QUANTIFICATION AND CORRECTION OF A SYSTEMATIC ERROR IN SIMRAD ES60 ECHOSOUNDERS

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Abstract

A series of experiments using Simrad ES60 echosounders quantified a systematic error that was previously observed during on-axis calibration-sphere tests. The systematic error has an overarching shape of a triangle wave of approximately 1dB peak-to-peak amplitude with a period of exactly 2721 data points. Close-up inspection of the triangle wave reveals a fine scale quantising step function where typically data points remain at the same value for 16 pings, after which there is a step to the next level where the next group of 16 data points will reside. The quantising value is equal to the amplitude resolution of the ES60, which is given as 10·log(2)÷256 or 1.176e-2dB. The direction of the step (either up or down) depends on the location of the group of 16 data points in relation to the overall triangle wave shape sequence. A key finding is that the error triangular wave structure can be established from the transmit pulse section of the echogram data. The error wave structure embedded in the transmit pulse can be used as a basis for correcting the entire echogram. A correction algorithm for this error wave was devised and applied to the data on a ping-by-ping basis. The potential to remove this systematic error greatly improves the potential of the Simrad ES60 for quantitative use. We have found that in a worst case scenario the error can be up to 1 dB. But in many cases the error will be substantially less depending on which portion of the data is used. By understanding the nature of the systematic error researchers can decide how their data may be affected and, if necessary, make the appropriate corrections.

Introduction

Simrad ES60 echosounders are being used by increasing numbers of commercial fishing vessels around the world. These digital echosounders are based on a sound engineering design with high signal-to-noise and large dynamic range. A full sample digitisation of the acoustic return signal data can be logged to disk.

By working with the commercial fishing industry, researchers have the prospect of being able to collect vast amounts of high quality and high resolution acoustic data at relatively low cost. There are a number of researchers' worldwide collecting ES60 data from commercial vessels for variety of scientific purposes. CSIRO Marine, Australia, has a three year collaborative project with the Blue Grenadier fishing industry to develop acoustic survey methods using ES60 sounders on their vessels (Ryan et al. 2003).

The ES60 sounders are aimed at commercial fishers and are not sold with any claim of absolute accuracy. It is therefore essential that these echosounders are correctly calibrated and that any limitations and errors associated be understood and measured if the data is to be used for quantitative studies.

A series of experiments are described that characterise and quantify a systematic variation that had been noticed in calibration sphere data sets. The experiment aims were:

- precisely characterise the systematic variation
- determine if other data types (S_v, test mode) are affected in the same way
- determine if various sounder parameters (power, pulse length, repetition rate, frequency etc) have any effect on the variation

Method

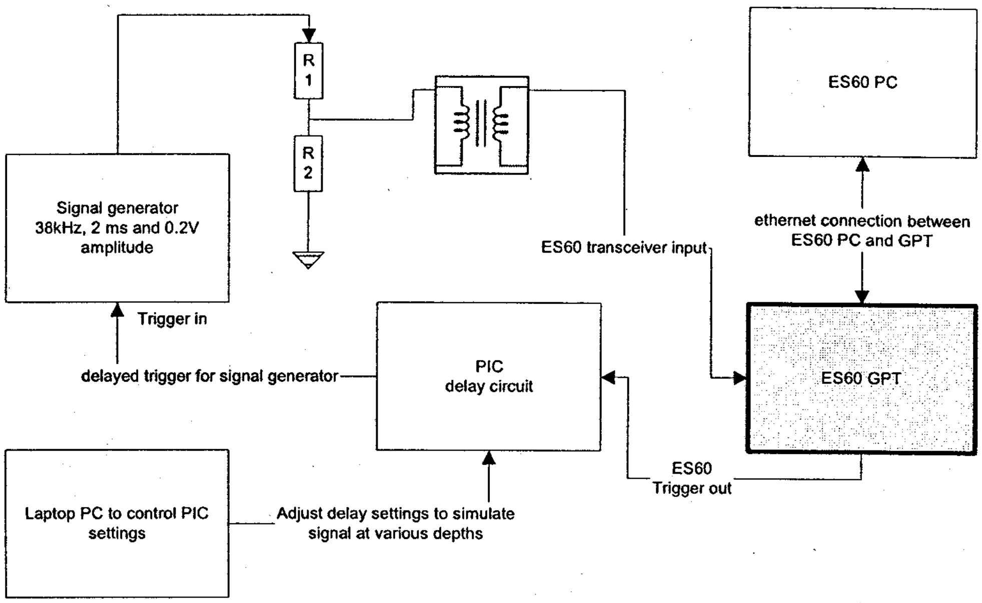
Full sample digitised data was recorded from Simrad ES60 echosounders for each of the following tests:

<u>Experiment 1. Calibration sphere S_v and single target TS data.</u>
Sounder mode: Active
Test: Whole of system test (transceiver and receiver section of ES60).
Description: Using the wharf-side calibration facility, a reference target sphere was suspended below a transducer using the methods described by Foote et al. (1987). The reference sphere was held on-axis while data was collected for a variety of ping repetition rates, pulse length and power settings.

<u>Experiment 2. ES60 internal test signal data</u>
Sounder mode: Test
Test: Receiver section of ES60 sounder.
Description: Test mode data recorded to disk.

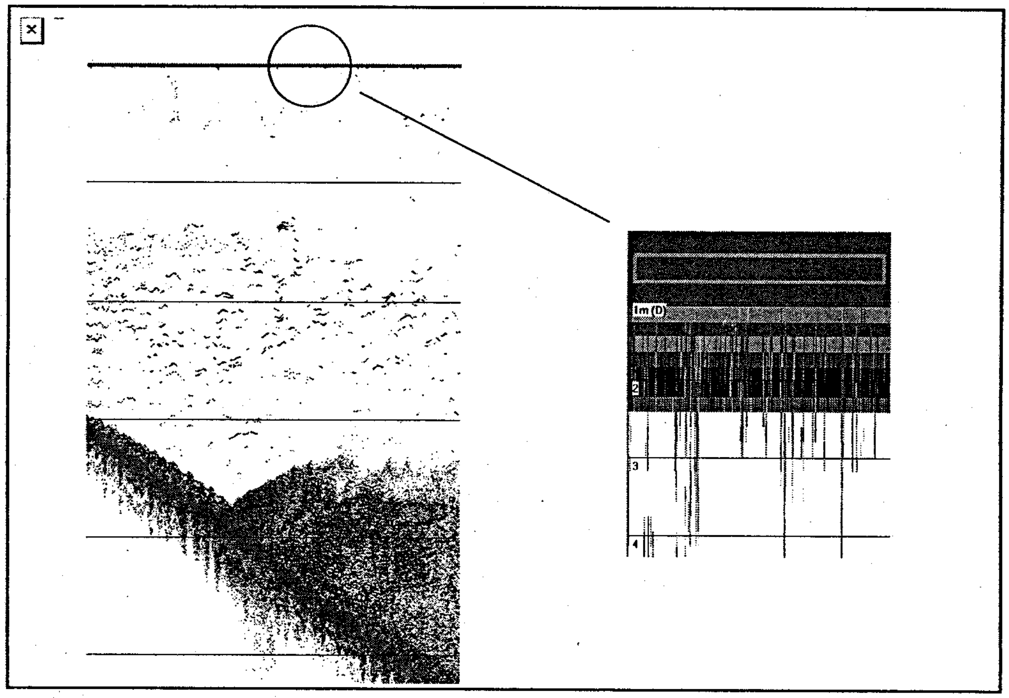
<u>Experiment 3. Synthesised test signal</u>
Sounder mode: Passive
Test: Receiver section of ES60 sounder injected with external test signal.
Description: A synthesised test signal at 38 kHz generated and fed into a delay circuit to simulate signals at various depths (Fig. 1). These signals were input into the ES60 receiver front end.

Figure 1. Block diagram of synthesised test signal circuit.



<u>Experiment 4. S_v values in echogram transmit pulse region</u>
Sounder mode: Active
Test: Can data from transmit pulse region (Fig. 2) be used to characterise the variation?
Description: S_v data from the transmit pulse region echointegrated. Plots of 10 ·log(s_A) vs. ping number inspected.

Figure 2. ES60 38kHz echogram at full sample resolution from transducer surface to 500 m water depth showing expanded view of echogram transmit pulse section. A portion of transmit pulse region S_v data is marked for export to comma separated variable (csv) format. Plots of exported S_v data can then be inspected to establish the error wave sequence.



Analysis

ES60 data was initially loaded into Echoview 3.1. Single target and selected regions of full sample S_v were exported to csv format for further analysis in MatLab. For each of the various experiments, plots of S_v or single target TS vs. ping number were closely inspected to establish metrics to characterise the variation.

