Proceedings of the Seventh European Conference on Underwater Acoustics, ECUA 2004
Delft, The Netherlands
5-8 July, 2004

COMPENSATION FOR CHANGING BEAM PATTERN AND RESIDUAL TVG EFFECTS WITH SONAR ALTITUDE VARIATION FOR SIDESCAN MOSAICING AND CLASSIFICATION

C. Capus, I. Tena Ruiz, and Y. Petillot

Chris Capus, Ocean Systems Laboratory, School of Engineering and Physical Sciences, Heriot-Watt University, Riccarton, Edinburgh, EH14 4AS, U.K.
e-mail: c.capus@hw.ac.uk

Sidescan sonar images characteristically display across-track intensity variations resulting from the transducers' beam pattern. Along-track these changes are complicated by intensity variations introduced by changing sonar altitude. The effects are particularly apparent in low altitude surveys displaying strong sidelobe returns from regions closest to the transducers. The fall off in intensity with range for main lobe returns is also more noticeable in these missions. A time-varying gain (TVG) is usually applied to sonar signals to compensate for this range-dependent effect, but cannot adequately compensate for beam pattern or altitude variations. In this paper methods are presented for correction of beam pattern and residual TVG effects in the presence of altitude change. Estimation of correction factors is performed directly from the data. It is preferable to seek an estimate for these factors over a seabed region with relatively even, small-scale texture, a few hundred lines of data being sufficient. The approach to the beam pattern problem uses time-scaled representations of each line of data to account for geometrical variations introduced by altitude change. The applied TVG function is assumed to be dominant towards the end of each line of recorded data and can usually be approximated using a smooth function. Multiplicative correction factors are calculated for the TVG function and scaled beam pattern. These are applied to the sonar data to produce a representation of the ensonified seafloor topography with intensities adjusted relative to some user defined datum point.

1. INTRODUCTION

This paper describes a method for correcting beam pattern and time-varying gain (TVG) effects in sidescan sonar data. The many aspects of the sonar process which contribute to intensity variations in recorded data are well understood and excellent models exist on which standard TVG and radiosity correction algorithms are based [1,2]. In this work these factors are grouped into those exhibiting a range-dependency, including spreading and absorption losses, and those having an angular dependency, such as the sonar beam pattern and grazing angle. Throughout this paper, the former are referred to as residual TVG effects and the latter are termed beam pattern effects. Separate correction factors are calculated for each.

The primary motivation for this work has been the correction of sidescan images for the detection and quantification of trawling impacts within the AMASON research project. This correction also improves visual appearance for display and mosaicing. It can produce images with more stationary statistics for classification purposes and can make better use of available dynamic range when converting data to 8-bit image formats. In sum these allow us to make effective use of more of the sonar swath, whether performing manual or automated analysis.

The method builds on previous work in the field of radiosity correction [3]. In many current applications, low altitude surveys mean that even quite small changes in vehicle altitude can affect the sonar image dramatically and this research has focussed on developing a correction algorithm which is appropriate for data sets characterised by clear altitude changes. Platform stability is assumed with respect to pitch and roll and processing proceeds on the assumption that the seafloor is level, or at least unchanging in slope, across track. No prior knowledge of the sonar is required and correction factors can be calculated directly from images, though there will be some degradation of performance if these have been constructed from original data with a higher bit depth than the image format used.

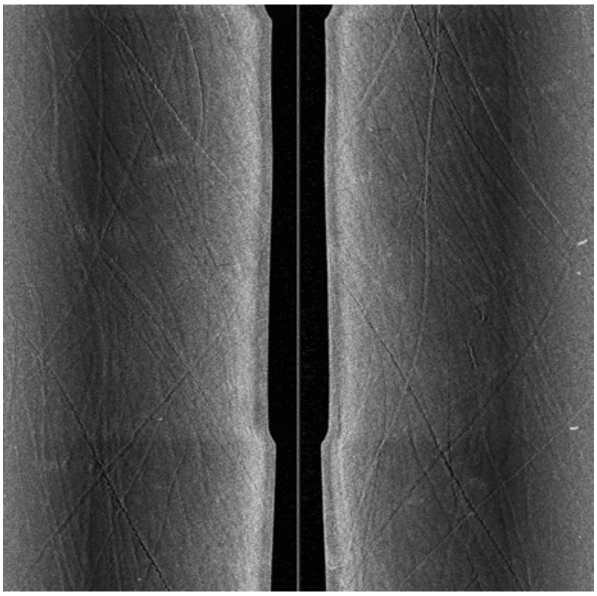

Fig 1: Sidescan sonar image showing impact of trawling operations near Gouves, Crete

