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Samantha Dugelay, Warren Fox

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Active Contours for Synthetic Aperture Sonar Snippet Registration

Samantha Dugelay and Warren Fox
Autonomous Mine Search
Centre for Maritime Research
and Experimentation
Italy
Samantha.Dugelay@cmre.nato.int

***Abstract*— In mine-hunting operations, there is currently a strong focus on using autonomous systems in order to remove personnel and ships from the minefield. These systems must perform their missions effectively, and the collected data should be exploited efficiently in order to maximize performance. Automatic target recognition (ATR) is a key enabling component of achieving this goal. Whilst immense progress has been made to design an optimal ATR, it still requires further improvement to perform at the level of a human operator in all environments. One way to increase automatic target recognition performance is to fuse multiple pieces of information on a given target, either, at data level (early integration), at feature level (intermediate integration) or at classification level (late integration). This paper details an algorithm for the registration and incoherent fusion of multiple views of synthetic aperture sonar snippets of targets at data level. The assumptions in this study are that data have been gathered on a target from opposing sides and targets have been detected with a basic detector.**

Keywords—Synthetic Aperture Sonar, Automatic, Target, Recognition, Image, Registration.

I. INTRODUCTION

Currently the first autonomous phase of the CMRE Mine-hunting UUV Shallow water Covert Littoral Expeditions (MUSCLE) system consists of an adaptive lawn mower pattern search and detect phase as described in [1,2] and shown in Fig. 1. Registration and fusion of high resolution synthetic aperture sonar (SAS) imagery snippets is non-trivial due to imperfect navigation of underwater vehicles. Previous wok at CMRE has demonstrated a technique to register two SAS snippets where viewing angles of objects differ by no more than 90 degrees [3] as shown in Fig. 2. The developed algorithm in this case relies solely on minimizing the total variation in the fused image. Locations of high value information and interest in the SAS snippets are the detection highlights which tend to present strong image gradients. The registration approach therefore exploits this characteristic by employing the Laplacian transform of the image. Whilst this approach works well when viewing angles differ by less than 90 degrees, an additional constraint is required in the case of opposing views.

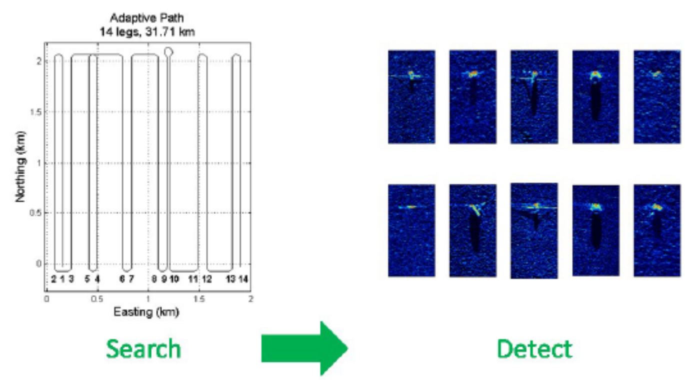


Fig. 1. First autonomous phase of the CMRE MUSCLE system for mine search and detction.

Fig. 2. Schematic concept of registration of two SAS snippets with data acquired at a 90 degrees difference angle.

This paper describes a new algorithm which proposes an additional constraint; this constraint is based on the implementation of an active convex hull approach to better constrain the registration of opposite highlights which have minimal overlap as shown in Fig. 3.

The remainder of the paper is organised as follows: Section II describes the theoretical development of the registration algorithm when fusing SAS snippets acquired on targets from opposite directions, Section III presents some of the initial results obtained on experimental data and in Section IV, we will summarise the conclusions on this method and provide some initial thoughts on future work.

