the cognitive sonar architecture aiming at target detection, localization, tracking and classification. The algorithm is developed to be implemented in real time on board the CMRE autonomous underwater vehicles (OEX-C AUVs) that are the key assets of a multistatic active sonar heterogeneous network [1]. The goal is to filter contacts coming from compact clutter present on the seabed insonified by an active acoustic source and detected in real time by each AUV, which tows a linear receive array of hydrophones. Most of the work conducted by CMRE in ASW applications refers to littoral, shallow water environments, where the contribution of compact clutter to the false alarm rate may be very significant. Reducing the false alarm rate at contact level by filtering a certain percentage of the compact clutter is of great importance in order to improve the tracker performance by feeding it with a lower number of false contacts. It is fundamental not to filter out contacts belonging to a target of interest, assumed as a moving vehicle.

We intend to identify clutter contacts based on their persistency (i.e., density over a geographical area as time passes) in order to decrease the false alarm rate. The approach exploits the output (i.e., the clusters) of the acoustic signal processing chain implemented on board the AUVs in order to progressively increase their knowledge of the surrounding environment while they are surveying a region; contacts that fall in an area identified as compact clutter are filtered out before feeding the tracker. The proposed filtering module is expected to reduce false alarms and increase the probability to retain target contacts among those ones selected for feeding the tracker. and sharing with the other nodes of the network.

Given the limited bandwidth of acoustic communications, tracks are first scored, in order to share only a subset of them with the other nodes of the network. This constraint makes the removal of tracks on persistent clutter even more important, because they could easily get a high score and reduce the probability to propagate the tracks related the real target.

II. CLUSTER FILTER

The cluster filter module (see Fig. 1) is designed to be included in the real-time AUVs' signal processing chain between the detector and the tracker [1, 2]. In the block diagram of Fig. 1 the modules of the pre-existing signal processing DLT chain are in rounded-corner light-blue boxes and the modules of the Cluster filter are enclosed by a red dashed line. For every ping, the detected clusters are first geo-referenced and then used to update the 2D histogram of cluster positions in latitude/longitude (or XY on a local grid projection). At the beginning of the mission there will be no accumulated evidence of locations with persistent cluster, but, as the mission progresses, the clusters associated to persistent seabed clutter are expected to contribute to an increase of density in particular locations, as each AUV is generally programmed to run along a racetrack for most of the mission (or remains in a confined area). The transient passage of a target is not expected to produce the same effect. A process of identification of the clutter on the 2D contact histogram follows, which provides the localization of small areas where the histogram peaks overcome a threshold. The selected areas become then *exclusion areas* where all contacts initially detected may be removed before feeding the tracker. Alternatively (see the pair of switches in the block diagram of Fig. 1), one can decide to use a pre-computed 2D histogram of clusters on the basis of a pre-survey mission, if available. An example of 2D histogram of cluster positions is shown in Fig. 2; these data feed the process of "identification of persistent clutter" shown in Fig. 1. The plots from Fig. 2 to Fig. 4 are selected as explanatory examples of partial results of the algorithm main steps; these results were computed from the at-sea data collected during about 1.5-hour mission by Groucho during DMON17 exercise (off South coast of Iceland, July 4, 2017).

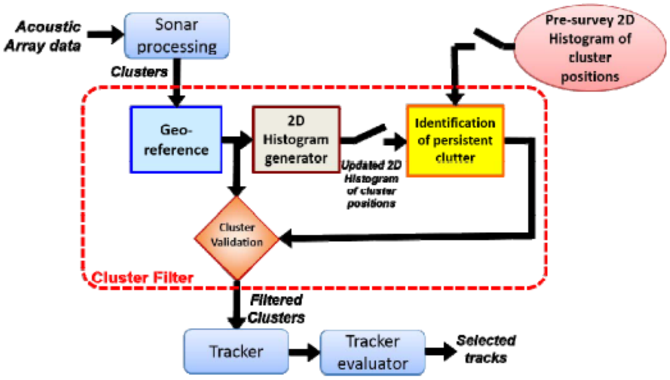


Fig. 1. Block diagram of the cluster filter, as included in the active sonar signal processing chain on the OEX-C AUVs.