In the algorithm as described, smoothing is applied only in calculation of the residual TVG and beam pattern estimates. The data itself, though corrected using these estimates is not directly subjected to any further smoothing or averaging process. This is the most desirable course of action for successful application of classification and detection algorithms to the corrected data, since these will often include their own smoothing procedures.

2. CALCULATION OF CORRECTION FACTORS

Fig. 1 is taken from a dataset gathered using a Geoacoustics towfish and illustrates the nature of the problem. Near to the water-column intensity variations are primarily due to changes in signal strength with beam angle, the sonar beam pattern. Returns from at least one narrow sidelobe are clearly visible. At the margins the variations are primarily due to over-compensation by the applied TVG function, which leads to a steeply rising image intensity.

To improve the along-track average for simultaneous estimation of the TVG residuals and beam pattern, a bottom detection algorithm can be used to line up first returns by shifting [3]. This approach is effective in data collected with relatively little altitude change, and will produce a good result for the data in Fig. 1, though implicit in the need for bottom detection is the acceptance that altitude change is to be expected.

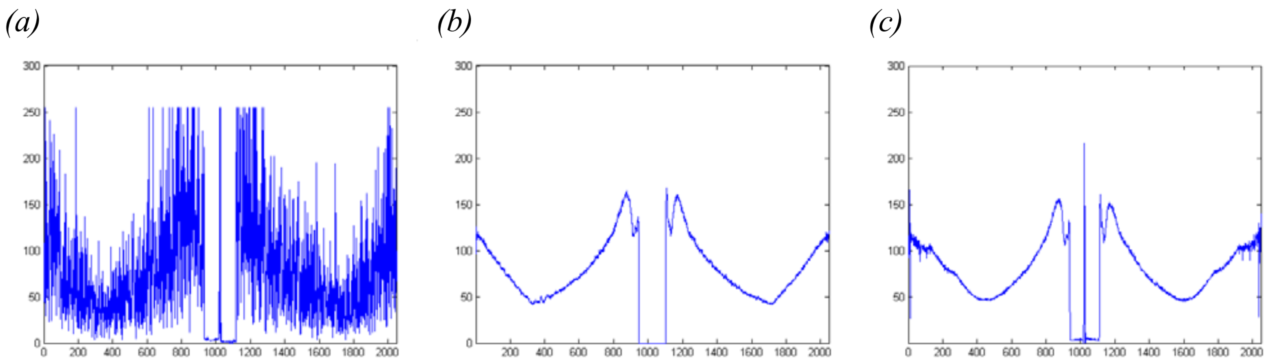

Fig 2: (a) Single scanline taken from image in Fig. 1 (Note that saturation in this data will lead to an irrecoverable loss of detail); (b) estimate for correction factors from [3]; (c) estimate using resampling but without separate consideration of beam pattern and TVG residuals.

Fig. 2(a) shows a single scanline taken from the image in Fig. 1. An estimate for radiosity correction produced by an along-track averaging procedure after alignment of first returns is given in Fig. 2(b).