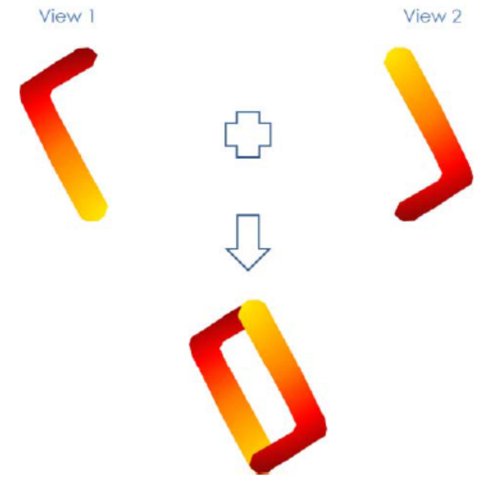


Fig. 3. Schematic concept of registration of two SAS snippets with data acquired at a 180 degrees difference angle.

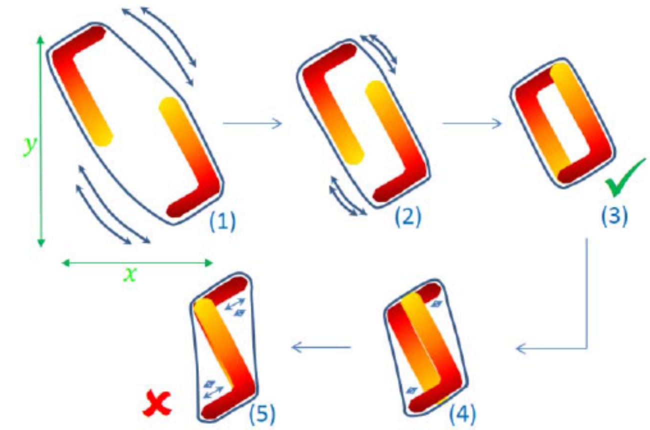


Fig. 4. Synthetic example of the elastic band concept. The registration process starts with highlights separated (step 1); the highlights are then gradually brought together (step 2) and the optimal registration is achieved at step 3. If the process continues either horizontally or vertically as shown in step 4, the shape and size of the convex hull changes. If correlation were to be employed for the registration, step 5 would be achieved resulting in an incorrect registration.

II. Image Registration and Fusion

When dealing with registering snippets acquired from opposite directions, the problem is how to **concatenate** these two highlights together in order to build up the target contour. The initial concept for the registration of snippets taken from opposite views is based on fitting an "elastic band", or in mathematical terms a convex hull, to the set of points in the image that compose the two sets of highlights. As shown in Figure 4, the first step starts with a stretched elastic when the highlights are too far apart. As the highlights come closer, the tension eases and comes to a resting position (shown with a green checkmark). As the highlights are displaced towards a maximum correlation, for example beyond the ideal position, the tension again increases as the elastic edges are separated from the highlight boundaries. The adopted solution in this report is inspired by the research undertaken in active contours for segmentation. Active contours, also called snakes, have been developed for image segmentation and in particular to locate boundaries. The concept of snakes is simply to iteratively move a curve from the outside boundary of an image inwards until the curve reaches a boundary, at which point it stops. These contours move under the influence of forces, either internal forces governed by the curve itself, or by external forces computed from the underlying image u_0. A snake model [4] is the curve C which minimises the following energy function:

$$J_1(C) = \alpha \int_0^1 |C'(s)|^2 ds + \beta \int_0^1 |C''(s)|^2 ds - \lambda \int_0^1 |\nabla u_0(C(s))| ds \,. \quad (1).$$

α, β and λ are positive weights, $C(s) = (C_1(s), C_2(s))$, and C' and C'' denote the first and second derivatives of C, respectively. The first two terms in the energy function translate the internal forces and correspond to the constraints on the smoothness of the curve; the third term is the external force and pushes the curve towards the object boundaries.

In the current study, the energy function E takes the following form inspired by Chan and Vese [5] and Kass et al. [4]:

$$E(CH_{xy}) = \alpha \frac{\text{Length}(CH_{xy})}{\max_{x,y}(\text{Length}(CH_{xy}))} + \beta \frac{\text{Area}\left(inside(CH_{xy})\right)}{\max_{x,y} \text{Area}\left(inside(CH_{xy})\right)} + \frac{\gamma(\int |\nabla^2 u_0(s)| ds)}{\max_{x,y}(\int |\nabla^2 u_0(s)| ds)}, \quad (2),$$

