Simrad EK60 calibration

Description of implementation in ER60

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Introduction

The main goal of this report is to describe the calibration of Simrad EK60 as implemented in the Simrad ER60 software.

The overall goal with a scientific split-beam echo sounder is to be able to collect absolute acoustic values from the instrument in a well described environment. Calibration can be one part of the many actions taken to obtain this goal. Calibration aims to compensate for potential differences between the theoretical description of the instrument performance and the actual instrument performance. Repeating calibration over time also aims to discover and potentially adjust for possible changes in instrument performance over time. The scientific split-beam echo sounder is usually used to collect two main types of acoustic values:

- Target strength (TS) - for description of single targets
- Volume backscattering strength (S_v) - for description of multiple targets.

Current Simrad EK60 protocol

The following describes the main parts of the calibration protocol for EK60. The calibration protocol is based on the use of a calibration sphere with known theoretical target strength. The sphere is moved around in the beam and backscatter data from the sphere from different locations in the beam are used for parameter estimation. The following procedure is common for both calibration of target strength and volume backscattering strength parameters:

1. The user specifies a set of standard single target detection criteria:

    • **Minimum threshold (dB)**
    TS of target must exceed this value.

    • **Minimum / maximum echo-length**
    Normalised echo-length (echo-length between 6 dB points relative to the peak value divided by the duration of the transmitted pulse) must exceed/be less than this value.

    • **Maximum phase deviation**
    Average phase jitter between samples inside a single-target echo must not exceed this value, set in units of phase steps.

    • **Maximum gain compensation**

Transducer gain model correction value must not exceed this value (one-way maximum gain compensation).

- **Minimum echo spacing**
Minimum spacing between two single echoes.

2. The user specifies a set of extra calibration sphere specific target detection criteria:

   - Theoretical TS for the sphere

   - Maximum allowed deviation from the theoretical TS

   - Upper and lower depth limits

3. The EK60 divides the beam limited by the 6 dB points in the alongship and athwartship direction into a regular grid consisting of 25 X 25 grid cells. Only the first single target detection in each cell will be accepted and used in the calibration.

4. The user physically moves the calibration sphere around in the beam and the EK60 estimates TS values for detections which comply with the criteria described above.

5. When user is satisfied with coverage of the single target detections in the beam, the user stops the calibration.

6. Optionally, the user manually removes some of the single target detections from being used further in the calibration process.

Single Targets - Target strength

In the case of single targets the important parameters to be measured are target position and target strength. Target position is both used by its own for e.g. behavior studies but also for estimating target strength as the target position information is needed to compensate for the transducer beam pattern. The equation typically used for estimating target strength in the instrument is:

$$TS = 10\log_{10}(P_r) + 40\log_{10}(r) + 2\alpha r - 10\log_{10}\frac{P_t\lambda^2}{16\pi^2} - 2G(\theta,\phi) \qquad (1)$$

Equation 5.1 shows that in order to obtain a correct TS estimate the parameters P_r, r, α, P_t, λ, θ, ϕ, and $G(\theta,\phi)$ all need to be estimated correctly. Some of these parameters will also be environment dependent. In EK500 and EK60 calibration has focused on calibration of $G(\theta,\phi)$. For target strength calibration the EK60 aims at estimating the parameters G_0, θ_0, ϕ_0, θ_{3dB}, and ϕ_{3dB} in the beam pattern approximated by the function:

$$G(\theta,\phi) = G_0 - 10\log_{10}(2)\left[\frac{|\theta-\theta_0|^2}{\left(\frac{\theta_{3dB}}{2}\right)^2} - \frac{|\phi-\phi_0|^2}{\left(\frac{\phi_{3dB}}{2}\right)^2} - 0.18\left(\frac{|\theta-\theta_0|^2}{\left(\frac{\theta_{3dB}}{2}\right)^2}\frac{|\phi-\phi_0|^2}{\left(\frac{\phi_{3dB}}{2}\right)^2}\right)\right] \quad (2)$$

The parameters are estimated as the parameters which minimizes the following error function:

$$err(G_0, \theta_0, \phi_0, \theta_{3dB}, \phi_{3dB}) = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\frac{TS_{theory} - TS_i}{2}\right)^2} \quad (3)$$

Multiple targets – Volume backscattering strength

In the case of multiple targets the important parameter to be measured is volume backscattering strength. The equation typically used for estimating volume backscattering strength in the instrument is:

$$S_v = 10\log_{10}(P_r) + 20\log_{10}(r) + 2\alpha r - 10\log_{10}\left(\frac{P_t\lambda^2 c}{32\pi^2}\right) - 2G_0 - 10\log_{10}(\tau_{eff}) - 10\log_{10}(\psi) \quad (4)$$