2.1. Resampling

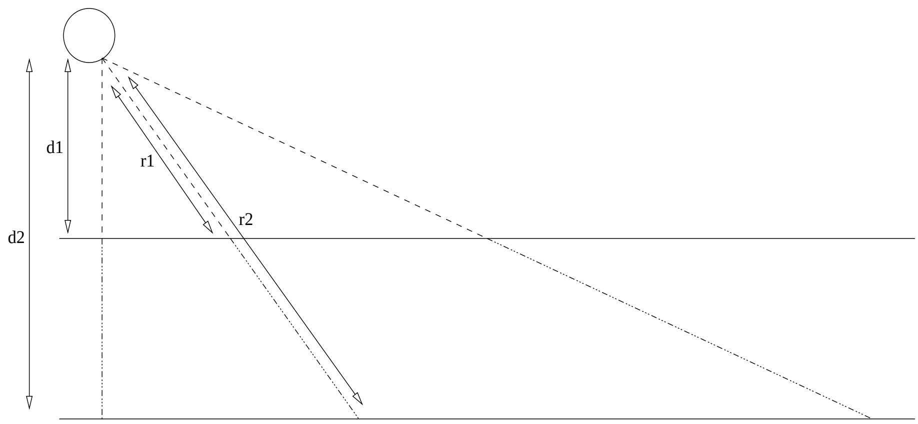

Fig 3: Rationale for resampling. Range for any given beam is proportional to vehicle altitude.

In the proposed algorithm alignment of the first returns is achieved by resampling rather than shifting the data. This is done to achieve better approximation of angle-dependent factors. Fig. 3 illustrates the proportional relationship between the vehicle altitude and the range at which any given beam strikes the seabed. It is this range which determines the position at which each beam is represented in the sonar scanline. Taking the lowest altitude scanline as a reference point other lines are corrected to this by resampling using a polyphase filter [4]. Sampling rate conversion for line n is set by the rational factor Sr/Sn, where Sr and Sn, derived from the bottom detection, define sample numbers for the first returns in the reference and nth data lines respectively. An along-track average for the data in Fig. 1, after this alignment but without separate consideration of range-dependent and angular factors, is given in Fig. 2(c). Estimation of the dominant beam pattern close to the water column is good, but further out the residual TVG effects, which do not have an angular-dependency, are poorly estimated. Additionally, following alignment of the first returns, there are fewer samples available for estimation towards the ends of each scanline, leading to an estimate which is relatively noisy at the extremes. Effective estimation over the full swath width using a resampling scheme will require separation of the angular and range-dependent factors.

2.2. Estimation of TVG Residuals

Some TVG functions applied to sonar returns are fixed in hardware. Others are, at least to some degree, operator dependent. None can adequately compensate for the range of conditions over which a sidescan system is operated and the variety of functions used leads to great variability in the residual TVG effects present in all sidescan datasets.

In the current case the residual TVG is characterised by a very steep rise towards the ends of the scanlines and its separation from the beam pattern provides something of a challenge. We proceed by noting once again that the resampling scheme has the effect of aligning sonar returns by beam angle as opposed to range. Columns in the realigned data represent the returns for one particular beam angle striking the seabed at a variety of ranges. These values can be converted to an estimate of residual TVG by recasting them as a proportion of the intensity for the corresponding beam angle in a reference signal. To ensure complete overlap with the resampled scanlines, the reference signal is an estimate of the intensity profile at the lowest altitude and can be calculated in the same way as the estimate given in Fig. 2(b). The columns of the resulting ‘proportion image’ give the variation in signal strength with range for each beam angle, relative to the reference signal. When reset to the original alignment, an along-track average produces an estimate of the range-dependent variation in signal strength isolated from the beam angle.

