Detection and classification of trawling marks in side scan sonar images

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SYNOPSIS

The objective of this project aims at detecting automatically trawling marks and quantifying their density for environment monitoring and fishing impact assessment. The work has been carried out on side scan sonar images, where these marks are characterised as long shadow straight lines. Hence, the process concentrates on detect every straight line in the image and then determine if these lines are trawling marks or not. To do this, pre-processing is first applied to the original image, then straight lines are detected using Canny filtering. Finally, before their density is evaluated, trawling marks are classified using length and curvature discrimination. Due to the specificity of this kind of images, no training is possible and results are presented directly in real images.

INTRODUCTION

Trawling marks are characteristic of human activity, and more precisely of fishing activity, in the seabed. These marks are produced by contact of nets with sea bottom, catching all typical sea elements from fishes till coral, seaweed, etc. The main objective of this project aims hence at automatically detecting trawling marks and quantifying their density for environment monitoring and fishing impact assessment.

This work has been carried out with side scan sonar images, which are composed of three areas not always well defined: shadow, echo and reverberation. The difficulty in separating these three areas is due to the existence of a typical noise in this kind of images: the speckle noise, which has to be eliminated or minimised as much as possible.

In order to carry out the main objective, this study is divided into three stages. The first stage consists of pre-processing such as the homogenisation of the illumination and the removal of the Speckle noise. A higher quality image is obtained, which can be processed in the next stage: the detection of straight lines in the image. Once these straight lines have been detected, they are classified as trawling / non-trawling marks and, finally, their density is measured in the area contained in the image.

This paper has been organised as follows. In next section, we will present pre-processing: the method used for homogenising the illumination and for removing speckle noise. Then, the process used to detect straight lines is discussed: Canny filter. After this, we will explain how these straight lines are classified into trawling marks using length and curvature discrimination. And finally, we will present the results obtained and the conclusion of the project.

PRE-PROCESSING

Pre-processing consists of operations that are applied to the original image to facilitate the subsequent processing. Imperfections in the image have to be corrected before the image can be used in the rest of the system.

Two main types of perturbations can be found in side scan sonar imagery. Both of them are due to the acquisition method used in this kind of images. On the one hand, we have an illumination problem. As it can be observed in Fig 1, the central part of the image, close to the towfish that contains the sensors, is brighter than the sides of the image which are distant of the towfish. It is necessary for the rest of the system that the image does not have brighter areas than others since it could have a negative influence on the further processing, i.e. edge detection, segmentation, etc. On the other hand, this kind of images presents a huge amount of Speckle noise, which must be removed. This kind of noise has multiplicative characteristic and appears like a granular form in the images, as it can be observed in Fig 1.

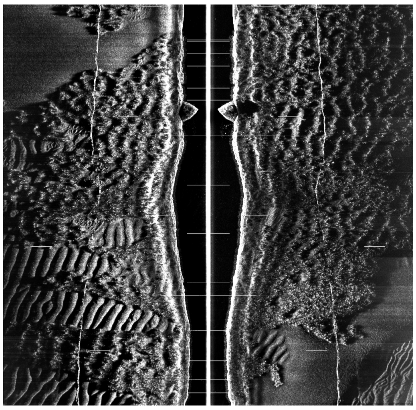


Fig 1 Side scan sonar image

Illumination homogenisation

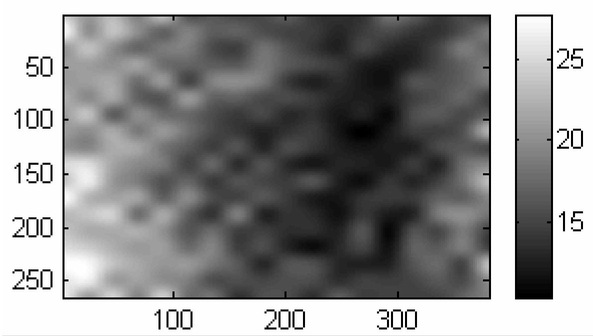
As it was said previously, one of the problems of side scan sonar images is the illumination discontinuity due to the acquisition process (areas close or distant to the towfish). It can be observed that illumination variations are low frequency, and thus, in order to homogenise the illumination, we can use methods trying to remove or soften such frequencies without affecting to the rest of the image.