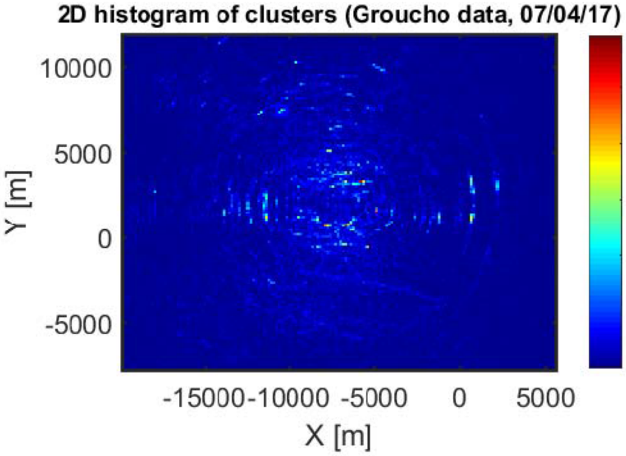


Fig. 2. Example of 2D histogram of cluster positions from 1.5h-long mission of Groucho AUV (DMON17 experimentation, 4 July 2017).

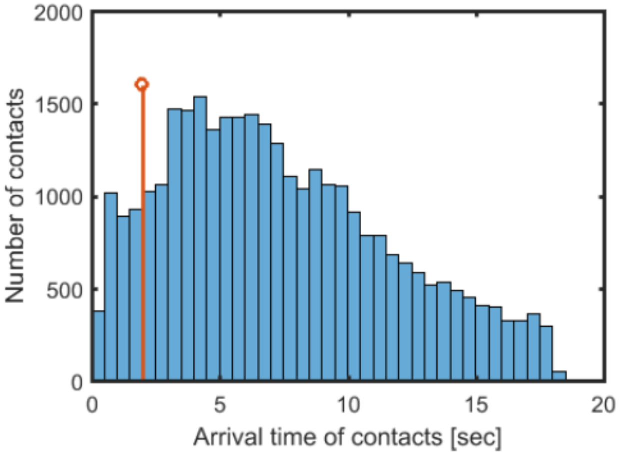


Fig. 3. Example of histogram of cluster positions as the range (i.e., the time of arrival) increases from the AUV's receive array. The red line represents the arrival of the direct blast.

The detailed description of the algorithms providing the automatic identification of persistent clutter follows.

A. Automatic identification of persistent clutter

The module for the automatic identification of the persistent clutter is fed with the 2D histogram of cluster positions.
The algorithm can be summarized by the following steps:

- ***Scaling of the cluster histogram:*** the matrix that represents the histogram of the distribution of the contacts in the XY plane is normalized by its cumulative sum in order to generate a pdf-like representation (Fig. 4(top) shows the result of scaling process applied to Fig. 2);
- ***Normalization of the histogram:*** the distribution of the contacts with the range from the receiver depends on the type and level of reverberation, but it is generally possible to state that it will decrease with range after the direct blast. A typical distribution is shown in Fig. 3, which shows the histogram of the arrival time of contacts. As a consequence of this non uniform distribution, it is necessary to apply a sort of equalization (or normalization) [3, 4] of the 2D histogram in order to allow the use of a constant threshold for the identification of the clutter points. The estimation of the background noise (Fig. 4(b)) on the image in Fig. 4(a) is done by calculating the median over a 2D sliding window [5]. The effect of the normalization on the histogram of contacts using a square window with size of 2 km is shown in Fig. 4(c): the distribution of the background noise can be now considered uniform, while the original peaks (identifying the most persistent clutter positions) have been preserved.
- ***Thresholding***
  A threshold is applied to detect peaks in the image which correspond to persistent clutter.
  The threshold is set as a percentage of the maximum peak value of the image.
  The threshold is iteratively increased until the ratio between the number of pixels above it and the area of the image is lower than a fixed value (set to 0.02).
  The result of the thresholding is the binary image shown in Fig. 5(a) (obtained with a relative threshold of 0.3 applied to Fig. 4(c)).
- ***Clustering***:
  A mathematical morphology [5, 7] algorithm is applied to the binary image in order to ignore peaks with a small number of pixels and to associate peaks in close proximity. The algorithm applies the following operators [8] in this order:
  - *Bridge*: bridges unconnected pixels, that is, sets 0-valued pixels to 1 if they have two nonzero neighbours that are not connected;
  - *Fill*: Fills isolated interior pixels (individual 0s that are surrounded by 1s);
  - *Diagonal fill*: Uses diagonal fill to eliminate 8-connectivity of the background.

