THE USE OF IMAGE ANALYSIS TECHNIQUES FOR PROCESSING SIDE-SCAN SONAR SURVEYS OF HERRING SPAWNING GROUNDS

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1. INTRODUCTION

The Atlantic herring (*Clupea harengus* L.) is one of the few marine fish species with a demersal spawning habit. It generally selects a high energy environment and will often spawn on silt-free gravel substrate (Haegele & Schweigert [5]). In some parts of its range (West of Scotland, Clyde), herring spawns on gravel beds with a characteristic ripple structure (Hemmings [7], Morrison et al [9]). The ripples in this area have a wavelength of approximately 0.5 meters and an amplitude of approximately 0.3 metres, and are found in relatively shallow water (15 - 25m), running parallel to the coast. One technique which has been widely adopted for the detection and mapping of such spawning grounds is side-scan sonar, which is ideal for the detection of this type of ground (Green [4], Harris & Collins [6]). Ridged gravel beds show up on the echogram as a distinctive striated area, which is easily visible to the eye. In all previous side-scan surveys of this type of ground the analysis of the echogram and subsequent mapping, has been carried out by hand (Edsall et al [2], Stubbs & Lawrie [10]).
Image processing techniques have been used with side-scan sonar data in a number of applications (Luyendyk et al [8], Voulgaris & Collins [11]), and are ideally suited to this type of analysis where the researcher is looking for a single type of ground which is characterised by a particular pattern. This paper describes an image processing technique for the analysis of side-scan images of this type of herring spawning ground. The approach is based on the application of convolution filters designed to detect short order variation to enhance the signal from the areas of gravel ripples. This is followed by a number of steps to clean up the image, and identify the ripple areas. A map is subsequently produced giving the locations of ripple patches based on positional data from navigational instruments. The technique is implemented entirely within the analysis computer with no requirement for the study of the echogram on paper or the preparation of a map by hand.

2. METHODS

2.1 Transducer and recording equipment

The side scan system was constructed by combining a Simrad EK400 scientific echosounder operating at 120kHz and a sidescan transducer. The sounder was equipped with two TVG functions on EPROM, providing 30 log R TVG functions with maximum ranges of 150 and 250m. The 30 log function is theoretically correct for the backscattering from omnidirectional targets illuminated by an annulus. The transducer was a single line array of circular elements giving a beam of approximately 1° horizontal by 35° vertical angles, mounted in a nylon towed body with a four fin tail section (area approximately 1 square metre). The echosounder was operated with a 0.3ms pulse length and a transmit power of 600 watts. The beam was angled at 17.5 degrees down.

2.2 Data Acquisition

A side scan survey for potential herring spawning grounds was carried out in the Clyde estuary Scotland (55° 35-45'N & 4° 45 - 5° 10'W) from the 20th to the 30th May 1991 on FRV "Clupea". The transects were plotted to allow detection of gravel areas with ripples running parallel to the vessel's course. The calibrated output from the echosounder was envelope detected and digitised to 12-bit precision at 0.666ms intervals. The detector and ADC system provided 50dB of dynamic range at better than 0.05dB linearity with a further 20dB at better than 0.2dB linearity. The digitising system is controlled by a Computer Automation 4/90 computer. The samples were recorded from an initial time of 6.6ms on each transmission and for a maximum of 512 samples per transmission. The data were collected into 8 kByte blocks along with header information on vessel position (every 10s), time and date obtained by serial link from the ships navigation system, and recorded on 150 mByte DC600 cartridges.

2.3 Image processing hardware

Image processing was carried out using an Innovision image analysis system. The main processor is a Sun SPARC IPC running under SunOS. The computer is equipped with a number of purpose built, high speed image processing boards (VME) supplied by Imaging Technology Incorporated, U.S.A. These were; an input/output board; a frame store; an arithmetic logic unit; a histogram-frequency analysis board; and a specific board for convolution filters. Operating software was supplied as "C" callable functions, incorporated into a "C" (Sun C) program written by the authors.