The method used in the project aims at obtaining the background of the image (low frequencies) and subtracting it from the original image obtaining a more homogeneous image. To do this, the original image has been divided into different blocks with the same size and then the arithmetic mean of each block has been calculated. Then, a bicubic interpolation has been done in order to obtain a mask, the background (Fig 2(b)), with the same size as the original image. Finally, after the subtraction, the image has been processed in order to obtain a grey level scale comprised in the correct range (Fig 2(c)).

Speckle reduction

Speckle noise is generated during the acquisition of the side scan sonar images for various reasons. Among these reasons, the most important are scattering of the acoustic signal in the marine environment, reverberation and internal noise of the electrical devices used in the process.

(a) (c)



(b)

Fig 2 (a) Original image, (b) background, (c) homogeneous image

In order to remove it from the image, different filters, whose common objective is to smooth the homogeneous parts while preserving the edges, have been used. Among others, mean, median, Lee, Frost, and anisotropic diffusion filters have been studied. All of them have in common the same drawback: they smooth excessively the contours (blurring them) when they are not sufficiently contrasted. On the other hand, multiresolution analysis (wavelets) has been also studied in order to reduce the speckle noise. In this case, the objective was to eliminate the low energy components of the wavelet transform of the image since it is where the noise is contained. However, this method was proven unsuitable for our project because of the appearance of artefacts in the resulting image.

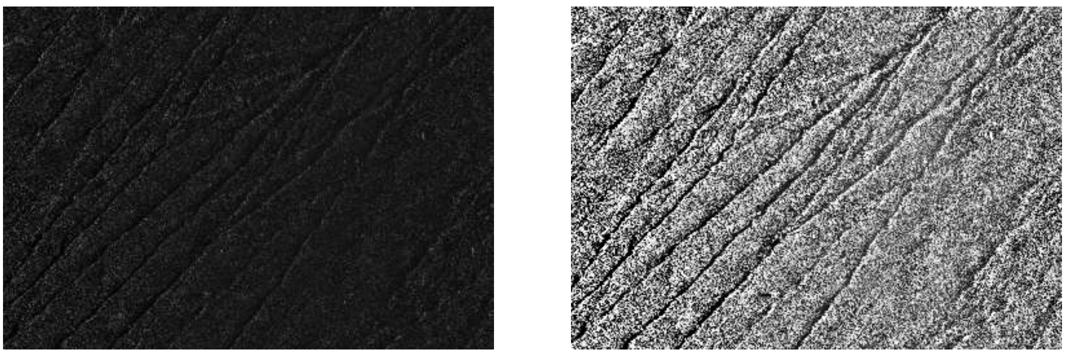
It is important to note that no reduction noise filter is going to be used, as it will be shown in section where the Canny filter is treated. However, the speckle reduction is useful for seabed classification.

STRAIGHT LINE DETECTION

As trawling marks are characterised as long straight lines of shadow in side scan sonar, it was decided to detect first any straight line of the image and then to determine if the detected straight lines are trawling marks or false alarms. The objective of this section is to explain the process for detecting trawling marks using Canny filter.

Histogram equalization

Before Canny filter, histogram equalization is carried out in order to enhance contrast in the image, as shown in Fig 3. A trawling mark is characterised, among others, as a shadow zone. Therefore, enhancing contrast, these zones will be highlighted, helping to the posterior detection.



(a) (b)

Fig 3 (a) Homogenised image, (b) enhanced image

Canny filter

The Canny filter (one of the most used in edge detection) is composed of four different stages. The image is first smoothed using Gaussian filter (low pass filter) with parameter σ. This low pass filtering eliminates the noise that could generate erroneous edges. Then, a differentiation (gaussian derivative) of the smoothed image is done. The next stage, non maxima suppression, consists in determining where the edges are thanks to a direction criterion and first and second derivatives. Finally, pixels belonging to an edge are determined using a hysteresis threshold. The detected edges are subsequently made thinner in order to keep only one pixel in width.