The output of the morphology filter is shown in Fig. 5(b). The obtained clusters are considered as exclusion areas. The aim of the filter is to connect fragmented areas in order to make clusters of connected pixels, without making them too big with respect to the original size. Too big exclusion areas may prevent the detection of the target in those segments of its path that intersect them, and hence may break its estimated track.

- ***Identification of Clusters (i.e., exclusion areas)***

Each cluster is localized in the image and surrounded by a bounding box having the following features:

  - coordinates of bounding box centre
  - orientation
  - major axis length
  - minor axis length

Fig. 5(c) shows the bounding boxes of the extracted connected areas, as superimposed to the original 2D histogram of cluster position (Fig 4(a); each box is considered as an *exclusion area* and sonar contacts within it will be classified as false alarms.

In the application of the sonar processing chain on each ping, only the contacts detected out of those exclusion areas are selected and passed to the tracker.

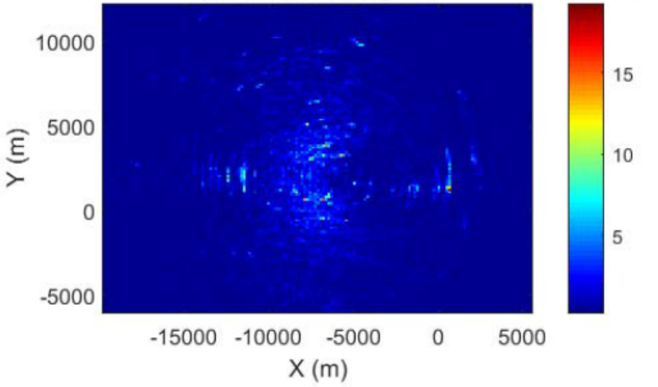
In order to keep the computational load limited onboard the AUVs, the number of contacts to pass to the tracker is maintained low; contacts are selected on the basis of their SNR; hence the application of the filter described, by reducing the number of false alarms, especially those with high SNR, is expected to increase the probability to retain target contacts among those ones selected for feeding the tracker and sharing with remote collaborators within the network.

III. EXPERIMENTAL RESULTS AND DISCUSSION

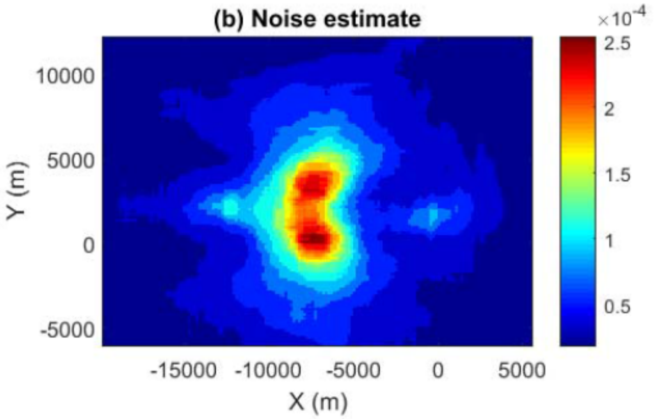
The proposed algorithm is verified and validated on a couple of data sets acquired during sea trials characterized by different environmental conditions in terms of density of clutter areas on the seabed. The first data set is the same used in support of the algorithm description in Section II and, as anticipated, is extracted from the DMON17 data of Groucho AUV, which was following straight racetracks in a shallow water area at the border of the South Iceland continental shelf. The area was characterized by high-density clutter regions. The data were acquired on July 4, 2017 between 10:40Z and 16:20Z, while the AUV made three full cycles along its racetrack. An artificial target (the CMRE DERS Echo-Repeater) was towed by the Icelandic Coast-Guard boat ICGV TYR.

Fig. 6 shows the beam-collapse plot of all contacts detected from the normalized beamformed data for the full mission, where the direct blast and the E/R tracks are shown. Several tracks can be easily seen, which are interpreted as seabed clutter. Some of them are dense of contacts, which may have SNR values comparable to the target. The bistatic range associated to the centroid of each exclusion area shown in Fig. 5(c) is calculated, and two coloured line are drawn around it in Fig. 6 in most cases these stripes bound tracks of high-density contacts which can be interpreted as compact clutter, *i.e.*, false-alarm tracks.