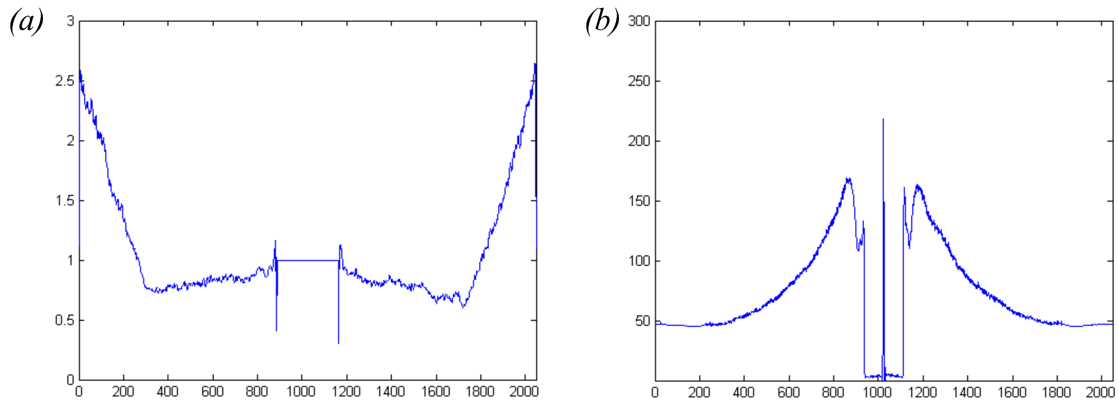

Fig 4: trawling impacts data: (a) residual TVG estimate; (b) beam pattern estimate. The differences in range for the y axes derive from the methods of calculation -- values in (a) are referenced to a level of 1.0; values in (b) are referenced to a target grey level

Fig. 4(a) shows the TVG estimate for the current case calculated in this fashion and does exhibit the expected sharp change in behaviour some 700 samples from the midline in each direction. It should be noted that in most cases the residual TVG estimate is less extreme and can be approximated well using a smooth function. The port and starboard channels are considered independently and a log-linear or cubic fit is usually sufficient. For this data the correction factor was calculated directly from the estimate in Fig. 4 (a).

2.3. Beam Pattern Estimation

The residual TVG estimate is used to calculate a multiplicative correction factor, which is applied to the original dataset with no realignment. This produces a first-pass TVG corrected version of the data from which a beam pattern estimate is derived. The same resampling scheme as above is used to realign the TVG-corrected data by beam angle and an along-track average provides the beam pattern estimate.

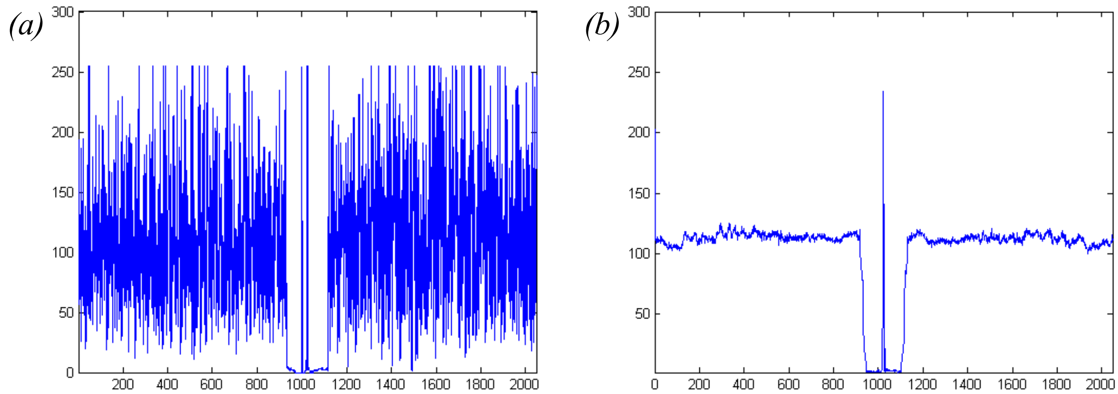

Fig 5: (a) sample line taken from corrected image; (b) mean values following correction for data in Fig. 1 – target mean grey level is 110.

As previously noted, realignment produces a relatively noisy estimate towards the ends of the scanline which can be reduced by smoothing the estimate at the extremes. This usually has little effect on the final output as in these regions the range-dependent TVG effects are expected to be dominant. Fig. 4(b) is the beam pattern estimate produced for the data in Fig. 1 following residual TVG correction. Fig. 5(a) gives the intensity values for a sample line drawn from the corrected data and Fig. 5(b) gives the mean grey level for each column in the corrected image. The target mean used for the correction in this case is grey level 110.

Fig. 6 further illustrates the importance of separating out the range-dependent and angle-dependent factors when using the proposed resampling scheme. The left image shows the result produced from the data in Fig. 1 without separate consideration of TVG residuals. The right image shows the result of the full correction procedure proposed above.