In EK60 the effective pulse duration is replaced with a combination of the nominal pulse duration and a correction parameter:

$$\begin{aligned} S_v = {} & 10\log_{10}(P_r) + 20\log_{10}(r) + 2\alpha r - 10\log_{10}\left(\frac{P_t\lambda^2 c}{32\pi^2}\right) - 2G_0 \\ & - \left(10\log_{10}(\tau_{nom}) + 2S_{a,corr}\right) - 10\log_{10}(\psi) \end{aligned} \quad (5)$$

Equation 5.5 shows that in order to obtain a correct S_v, the parameters P_r, r, α, P_t, λ, c, $S_{a,corr}$ and ψ all need to be estimated correctly. Some of these parameters will also depend on the environment. In the EK500 and EK60 the calibration has however focused on calibration of G_0 and $s_{a,corr}$.

Volume backscattering calibration of the EK60 assumes that G_0 has been correctly estimated through the target strength calibration. Thus, for volume backscattering calibration, the EK60 aims at estimating the effective pulse duration by estimating a correction value defined as:

$$\tau_{eff} = \tau_{nom} 2s_{a,corr} \quad (6)$$

The effective pulse duration can be estimated from the received power values obtained from the calibration sphere:

$$\tau_{eff} P_{\max x} = \int P(t) dt \tag{7}$$

The correction value is then given by:

$$2 s_{a,corr} = \frac{\int P(t) dt}{\tau_{nom} P_{\max}} \tag{8}$$

As the sampling interval in EK60 is

$$dt = \frac{\tau_{nom}}{4}, \tag{9}$$

the correction value may then be estimated as:

$$s_{a,corr} = \frac{1}{2} \frac{\frac{\tau_{nom}}{4} \sum_i P_i}{\tau_{nom} P_{\max}} = \frac{1}{2} \frac{\sum_i P_i}{4 P_{\max}} \tag{10}$$

The ratio can be estimated using the area backscattering strength and target strength values measured by the instrument from single target detections of the calibration sphere close to the acoustic center. Beam pattern is taken into account for all detections.

The EK60 initially only uses single target detections from the 3x3 cells closest to the center. If there are less than three detections in these nine cells, the EK60 uses data from the 5x5 cells closest to the center. If there are less than five detections in these cells, the user is notified that more detections around the center are needed. An "average" of the estimates from these detections is used as the final estimate of $s_{a,corr}$. A detailed description of how $s_{a,corr}$ is obtained from area backscattering values and target strength is given in the Appendix.

Appendix: Details regarding volume backscattering calibration

The backscattering cross section for the calibration sphere is estimated by EK60 as:

$$\sigma_{bs,sphere} = \frac{P_{r,\max} 16\pi^2}{P_t g^2(\theta,\phi)\lambda^2} r_{sphere}^4 10^{2\alpha r_{sphere}} \tag{A1}$$

Each volume backscattering sample from the sphere samples is estimated by EK60 as:

$$s_{v,i} = \frac{P_{r,i} 32\pi^2}{P_t g_0^2 \lambda^2 c\tau_{nom}\psi} r_i^2 10^{2\alpha r_i}$$
$$= \frac{P_{r,i}}{P_{r,\max}} \frac{g^2(\theta,\phi)}{g_0^2} \frac{r_i^2 10^{2\alpha r_i}}{r_{sphere}^4 10^{2\alpha r_{sphere}}} \frac{2\sigma_{bs,sphere}}{c\tau_{nom}\psi} \frac{c\tau_{nom}}{8} \quad \text{(A2)}$$

The area backscattering strength for the calibration sphere is estimated by the EK60 using the volume backscattering samples from the sphere as:

$$s_{a,sphere} = \sum_i s_{v,i} \frac{c\tau_{nom}}{8} \quad \text{(A3)}$$

If we make the approximation $r_i \approx r_{sphere}$ we obtain:

$$s_{a,sphere} = \frac{\sum_i P_i}{4P_{\max}} \frac{\sigma_{bs,sphere}}{\psi r_{sphere}^2} \frac{g^2(\theta,\phi)}{g_0^2} \quad \text{(A4)}$$

By rearranging we obtain:

$$s_{a,corr} = \frac{1}{2} \frac{\sum_i P_i}{4P_{\max}} = \frac{1}{2} s_{a,sphere} \frac{\psi r_{sphere}^2}{\sigma_{bs,sphere}} \frac{g_0^2}{g^2(\theta,\phi)} \quad \text{(A5)}$$