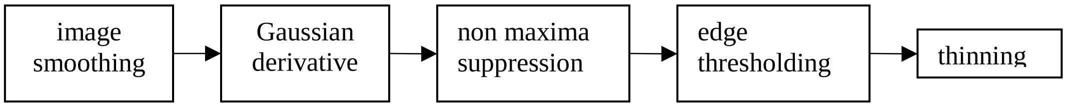
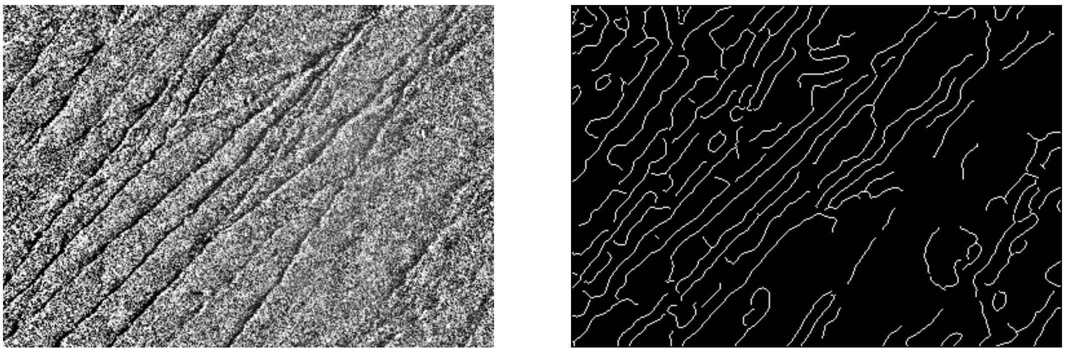


Fig 4 Canny filter schema

As we have seen in the first step of this filter, the image is smoothed using a Gaussian filter with parameter σ. Noise, among which we can include Speckle noise due to its granular aspect, is removed. That is the reason for not eliminating such noise of the original image, as it was said in the previous section. If such pre-processing would be done, it would be redundant with the first stage of the Canny filter, therefore wasting resources. In our case, the parameter is fixed using the width of the trawling mark *W*: $\sigma = W/2$.



(a) (b)

Fig 5 (a) Image before Canny filter, (b) trawling marks detection using Canny filter

CLASSIFICATION OF TRAWLING MARKS

As it can be observed in the Fig 5(b), some of the edges detected by the Canny filter cannot be considered as trawling marks due to their small length or high curvature. The objective of the classification is therefore to eliminate such edges while preserving the ones which can be considered as straight lines and so trawling marks.

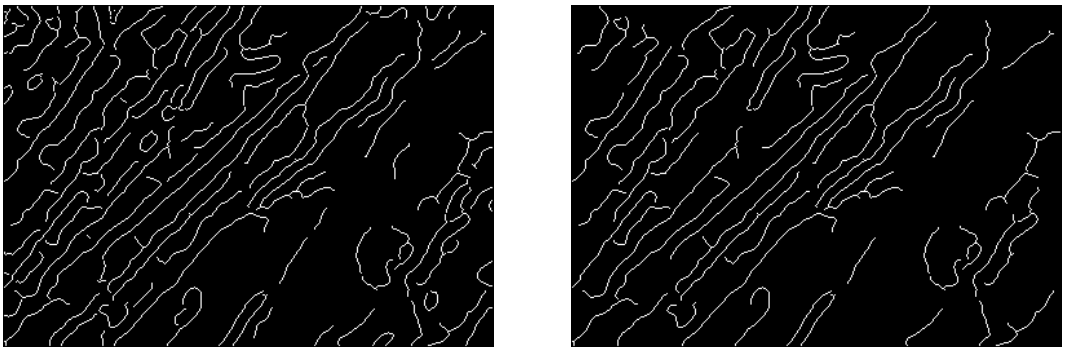
Length discrimination

The first part of the classification consists in discriminating the edges according to their length, as shown in Fig 6. To do this, all edges in the image have been labelled according to an eight-pixels connectivity, and then, the length has been determined. If this length is lower than a minimal length (given by the user), the edge is removed of the image; if not, it is preserved.

Curvature discrimination

The second part of the classification consists in discriminating the edges according to their curvature. To do this, it has to be taken into account the fact that the resulting edges can be divided into two groups: simple and compound. These last are defined as edges containing branches.