where CH_{xy} is the convex hull (or elastic band) which fits the two highlights for a given horizontal translation x and a vertical translation y as shown in Fig. 4 and α, β and γ are positive fixed parameters. Rather than using an active contour to establish a segmentation, an initial highlight segmentation for both snippets is performed prior to the registration step using a combination of histogram thresholding and morphological operators as described in [6]. An **active convex hull** CH is then employed to tighten the highlights together. The third term in the energy function translates the requirement to retain strong edges and is based on the total variation approach described in [6] for the registration of SAS snippets whose viewing angles differ by no more than 90 degrees. In this case, the registration approach solely exploits the strong edges characteristic by employing the Laplacian transform of the image. The Laplacian of an image is a useful operator to detect rapid changes and can give a measure of the total variation contained within an image. The Laplacian of an image $I(x,y)$ is given by:

$$L(I) = \frac{\partial^2 I}{\partial x^2} + \frac{\partial^2 I}{\partial y^2}. \quad (3)$$

The total variation in an image is given by:

$$TV(I) = \sum_x \sum_y |L(I)| \,. \quad (4)$$

This is the discretised version of the third term in the energy minimisation function. The minimisation problem is then seen as:

$$\min_{CH_{xy}} E(CH_{xy}) . \qquad (5)$$

In order to accelerate the estimation process, the search is initialised using a correlation of target highlights found from the segmentation process and a multi-scale parameter space partition described in [6].

Once registration has been achieved fusion of the image is achieved by normalising the two snippets and taking the maximum pixel value between the two snippets at every location of the fused image.

III. Results

A. The MUSCLE system

The CMRE Mine-hunting UUV for Shallow water Covert Littoral Expeditions (MUSCLE) system is a Bluefin unmanned underwater vehicle (UUV) equipped with a Thales synthetic aperture sonar and designed specifically for mine-hunting search and map missions; schematics are shown in Fig. 5. The 300 kHz interferometric SAS can achieve an along track resolution of 2.5 cm, typically to a range of 150 m and a 1.5 cm across track resolution with a 60 kHz bandwidth.

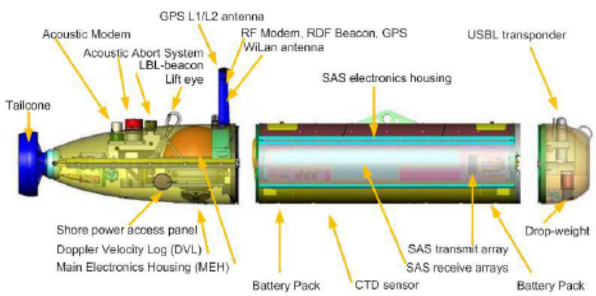


Fig. 5. Diagram of the CMRE MUSCLE system.

B. A case study

In this section, a case study exemplifies the issues with registering two views on a target acquired from opposite directions. In Fig. 6, two views from opposite directions have been acquired on a target as shown on the top left and top right. These snippets are projected onto plan range, rotated according to vehicle heading and are projected onto a 2.5 x 2.5 cm resolution grid. The highlights of each view are segmented and the segmentations are correlated; the lag of the peak of the correlation function is used to provide the starting point for the image registration process. This correlation tends to superimpose the highlights and does not in general provide the desired result. This is also the case for a straightforward subpixel correlation via a Discrete Fourier Transformation (DFT) as shown in Fig. 7. In this case the highlight from view 1 tends to be superimposed centrally over the highlight of view 2 (see image (a)); the highlight contribution from view 1 is delineated in purple in the zoomed-in snippet on the bottom left. Instead, this contribution from view 1 should be placed to the left and higher up with respect to the highlight contribution from view 2 as shown in snippet (b) bottom.