Results

Characterisation of the error wave

Plots of either TS, S_v or 10·log(s_A) vs ping number are shown for each of the four experimental data sets (Fig. 3 a to d).

Figure 3a Experiment 1. Plot of compensated single target TS data vs ping number for 38.1 mm tungsten carbide calibration sphere return signal. Power = 1000W, ping rate = 0.5s.

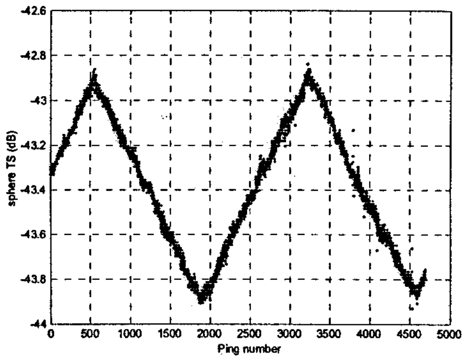
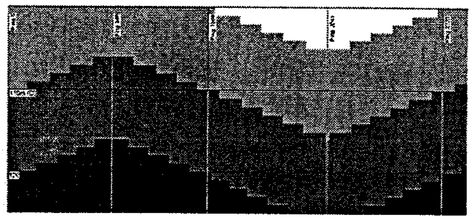


Figure 3b. Experiment 2. Echogram screenshot of ES60 internal test signal data showing variation in on screen S_v data over a full error wave cycle



Colour legend

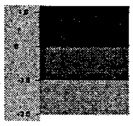


Figure 3c. Experiment 3. Plot of 10·log(s_A) vs. ping number for synthesised test signal at a simulated depth of 30 metres for multiple error wave cycles. Note how hardware reset restarted the error wave from the zero crossing point.

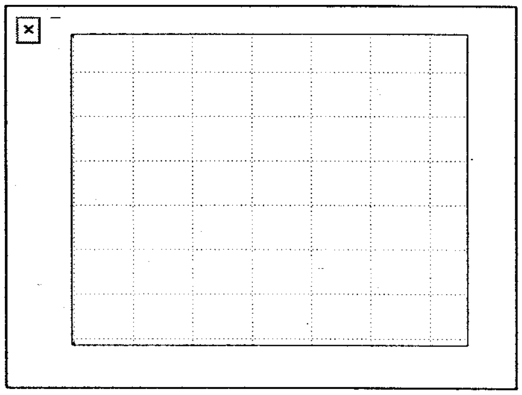
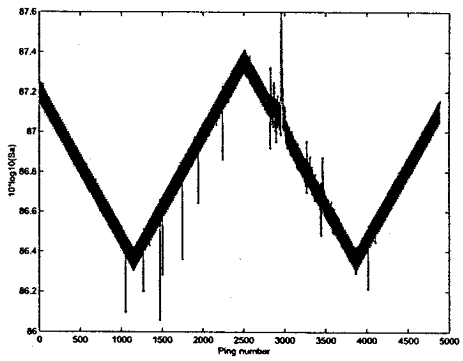
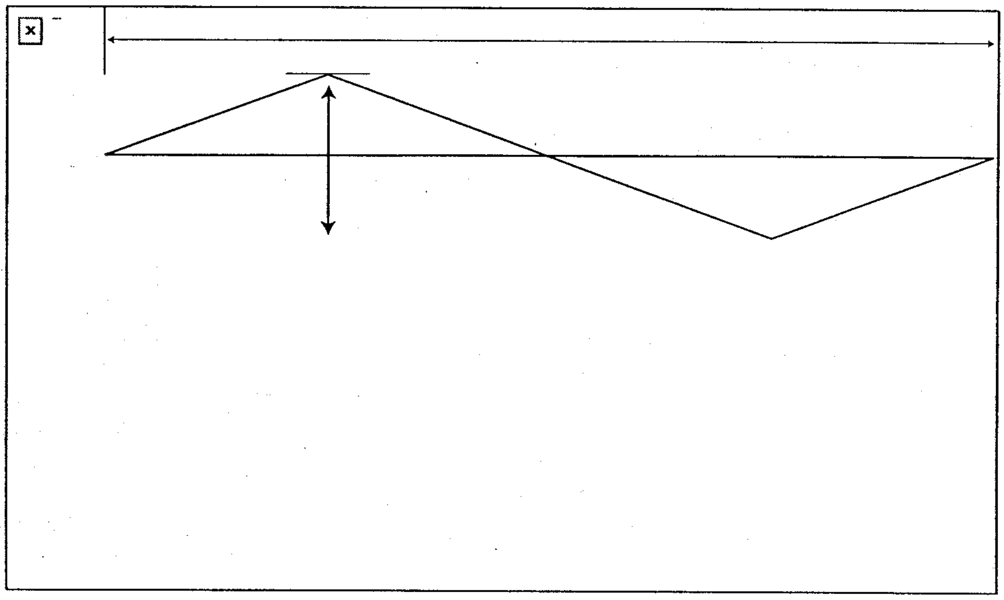