2.4 Data entry

Each data point, representing the echo amplitude (voltage) from 0.666ms samples from a single transmission, is produced by the digitiser as a 12 bit number. This is reduced to eight bits for image processing. In this particular design we removed the least significant two bits, and clipped the resulting 10 bit number to a maximum of 255.

The data points are built into a series of 128 x 512 pixel image files. The columns representing 128 consecutive transmissions, and the rows, the voltages from consecutive 0.666ms samples. Four consecutive image files, loaded into the frame store and presented on a colour VDU, produce a completed screen, 512 transmissions wide. This is displayed using a suitable pseudocolour look-up table. Each pixel represents a single sample from a single transmission. Each quarter screen image file also includes header information on time, date, position and type of sounder.

2.5 Image processing

Once loaded into the frame store the echogram image can be processed to highlight the areas of gravel ripples. This is carried out using the steps described below.

2.5.1. First order change filter. The first step was to pass the image through a convolution filter designed to highlight ripple areas. The wavelength of the ripples was approximately the same as the sample size. Therefore, ripple areas appeared on the echogram as a series of consecutive high and low value samples. We designed a convolution filter which would produce maximum output values from areas of ripples lying parallel to transects and which would pass other areas relatively unchanged.
A three by three filter with the following kernel was used:

$$K_{ij} = \begin{vmatrix} -1 & -2 & -1 \\ 2 & 3 & 2 \\ -1 & -2 & -1 \end{vmatrix}$$

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The value of each pixel of index (x,y) is then given by the following convolution:

(1)

Where:
R(x,y) is the resultant pixel value
K_{ij} is the kernel element
P(x,y) is the original pixel value

The resultant pixel values are taken as an absolute value. There is no correction as the sum of the kernel elements is 1. The effect of this convolution is illustrated in the following examples with simulated data sets.

Example 1. Ripples lying parallel to the vessel's course.

Original values

10	10	10	10	10
1	1	1	1	1
10	10	10	10	10
1	1	1	1	1
10	10	10	10	10

Central nine pixels after convolution

73	73	73
62	62	62
73	73	73

The averaged value for the central pixel with its neighbours before convolution would be 4, and after convolution would be 69.

Example 2. The same data set with values randomly assigned.

Original values

10	10	1	10	1
10	1	10	10	10
10	1	10	1	1
1	10	10	10	1
10	10	1	10	1

Central nine pixels after convolution

10	2	36
10	41	33
2	28	16

The averaged value for the central pixel with its neighbours before convolution would be 7, and after convolution would be 20.

Example 3. More varied random results.

Original values

1	5	10	1	10
5	1	10	1	5
1	5	5	10	1
10	1	1	5	10
5	1	10	5	1

Central nine pixels after convolution

4	17	15
4	15	5
8	36	15

The averaged value for the central pixel before convolution would be 4, and after convolution would be 12.

The above examples demonstrate the effectiveness of the filter in highlighting areas with gravel ripples over other areas with a more varied profile. When this filter is applied to a real echogram, patches with gravel ripples will appear as areas with a high average pixel value against a generally lower pixel value background.

2.5.2. Smoothing. The enhanced image is then smoothed to remove unwanted noise and prepare the image for further analysis. Smoothing is carried out by neighbourhood averaging of each pixel. A three by three "blur" filter with the following kernel was used :

$$K_{ij} = \begin{vmatrix} 1 & 2 & 1 \\ 2 & 1 & 2 \\ 1 & 2 & 1 \end{vmatrix}$$

The value of each pixel of index (x,y) is then given by the following convolution:

(2)

Where:
R(x,y) is the resultant pixel value
K_{ij} is the kernel element
P(x,y) is the original pixel value
C is a constant which can be given by:

(3)

The constant is applied to give an average of the summed pixel values and give a resultant pixel value in the same range as the original.