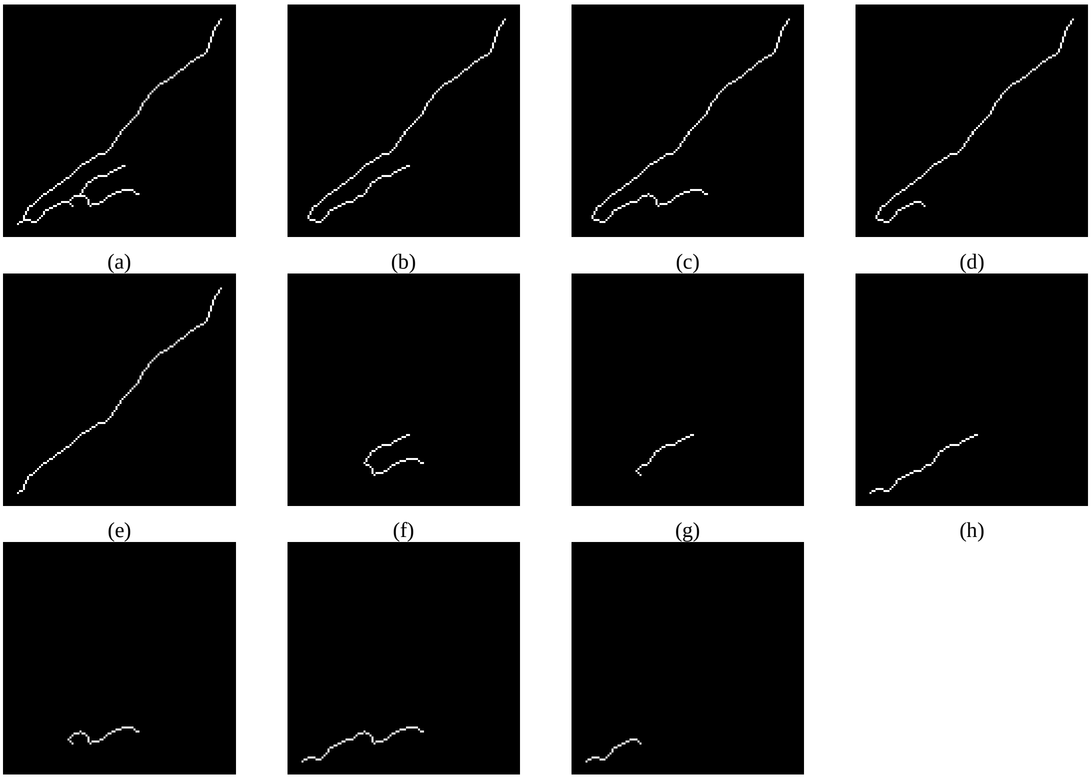
Therefore, the method consists in determining first if the edge is simple or compound. Then, if the edge is simple, the curvature is evaluated. If this parameter is bigger than a threshold, the edge is removed from the image, as it cannot be considered as enough straight to be a trawling mark. If not, the edge is kept as a trawling mark.



(a) (b)

Fig 6 (a) Trawling marks detected, (b) length discrimination

Before the evaluation of the curvature of the compound edge, the representative segment of the edge has to be chosen according to the curvature. To do this, all possible segments of the edge (as shown in Fig 7) are considered. Then, the one which has the smaller curvature is chosen. Finally, this segment is treated as a simple edge, which implies that if its curvature is small enough, it is kept in the image. If not, it is erased. The whole method has been summarised in Fig 8.



(a) (b) (c) (d)

(e) (f) (g) (h)

(i) (j) (k)

Fig 7 (a) Initial edge with branches, (b) to (k) possible segments

To evaluate the curvature, the Fourier descriptors (cf Appendix) are used, as the evaluation of the curvature remains independent of the position of the edge as well as translation, rotation or changing scale.