Figure 3d. Experiment 4. Plot of 10·log(s_A) vs ping number for echointegrated active mode S_v data from the top 2 meters of echogram (i.e. fire pulse region).



A systematic variation in data values can be seen in figures 3a-d. Close-up inspection of the data reveals that error component varies as a step function (Fig. 4). Data points remain at the same value for typically 16 pings after which there is a step in value to the level where the next group of 16 data points will reside. The quantisation step is equal to the amplitude resolution of the ES60, 10·log(2)÷256, or 1.176e-2dB (Simrad 2003; Macaulay 2003) (Fig. 4). The overarching shape of the step function is a triangle wave which has a period of <u>exactly</u> 2721 data points (Fig. 4).

Figure 4. Diagram of the error wave cycle showing metrics of the overarching triangle wave shape and close up detail of the underlying step function.



The peak-to-peak amplitude is approximately 1dB but the precise value is derived as follows:

The exact rate of change per ping, *R*, can be calculated from the amplitude resolution, *A*, and the number of data points, *N*, that reside at a given level in the step function.

$$R = \frac{A}{N} \quad \text{dB per ping}$$

$$R = \frac{10 \cdot \log(2)}{256 \cdot 16} \quad \text{dB per ping}$$

$$R = 7.349365\text{E-}4 \quad \text{dB per ping.}$$

Knowing the rate of change R and the period *P*, the absolute value of change in dB over a full error wave cycle, $|\delta|$, can be calculated.

$$|\delta| = R \cdot P \quad \text{dB}$$

$$|\delta| = 2721 \cdot 7.349365\text{E-}4 \quad \text{dB}$$

$$|\delta| = 1.99976 \quad \text{dB}$$

The peak-to-peak amplitude, γ, will be half this

$$\gamma = \frac{|\delta|}{2} \quad \text{dB}$$

$$\gamma = 0.999881 \quad \text{dB}$$

Generality of results

Our various experiments found that the triangle wave metrics of amplitude and period are the same regardless of:

- Ping rate
- Power level
- Pulse repetition rate
- Duration of test (i.e. sounder is stable over time periods of at least 24 hours)
- Echosounder mode (i.e. active, test, passive with injected signal)
- Frequency
- GPT model
- Data type (S_v or TS)
- Depth of signal

Other findings

The error component commences back at the zero crossing level after hardware reset but continues from where it left off after exiting and restarting the ES60 software.