(a) Scaled histogram



(b) Noise estimate



(c) SNR of histogram

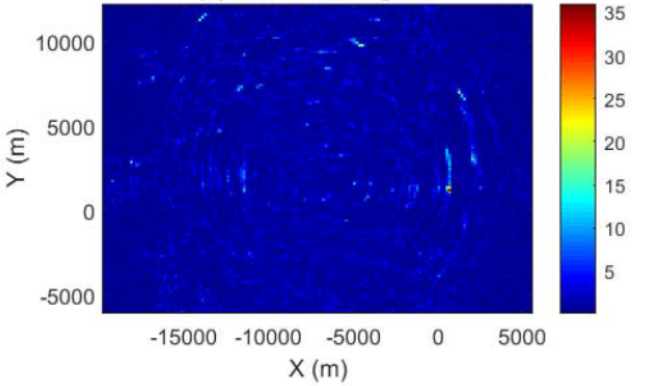
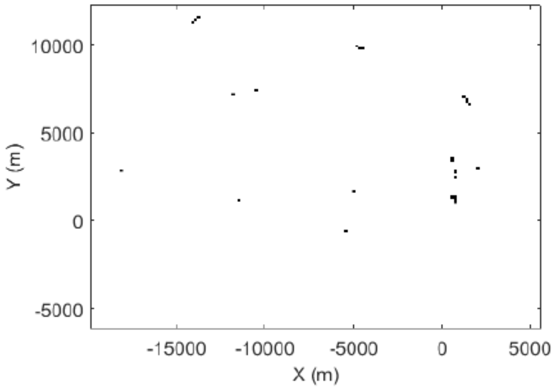
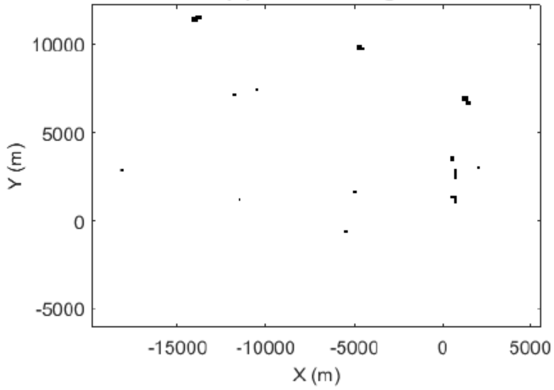


Fig. 4. Results of processing steps applied to the 2D histogram of cluster positions shown in Fig. 2. (a) 2D histogram of cluster positions normalized with respect to its cumulative sum in order to obtain a pdf-like representation. (b) Background noise estimate of image (a) achieved by computing the median over a 2D sliding window. (c) Histogram achieved by computing the ratio between image (a) and image (b); it represents the normalized version of the original histogram in (a) where the noise distribution can be assumed uniform.

(a) Binary image (from histogram thresholding)



(b) Cluster image



(c) Clutter areas on the original 2D histogram

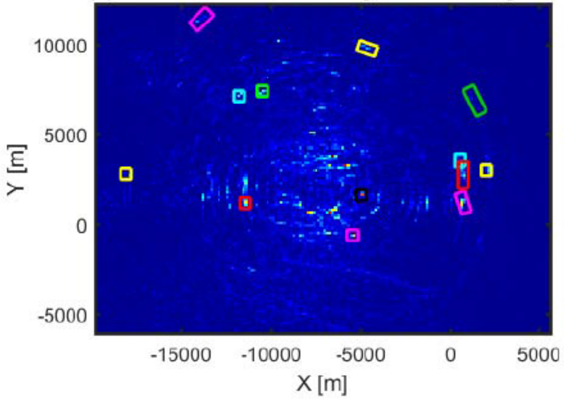


Fig. 5. (a) Binary image, result of the thresholding process applied to Fig. 4(c). The pixels above the threshold are in black. (b) Result of image processing aimed at connecting adjacent small sub-areas into clusters. (c) Identification of clusters of plot (b) overlapped to the original 2D histogram of Fig. 4(a).