3. CONCLUSIONS

The algorithm presented in this paper is suitable for the correction of various artefacts in sidescan imagery and successfully separates range-dependent and angle-dependent. This enables the algorithm to be applied to data exhibiting a greater variation in vehicle altitude than is the case where these factors are not considered separately. The methods are most appropriate for low altitude surveys with frequent altitude variations and are useful for application to data gathered during shallow and very shallow water missions.

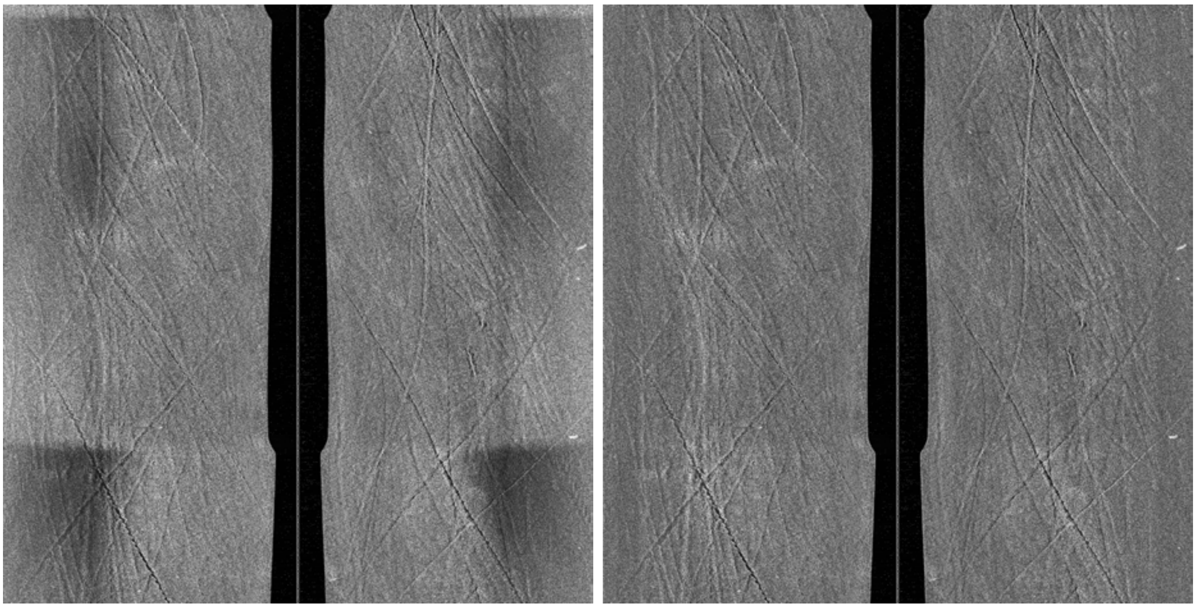

Fig. 6: Left image: data corrected without separate consideration of residual TVG effects. Right image, data corrected using the proposed algorithm.

4. ACKNOWLEDGEMENTS

This research has been supported by 5th Framework Program of the European Community through the AMASON project (EVK3-CT-2001-00059). The authors would like to thank Chris Smith and Andy Banks of IMBC, Crete for the trawling impacts data.

REFERENCES

[1] **R. J. Urick**, Principles of Underwater Sound, McGraw-Hill, New York, 1975.
[2] **APL-UW**, APL-UW High-frequency ocean environmental acoustic models handbook, Applied Physics Laboratory, University of Washington, 1994.
[3] **S. Anstee**, Removal of range-dependent artifacts from sidescan sonar imagery, Aeronautical and Maritime Research Laboratory *DSTO*, technical report, 2001. Available at: http://www.dsto.defence.gov.au/corporate/reports/DSTO-TN-0354.pdf
[4] **J.G. Proakis** and **D.G. Manolakis**, Digital Signal Processing: Principles, Algorithms and Applications, 3rd Edition, Prentice-Hall, New Jersey, 1996.