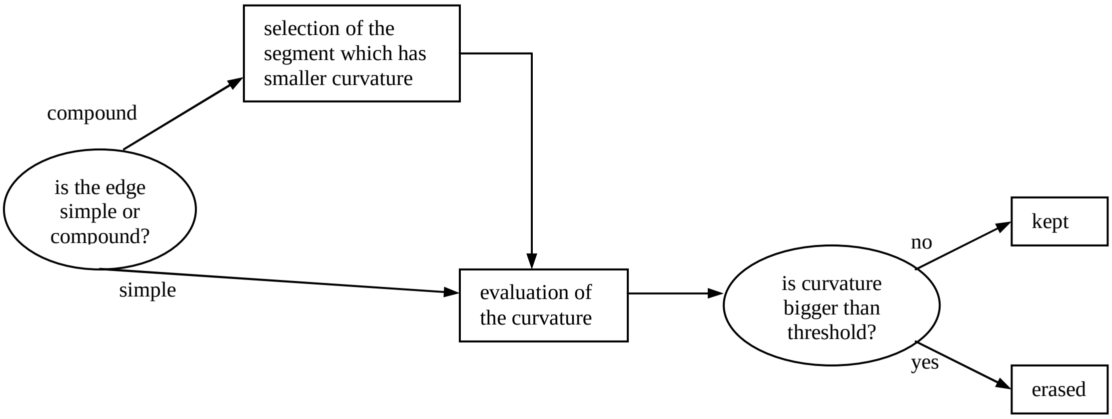
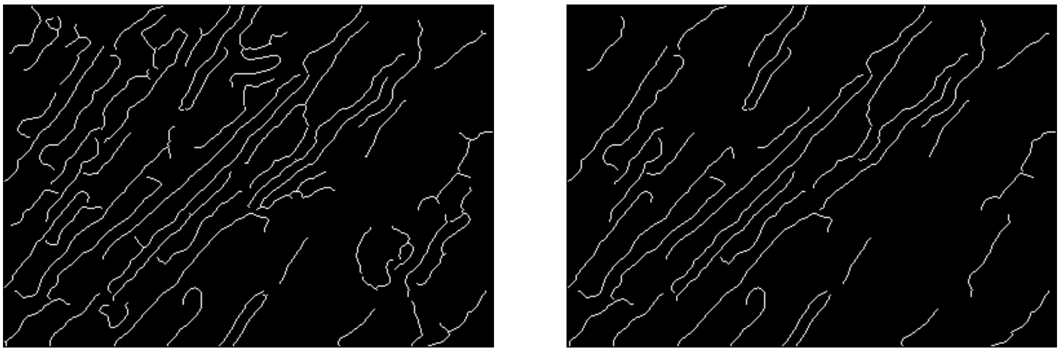


Fig 8 Curvature discrimination schema



(a) (b)

Fig 9 (a) Length discrimination, (b) curvature discrimination

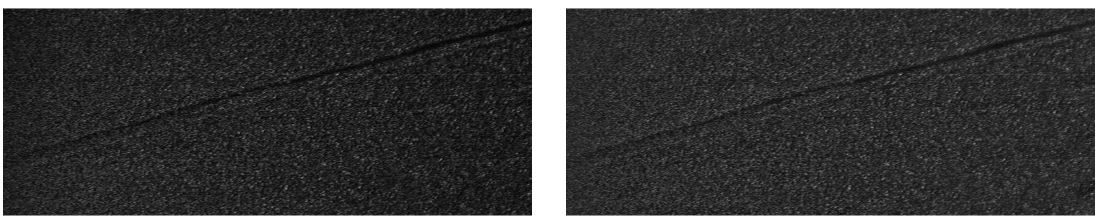
RESULTS

For the time being, the density of trawling marks in one image is evaluated arbitrarily, i.e. counting them directly from the image**.** Here are the results for the image shown across this paper. An expert has determined the number of trawling marks.

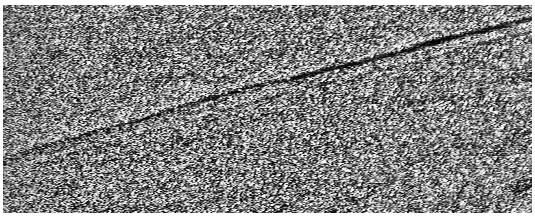
Table I Results for the image shown along this paper

Number of trawling marks	12
Number of trawling marks detected	24
where true trawling marks	10
where false trawling marks	14
Number of trawling marks non-detected	2
Error	16.67 %
False alarms	116.67 %

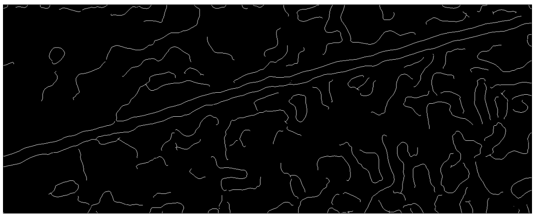
Here are the results for a different image.