2.5.3. Binary thresholding. The image is now transformed to a binary configuration. This is done by thresholding the image. All the pixels (representing individual samples) have a value in the range of 0 to 255. A value is chosen between 0 and 255. Any pixel whose value is below this threshold (the background) is set to zero, any pixel whose value is higher (the object) is set to one.
The value chosen for such a threshold is clearly critical, and will depend to a high degree on the particular data set and preceding smoothing operations. A frequency histogram of the pixel values can be used to assist in setting an effective threshold. For further information on thresholding and histogram analysis see Castleman [1] & Gonzalez & Wintz [3]. In this case we chose a threshold of 120.

2.5.4. Binary operations. The binary image now contains a black and white image, with the white areas representing the ripple areas. The image is still noisy with ripple areas poorly defined and small isolated patches apparent. The image was then cleaned to leave only the major areas of gravel ripples. This was achieved by two steps.
a. Majority filter. A majority filter functions by examining every pixel in relation to its eight neighbours. If any pixel has more than a set number of neighbouring object (value 1) pixels it is set to 1, if it has less it is set to zero. In this case the threshold was set at four neighbours. This has the effect of removing small groups of object pixels (value 1) from the image, smoothing the outline of the remaining areas of gravel ripples and filling in any small holes within the ripple areas.
b. Erosion and dilation. The image is then eroded through four cycles. In simple terms, for erosion of a binary image, a layer of pixels is removed from the outside of any object in the image. An object is considered as any group of non-zero pixels. Binary erosion is carried out according to the following algorithm;
The binary value of pixel P(x,y) is given by:

(4)

Where:
B(x,y) is the resultant binary pixel value
P(x,y) is the original binary pixel value
i,j represent the vertical & horizontal displacement from the central pixel.
Thus if a central pixel has one or more zero (background) pixels among its eight neighbours, it is set to zero, regardless of its original value. Thus, small groups of non-zero pixels, are removed from the image. Larger objects are reduced in scale.
The image is then dilated through four cycles. Dilation is the opposite of erosion. If a pixel has one or more non-zero (object) pixels among its eight neighbours, it is set to one, regardless of its original value. Any remaining objects (groups of non-zero pixels) are magnified, thus returning them to approximately the same dimensions as prior to the erosion steps.

2.5.5. Identification of gravel ripple areas. The final step is to identify the gravel ripple areas and determine their dimensions and positions. The image is passed through a series of object labelling routines supplied by the manufacturer of the image processing hardware (Imaging Technology Inc.). Briefly, these assign each object pixel to a larger object based on "eight connectivity". Every non-zero (object) pixel has eight neighbours, if one or more of those are also object pixels then it becomes part

of a mask which describes this object. In this way the system assigns all the object pixels to masks whose location and dimensions are known. The ripple areas are identified by the system, and in the final binary image, following erosion and dilation, are outlined by boxes.
Thus far, the dimensions of the ripple areas are only known in terms of X and Y co-ordinates on the screen. These were then converted to the true dimensions of the original ripple area. Each pixel represents a single sample from a single transmission, samples are taken at 0.666ms intervals. The extent of a gravel ripple area away from the vessel is calculated from the equation:

(5)

Where:
d = length of gravel area
c = speed of sound in water (c. 1500 ms^{-1})
t_1 = delay in signal from near edge of gravel area
t_2 = delay in signal from far edge of gravel area
D = Height of transducer from sea-bed (in this case 10m)

The measured horizontal dimensions of a pixel are determined from the vessel's speed and the transmission interval. The transmission interval is related to the range set on the recording instrumentation, in this case, one transmission per 0.5 second. The vessel's speed can be taken from the log or calculated from the navigational data recorded with the echogram. It should be noted that both methods are subject to potential errors. The pixel width is then found by multiplying the vessel speed (in this case 2.25 $m.s^{-1}$) by the transmission interval. The horizontal dimensions (in metres) are then calculated using the width of a pixel (in metres), multiplied by the number of pixels across the object. In this case the large area on the right of the image is 174 transmissions wide (196 m) and extends away from the vessel for 238 samples (119 m).