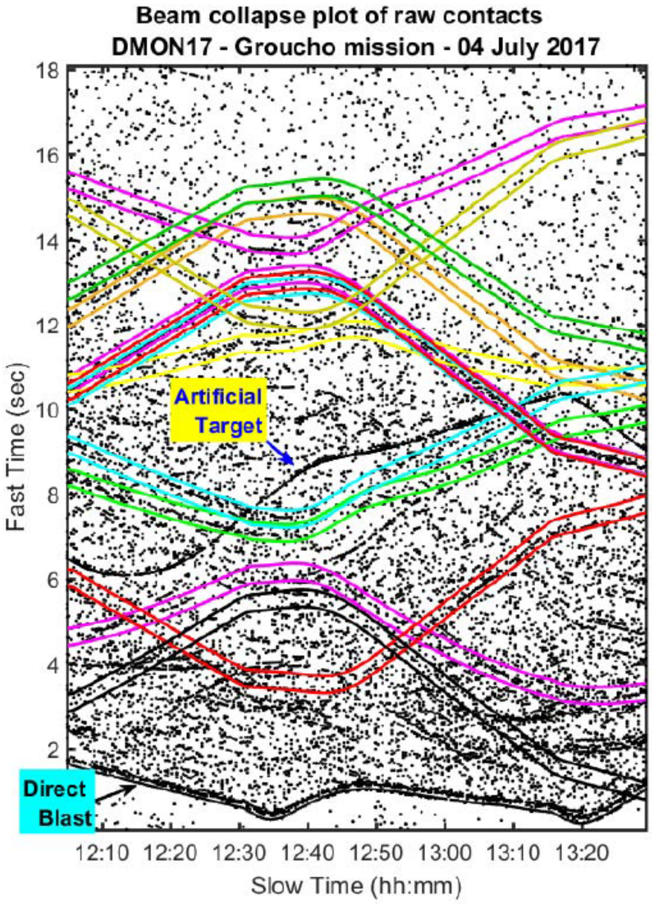


Fig. 6. Beam collapse plot of raw contacts during Groucho mission on 4 July 2017; the colored lines outline the clutter areas identified in Fig. 5(c). In most cases the colored lines bound stripes of very dense contacts, corresponding to compact clutter. The contacts related to the direct blast and to the artificial targets are indicated.

Fig. 7 compares the output results of the tracker when it is fed with all contacts (Fig. 7(a)) or only with the filtered contacts (Fig. 7(b)). The longest track belongs to the artificial target. The filter is able to significantly clean the track image from tracks coming from compact, persistent clutter, while preserving transient signals of interest, such as the passage of a moving target. Figs. 8 and 9 report similar results, but from the mission of Harpo OEX-C AUV, running in an adjacent region in the same time. Due to the different geometry and racetrack orientation, Harpo "sees" a more complicated scenario, with much more clutter. As shown in Fig. 8 the processing identifies a number of clutter areas; the comparison of tracking results with all the contacts (Fig. 9(a)) and with filtered contacts (Fig. 9(b)) shows that the approach significantly helps in cleaning the track image: many false tracks are filtered out, while the target tracks (the longest red lines) are unaffected by the filtering process.