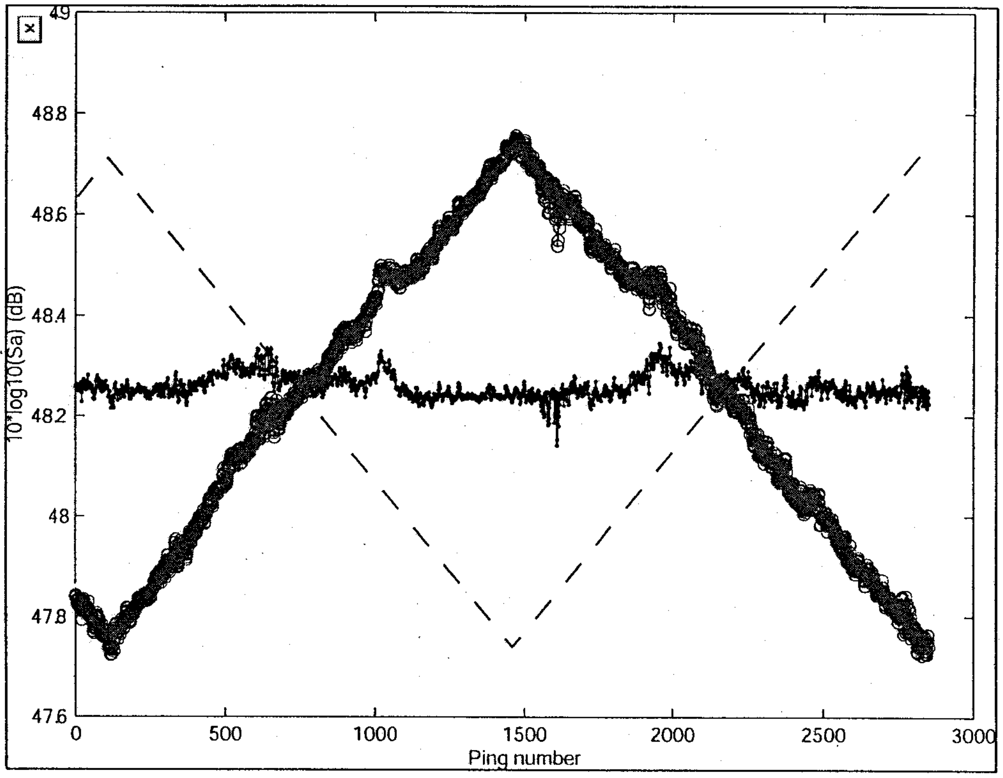
Test mode data from an EK60 echosounder was inspected but there was no indication that this error exists on that model.

Correction algorithm

The triangular wave error embedded in the ES60 data can be corrected by adding a mirror image of the error to the data. The error component of the first ping in relation to the error wave sequence must first be found when correcting on a ping-by-ping basis. Our convention is that ping 1 of 2721 starts at the zero crossing point and heads towards the maximum value (Fig. 4). Once the initial error component is established a value of equal magnitude but opposite sign to the error component is added to the data in the first ping. This continues for all subsequent pings as the mirror image of the triangle wave cycles through its 2721 ping sequence.

The correction algorithm reduced the standard deviation of on-axis calibration-sphere echointegrated data from 0.3 to 0.02 dB (Fig. 5).

Figure 5. Plot of i) echointegrated calibration return signal S_v data, ii) correction waveform and iii) result of adding correction waveform to the original data to produce a raw data set with the error component removed.



Discussion

The experiments were able to quantify precisely the key metrics needed to describe the triangle wave error. This led to a semi-automated correction algorithm which requires the error component of the first ping's data to be located in relation to the error wave sequence. The algorithm is robust as long as no hardware resets have occurred as these will restart the error wave sequence invalidating the correction algorithm from that point forward. ES60 sounders do occasionally lock up unexpectedly and the commercial fishers are quite used to power cycling the hardware; recipients of ES60 data sets who intend to apply our correction algorithm should be aware of this possibility. Corrected data should be inspected to ensure that the error component has indeed been eliminated.

A key finding is that the error wave structure can be established from the transmit pulse section of the echogram data. ES60 echogram data is always recorded from the surface and thus inherently includes the transmit pulse region. As long as the dataset contains enough pings to establish the error wave sequence then there is sufficient information to enable correction; it takes at most ½ of the period (< 1361 pings) to establish the error sequence. This greatly improves the potential of the Simrad ES60 for quantitative use.

A more sophisticated correction algorithm than the one presented could analyse the error component information embedded in an echogram's transmit pulse section and then automatically correct the entire ES60 echogram. Such an algorithm would need to be able to cope with occasional erratic jumps (dropouts and spikes) in the transmit pulse data caused by aeration and wave-slapping in rough weather.

We have found that in a worst case scenario the error can be up to 1dB but in many cases it will be substantially less than this. By understanding the nature of this systematic error, researchers can decide how their data may be affected and if necessary make the appropriate corrections.

References

Foote, K.G., Knudsen, H.P., Vestnes, G., MacLennan, D.N., and E.J. Simmonds. 1987. Calibration of acoustic instruments for fish density estimation: a practical guide. ICES Cooperative Research Report. No. 144 69 pp.

Macaulay, G. 2003. (National Institute of Water and Atmosphere, New Zealand). 2003 pers comms

Ryan, T.E., Kloser, R.J., Geen, G, Lewis, M. 2003. Development of a sustainable industry-based observation system for blue grenadier at the primary spawning sites. Progress report 1

Simrad 2003. EK60 manual. 850-164696/Rev.A. ISBN 82-8066-012-7