If the method developed previously for views taken at 90° is used [6], i.e. when $\alpha = \beta = 0$ in the energy function, then the least total variation is achieved when the two snippets are superimposed as shown in Fig. 8. Setting $\alpha = \beta = \gamma = 1$, the fusion result shown in Fig. 9 is obtained. The total variation term is in this case outbalanced by the two convex hull expressions, and it could be argued that the total variation term is unnecessary; it is however retained to account for examples where more variation on the seabed is present. Fig. 10 shows a zoom on the highlight and correctly places the highlight contribution from view 1 with respect to that of view 2

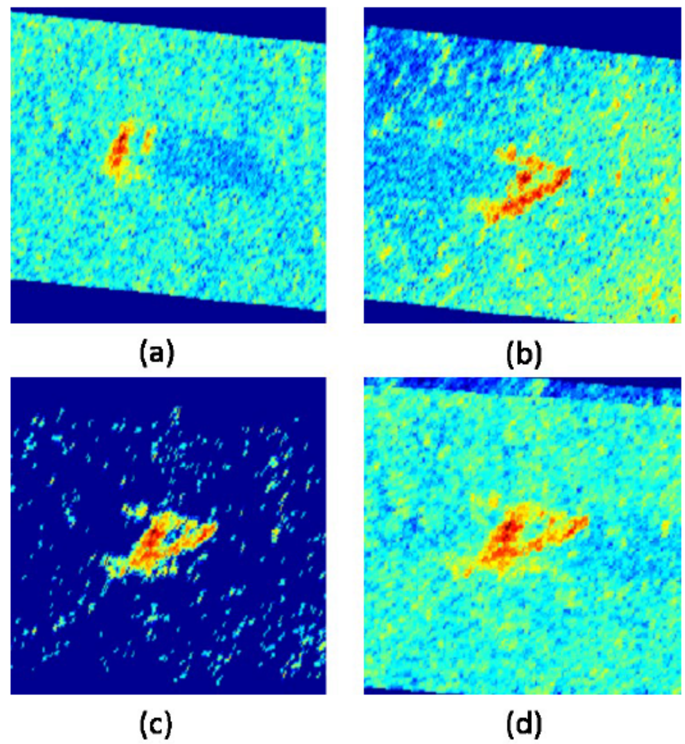
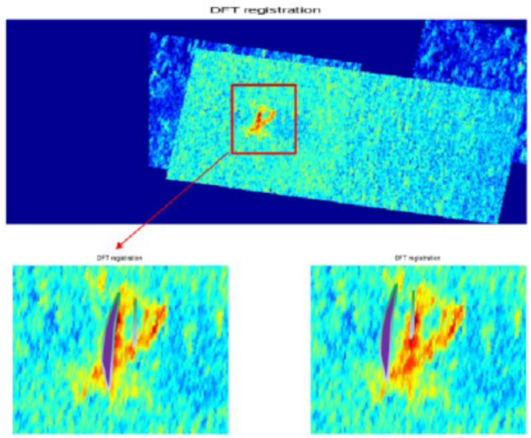


Fig. 6. Zoom in of the previous example of two opposite views: (a) View 1, (b) View 2 acquired at 180° to view 1, (c) fusion after threshold of the two views using correlation of the two segmentations and (d) fusion of the two views using peak correlation of the two segmentations.



(a) Result obtained via DFT (b) Desired result

Fig. 7. Fusion result obtained using a discrete Fourier transform correlation. The top image is the result; notice the wrap-around effect. The zoom on the left shows that the highlight contribution from View 1 (delineated in purple) is placed centrally across the highlight contribution from view 2. The zoom on the right shows where the delineated highlight from view 1 should be registered with respect to view 2.

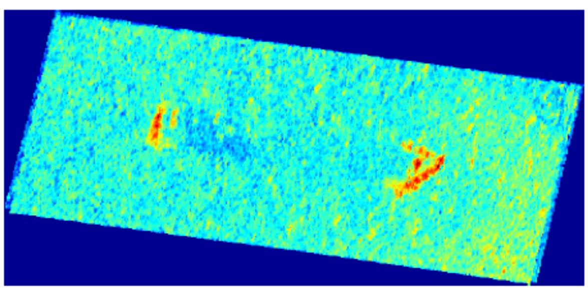


Fig. 8. Result of the image registration and fusion using an energy function which only takes into account the total variation in the image.