2.6. Plotting the map

The exact position (within the accuracy of the navigational equipment) and scale of each patch can now be plotted within a spreadsheet. For plotting, the image was broken down into blocks of 10 samples by 5 transmissions, other protocols may be used depending on the area to be plotted and the size of spreadsheet available. The image is scanned along one in every 5 transmissions in 10 sample units. If any object pixels (i.e. gravel patches) are detected, the block is recorded as including gravel ripples. The block is then entered into the spreadsheet at a location determined from the positional data recorded in the image file header. The positional data are also used to determine the course of the vessel and, hence, the orientation of the blocks. The map produced can then be manipulated as desired within the spreadsheet, e.g. to join together patches detected on sequential transects, or to give graphical output.

3. DISCUSSION

Image processing techniques have been widely used in the analysis of sea-bed structure from side-scan surveys (Luyendyk et al [8], Voulgaris & Collins [11]). Such techniques are most commonly applied in the study of sedimentation and geology in large-scale program's (e.g. GLORIA: Geologic Long Range Inclined Asdic). The technique described here is the first description of the use of such

techniques for the analysis of fish spawning grounds. Previous workers (Edsall et al [2], Stubbs & Lawrie [10]) have used simple mosaics of the paper echograms to construct the maps. This requires the vessel to maintain a steady course and speed, and accurate placing of sequential transects, to ensure that when placed together, the echograms will represent the study area accurately. Alternatively, the researcher can determine the positions of gravel beds by eye from the echogram and construct the map manually. The technique described here removes the need for precise control of the vessel's speed and course, as the position of each gravel area is determined from the positional data in the image file header. It also automates the tedious process of identifying the ripple areas. The processing steps described take approximately 20 seconds per full screen (512 transmissions). The system could therefore, be suitable for use in real-time, as well as post-analysis.
Although the present study was carried out using relatively complex, dedicated equipment, the techniques involved could easily be implemented on a simple image analysis system using a PC, though this would increase the time for the analysis. The most important part of the analysis is the design of the filter to highlight the ripple areas. Other filters could be designed which could highlight different textures in the side-scan echogram.

4. REFERENCES

[1] R A CASTLEMAN, 1979. 'Digital Image Processing', Prentice Hall, Englewood Cliffs, U.S.A (1979)

[2] T A EDSALL, T P POE, R T NESTER & C L BROWN,'Side-scan sonar mapping of lake trout spawning habitat in northern Lake Michigan', N Am J Fish Manag, 9 p269 (1989)

[3] R C GONZALEZ, & P WINTZ. 'Digital Image Processing', Addison-Wesley, Reading, Mass. (1987)

[4] M O GREEN. 'Side-scan sonar mosaic of a sand ridge field: Southern Mid-Atlantic Bight'. Geo-Mar Lett, 6 p35 (1986)

[5] C W HAEGELE & J F SHWEIGERT. 'Distribution and characteristics of herring spawning grounds and description of spawning behaviuor'. Can J Fish Aquat Sci, 42 p39 (1985)

[6] P T HARRIS & M B COLLINS. 'Side-scan sonar investigation into temporal variation in sand wave morphology: Helwick sands, Bristol Channel'. Geo-Mar Lett, 4 p91 (1984)

[7] C C HEMMINGS. 'Underwater observations on a patch of herring spawn'. Scot Fish Bull, 23 p21 (1965)

[8] B P LUYENDYK, E J HAJIC & D S SIMONETT, 'Side-scan sonar mapping and computer-aided interpretation in the Santa-Barbara Channel, California'. Mar Geophys Res, 5 p365 (1983)

[9] J A MORRISON, I R NAPIER & J C GAMBLE. 'Mass mortality of herring eggs associated with a sedimenting diatom bloom'. ICES J mar Sci, 48 p237 (1991)

[10] A R STUBBS & R G G LAWRIE. 'Asdic as an aid to spawning ground investigations', J du Conseil, 27 p23 (1962)

[11] G VOULGARIS & M B COLLINS, 'Linear features on side-scan sonar images: An algorithm for the correction of angular distortion' Mar Geol, 96 p187 (1991)