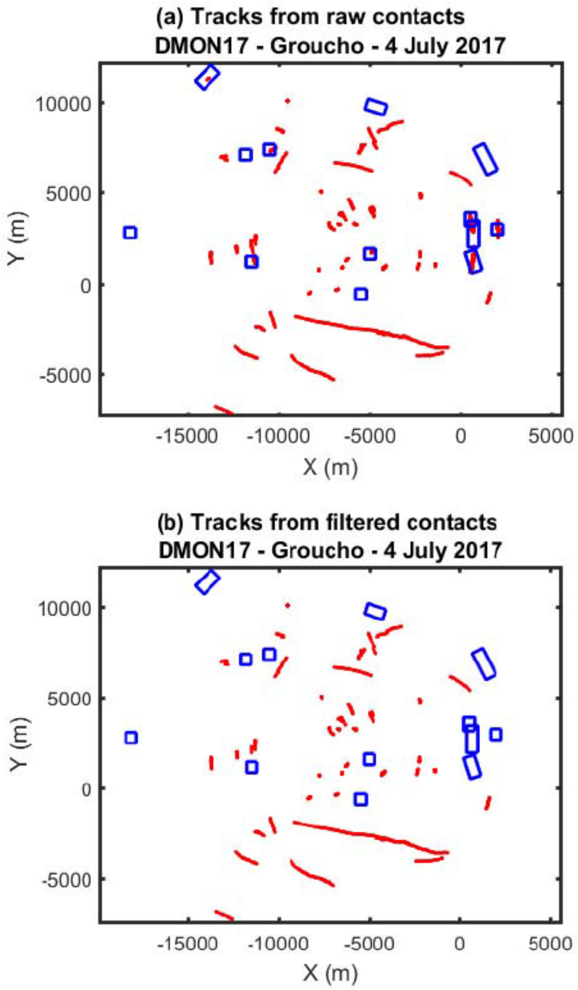


Fig. 7. Tracker outputs (tracks in red) related to mission of Groucho on 4 July 2017 (DMON17 sea trial). The exclusion areas identified in Fig. 5(c) are overlapped. (a) The tracker is fed with all contacts detected by the signal processing chain. (b) The tracker is fed only with the contacts that fall out of the exclusion areas identified in Fig. 5(c).

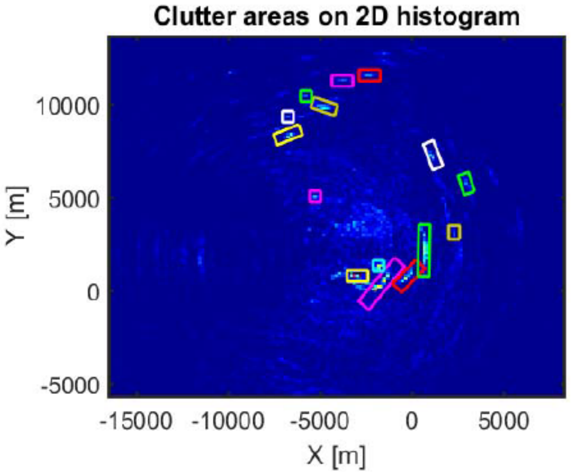


Fig. 8. 2D histogram of clusters and detected bounding boxes of clutter related to the survey of Harpo AUV ((DMON17 sea trial, 4 July 2017).

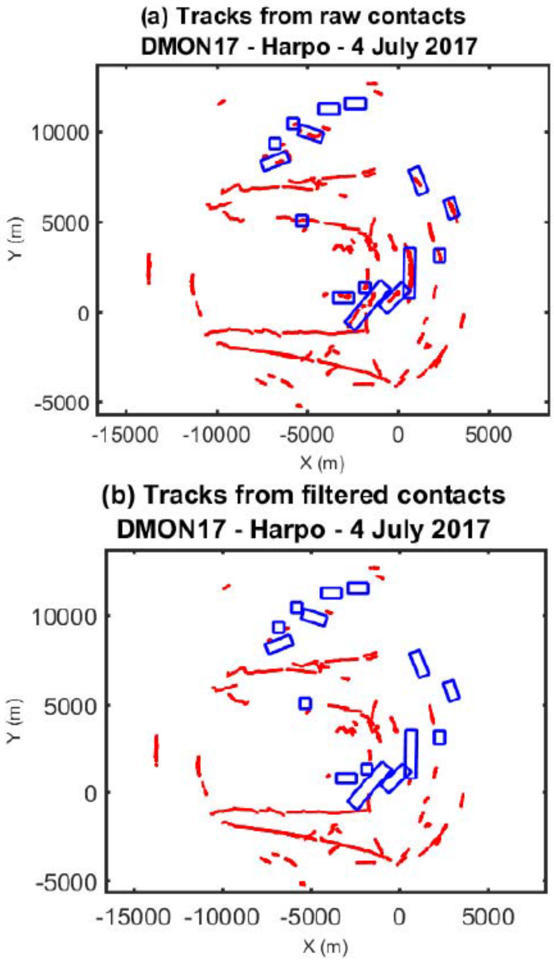


Fig. 9. Tracks (in red) found by Harpo AUV on 4 July 2017 (DMON17). The exclusion areas identified in Fig.8 are overlapped. (a) The tracker is fed with all contacts detected. (b) The tracker is fed with the filtered contacts.

The second data set comes from LCAS16 experimentation, occurred in a coastal area of the Gulf of Taranto, Italy, in October 2016. The filter is built on the basis of a mission of Harpo occurred on October 19 from 11:00Z to 14:30Z. The missions were conducted in a shallow water, littoral area characterized by mid-density compact clutter. Results are reported in Figs. 10 and 11. The proposed methodology is shown to be very effective in cleaning the track image.