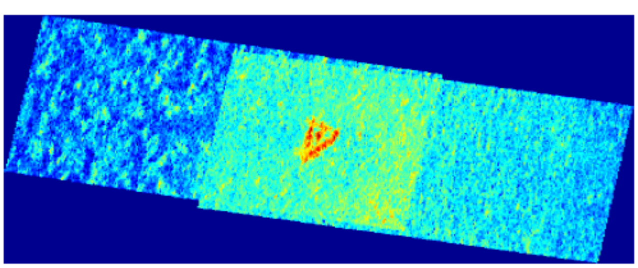


Fig. 9. Registration and fusion result when all terms of the energy function are combined equally.

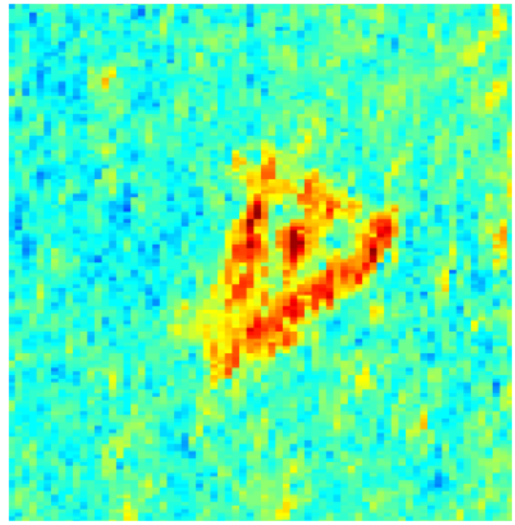


Fig. 10. Registration and fusion result zoom of the previous figure when all terms of the energy function are combined equally.

C. *Example 2*

Example 2, in Fig. 11 shows two opposites view of a modern mine.

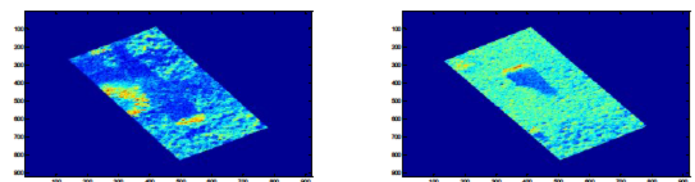


Fig. 11. Example2: two opposite views on a modern mine.

The resulting fusion of the two snippets is presented in Fig. 12 showing a good target highlight reconstruction and a good alignment of seafloor structure. A zoom on target is shown in Fig. 13.

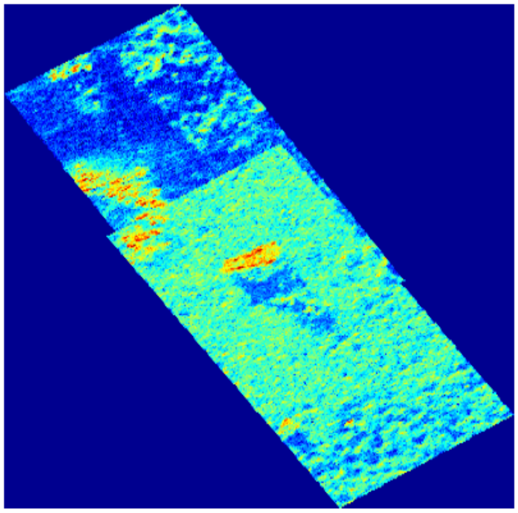


Fig. 12. Registration and fusion result when all terms of the energy function are combined equally.

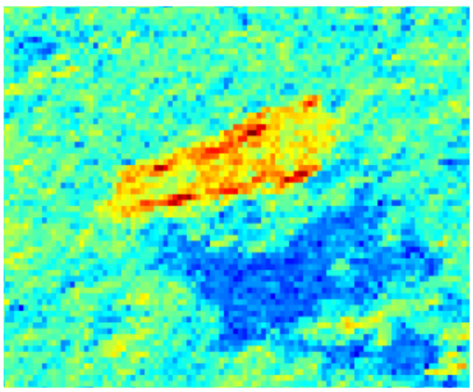


Fig. 13. Registration and fusion result zoom of the previous figure when all terms of the energy function are combined equally.

D. *Example 3*

Fig. 14 shows two opposites view of a rock. In one view (left) the highlight appears similar to a truncated cone shape, in the opposite view (right) it appears like a cylinder. The resulting fusion of the two snippets is presented in Fig. 15 and Fig. 16 zoomed on the highlight showing again good target highlight reconstruction.