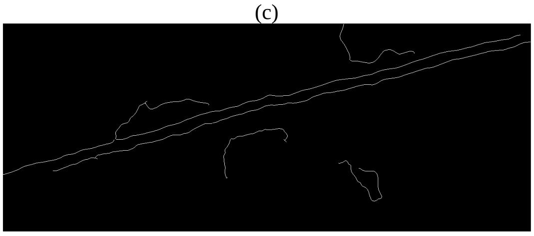
(a) (b)



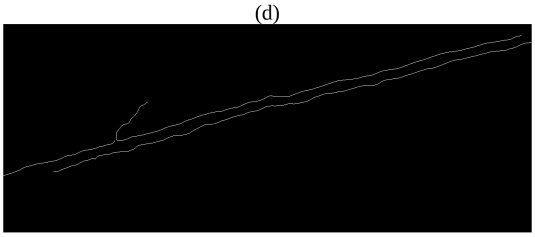
(c)



(d)



(e)



(f)

Fig 10 (a) Original image, (b) homogenised image, (c) enhanced image,
(d) potential trawling marks, (e) length discrimination, (f) curvature discrimination

Table II Results for the image in Fig 10

Number of trawling marks	1
Number of trawling marks detected	1
where true trawling marks	1
where false trawling marks	0
Number of trawling marks non-detected	0
Error	0 %
False alarms	0 %

The error and false alarms were calculated as (1) and (2), respectively.

$$error = \frac{number\ of\ trawling\ marks\ non-detected}{total\ number\ of\ trawling\ marks} \quad (1)$$

$$false\ alarm = \frac{number\ of\ false\ trawling\ marks}{total\ number\ of\ trawling\ marks} \quad (2)$$

CONCLUSION

As shown in this paper, to detect and classify trawling marks, it is necessary in a first step to carry out some pre-processings to the image. In this case, it was the homogenisation of the illumination on the image. Then, the Canny filter is used to extract the edges or potential trawling marks. Finally, these edges are discriminated according to the length and curvature in order to obtain the trawling marks.

Future work in this project aims at reduce false alarms by taking into account the comparison between the edge and the original images according to statistical methods. In the same way, future work will considerate the evaluation of the density automatically.

ACKNOWLEDGEMENT

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BIBLIOGRAPHY

1. R C González, R E Woods, 'Digital Image Processing', Addison-Wesley (1999).
2. S Theodoridis, K Koutroumbas, 'Pattern Recognition', Academic Press (1999).
3. E Coiras, 'Registro automático de imágenes de bandas espectrales alejadas', Facultad de Ciencias Físicas, Universidad Complutense de Madrid (1999).
4. J Bell, 'A model for the simulation of sidescan sonar', thesis, Heriot Watt University (1995).
5. J Bell, 'Sidescan sonar tutorial', Heriot Watt University (2003).
6. 'Side scan sonar – Record interpretation (training manual)', Klein Associates inc (1985).
7. M Legris, C. Sintes, 'Despecklisation d'images sonar', Extraction et exploitation de l'information des environnements incertains, ENST Bretagne, GESMA, ENSIETA (2003).
8. G Elston, 'Sonar simulation and visualisation using an acoustic pseudospectral time domain model', Thesis, Heriot Watt University (2003).
9. M J Black, G Sapiro, D H Marimont, D Heeger, 'Robust anisotropic diffusion', *IEEE Transactions on Image Processing,* Vol.7, No. 3,(March 1998).
10. R van den Boomgaard, 'Algorithms for non-linear diffusion – Matlab in a literate programming style', Intelligent Sensory Information System, University of Amsterdam.
11. Y-L You, W Xu, A Tannenbaum, M Kaveh, 'Behavioral analysis of anisotropic diffusion in image processing', *IEEE Transactions on Image Processing,* Vol.5, No. 11 (November 1996).
12. Y Yu, S T Acton, 'Speckle reducing anisotropic diffusion', *IEEE Transactions on Image Processing*, Vol.11, No.11 (November 2002).
13. L Gagnon, 'Wavelet filtering of speckle noise - Some numerical results', Proceedings of the Conference Vision Interface, Trois-Rovières (1999).
14. L Kaur, S Gupta, R C Chauhan, 'Image denoising using wavelet thresholding', Department of CSE, SLIET, Longowal.
15. Y H Lu, Y L Loh, T S Yeo, C B Zhang, 'Speckle reduction by wavelet transform', Asia Pacific Microwave Conference (1997).
16. R Rangarajan, R Venkataramanan and S Shah, 'Image denoising using wavelets - wavelets & tiem frequency' (2002)
17. P L Worthington, 'Enhanced Canny edge detection using curvature consistence', *16th International Conference on Pattern Recognition, IEEE Proceedings,* Vol. 1 , pp. 596 –599 (Aug. 2002).
18. M Fleck, 'Some defects in finite difference edge finders', *Pattern Analysis and Machine Intelligence, IEEE Transactions on* , Vol. 14, No 3, p337-345, 1992.
19. E Maudez, 'Geometric Descriptors Extraction and Classification for the Automatic Survey of Trawling Mark Impact on the Seabed from Video Data', Internal report, Ocean System Laboratory, Heriot Watt University (2003).
20. J Sklansky, 'On the Hough Technique for Curve Detection', *IEEE Transactions on Computers,* Vol. 27, No. 10, pp. 923-926 (1978).
21. M Mignotte, C Collet, P Pérez, P Bouthemy, 'Three-Class Markovian Segmentation of High-Resolution Sonar Images', *Computer Vision and Image Understanding,* Vol. 76, No. 3, pp. 191-204 (December 1999).
22. S Reed, Y Petillot, J Bell, 'A Model-Based Approach to the Detection and Classification of Mines in Sidescan Sonar', Ocean System Laboratory, Heriot Watt University (May 2003).
23. J M Bell, E Dura, S Reed, Y R Petillot, D M Lane, 'Extraction and classification of Objects from Sidescan Sonar', Ocean System Laboratory, Heriot Watt University.