IV. CONCLUSIONS AND WAY AHEAD

This paper has addressed the development of a filter of compact clutter to reduce the false alarm rate of a multistatic active sonar system. The filter is thought to run in real time onboard CMRE OEX-C AUVs which, each towing a linear hydrophone array, play the role of acoustic receivers in a hybrid (manned-unmanned) heterogeneous network devoted to target detection, localization and classification.

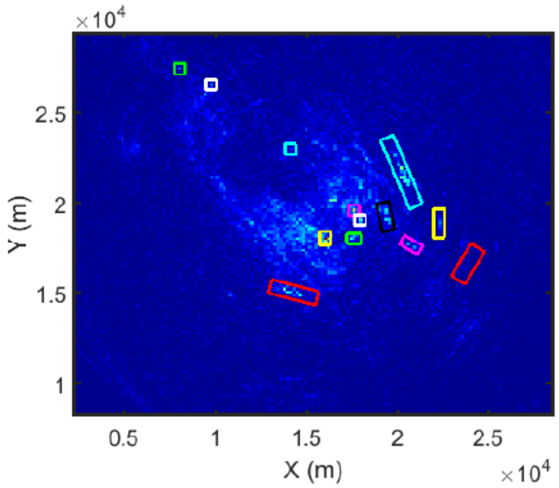


Fig. 10. 2D histogram of clusters and detected bounding boxes of clutter related to the survey of Harpo AUV (LCAS16 sea trial, 19 Oct 2016).

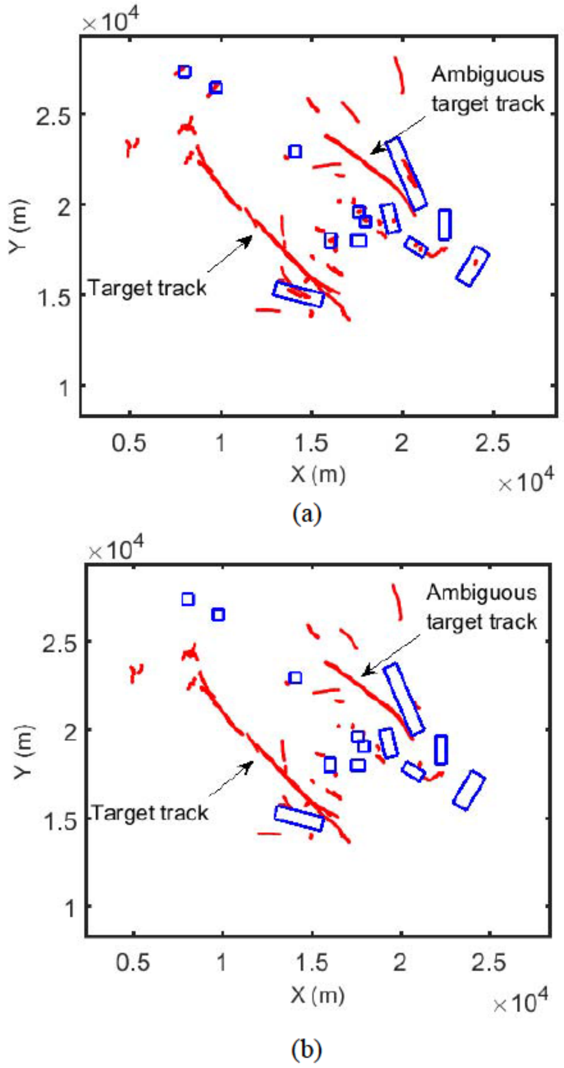


Fig. 11. Tracks (in red) found by Harpo AUV (LCAS16, 19 Oct. 2016). The exclusion areas identified in Fig.8 are overlapped. (a) The tracker is fed with all contacts detected. (b) The tracker is fed only with the filtered contacts.

It is built along the AUV survey mission (even in the presence of a mobile target) and aims at filtering out contacts related to persistent clutter; it has been successfully validated in post-analysis against data collected during at-sea experimentations occurred in areas (e.g., off the South coast of Iceland, Gulf of Taranto, Italy) characterized by a variety of compact clutter densities. Given the very promising results, the proposed approach will be included in the real-time cognitive sonar architecture running onboard Harpo and Groucho AUVs in the next sea trials.

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Keywords

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