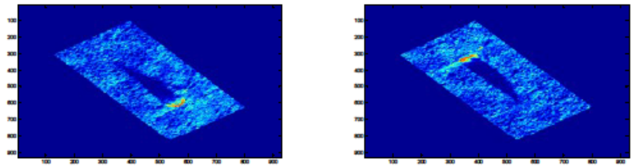


Fig. 14. Example3: two opposite views on a rock.

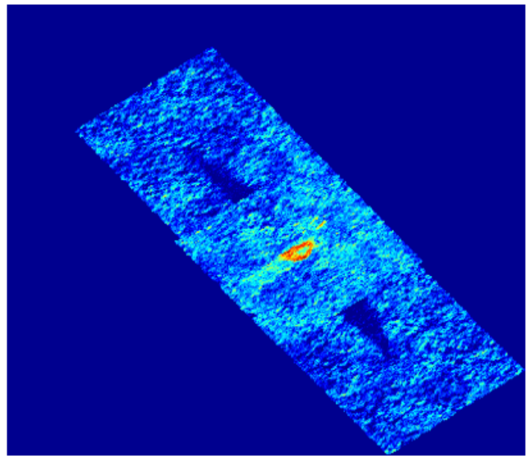


Fig. 15. Registration and fusion result when all terms of the energy function are combined equally.

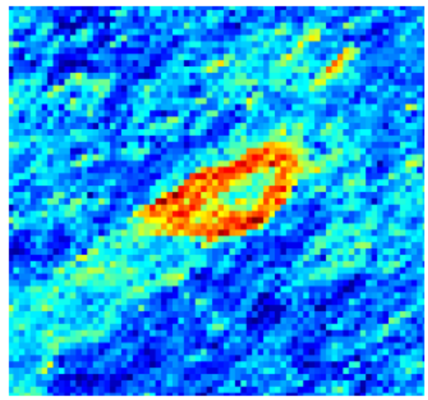


Fig. 16. Registration and fusion result zoom of the previous figure when all terms of the energy function are combined equally.

IV. Conclusions and Future Work

This paper describes the work in progress relating to synthetic aperture sonar image registration undertaken at CMRE within the Autonomous Mine Search project. The aim of the work is to reconstruct the target highlights from multiple views in order to eventually achieve a full 360° object highlight image, or increase information on target sufficiently to be able to classify it with improved certainty. The registration process is based on minimising the length and area of an active convex hull which surrounds the target highlights and the variation within the fused image where variation is estimated using the Laplace operator. At present, only translation is estimated via a multi-scale search within the parameter space. Fusion is achieved presently by taking the maximum value pixel at each location of the registered rescaled images.

Results demonstrate the potential of the fusion approach for opposite views with the added constraints on the perimeter and area of the convex hull of the target highlights. The energy function mostly takes into account the information on target highlight but also includes seabed structures if present.

Immediate future work will focus on creating a database of fused images to assess the increase in information gained and to initiate work on classifying fused images. The study on image registration will also centre on unifying the methods for views taken at multiple angles between 0 and 180 degrees and investigating (1) porting the algorithms on-board the MUSCLE and (2) tactics for using image fusion on-board and in-mission.

The unification of the two methods ((1) less than 90 degrees and (2) around 180 degrees) is necessary as the assumptions on the minimisation of the active convex hull no longer holds true for angles less than 180 degrees ± 20 degrees. But the use of the total variations within the image does hold true. It is anticipated that weighting components α, β and γ will need adjusting as a function of difference in viewing angles.

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Author(s)

Samantha Dugelay, Warren Fox

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Abstract

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Keywords

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Issuing Organization

NATO Science and Technology Organization
Centre for Maritime Research and Experimentation

Viale San Bartolomeo 400, 19126 La Spezia, Italy

[From N. America:
STO CMRE
Unit 31318, Box 19, APO AE 09613-1318]

Tel: +39 0187 527 361
Fax:+39 0187 527 700

E-mail: library@cmre.nato.int