APPENDIX: FOURIER DESCRIPTORS

Let be $(x_k, y_k), k = 0,1,..., N-1$, the coordinates of an edge composed of N points. For each coordinate, the complex value $u_k = x_k + j\, y_k$ is defined.

For the N points u_k , the discrete Fourier transform (DFT) is calculated following (3).

$$f_l = \sum_{k=0}^{N-1} u_k \exp\left(-j \frac{2\pi}{N} l\, k\right), l = 0,1,..., N-1 \qquad (3)$$

Hence, N Fourier descriptors defining the edge are obtained, $f_l, 0 \le l \le N-1$. In the context of this project, only the first nine descriptors are considered.

Let be $f_i, i = 2,...,8$ the Fourier descriptors set of the edge composed of N points; and $f_i^{'}, i = 2,...,8$ the Fourier descriptors set of a straight line also composed of N points. To evaluate the curvature, the distance between these two sets is calculated following (4).

$$d = \sqrt{\sum_{i=2}^{8} \left(f_i - f_i^{'}\right)^2} \qquad (4)$$

Here are the demonstration that Fourier descriptors used are independent of the translation, rotation and changing scale.

Translation

Let be $\left(x_k^{'}, y_k^{'}\right) = \left(x_k, y_k\right) + \left(\Delta x^{'}, \Delta y^{'}\right)$ the new coordinates of the edge, so $u_k^{'} = u_k + \Delta u^{'}$ where $\Delta u^{'} = \Delta x^{'} + j\,\Delta y^{'}$.

It can be demonstrated that $f_k^{'} = f_k + \Delta u^{'}\,\delta(l)$, hence translation just affects to the first Fourier descriptor, f_0.

Rotation

Let be $\left(x_k^{'}, y_k^{'}\right) = \left(x_k \exp(j\,\theta), y_k \exp(j\,\theta)\right)$ the new coordinates of the edge, so $u_k^{'} = u_k \exp(j\,\theta)$.
It can be demonstrated that $f_k^{'} = f_k \exp(j\,\theta)$, hence rotation just affects to the phase of the Fourier descriptor. As comparison in this project is done using the module of these descriptors, this property can be considered as invariant.

Changing scale

Let be $\left(x_k^{'}, y_k^{'}\right) = \left(a\,x_k, a\,y_k\right), a \in \Re$ the new coordinates of the edge, so $u_k^{'} = a\,u_k$.

It can be demonstrated that $f_k^{'} = a\;f_k$, hence the modification of the scale affects to the module of the Fourier descriptors. However the relation $\frac{f_i^{'}}{f_j^{'}} = \frac{a\;f_i}{a\;f_j} = \frac{f_i}{f_j}$ remains constant.

Invariable

As shown, Fourier descriptors are not strictly independent of translation, rotation or changing scale. However, it is possible to perform some operations to convert these descriptors invariable:

- as translation only affects to the first descriptor, f_0, this one is not taken into account;
- as relation $\frac{f_i^{'}}{f_j^{'}} = \frac{f_i}{f_j}$ remains constant in all the cases, all Fourier descriptors are divided by f_1.

Hence, the descriptors used, $f_i^{new} = \frac{f_i}{f_1}, i = 2,...,8$, are invariable with regards to translation, rotation and changing scale.