Digital Side-scan: is this the end of TVG and AGC?

Consider the levels of sound in the sea that are encountered when on a side-scan survey job. The background sea noise comes from the temperature of the water around the towfish, the noise from waves, biological activity and noise from vessels. The difference between this sea noise and the sonar ping might be over 130dB (remember that 6dB is a doubling of the pressure level in the sound). To compare this with human hearing, a 50dB reduction in sound is the difference between talking to someone face to face in a pub and listening to a talk-show on the radio with the volume turned down to just below the level at which it can be understood. The human ear can hear sounds over a 120dB range – the difference between silence and a jet plane taking off.

How is this relevant to sonar? You do not listen to side-scan sonar signals: the frequency is usually beyond the range of hearing. You view the data on a PC screen, usually in 8-bit greyscale. These 8 bits correspond to only a 48dB change in the signal: where is all the rest of the information? The answer is that the signal has been compressed into these 8 bits by adjusting and 'zooming' to try to best show the interesting features. There is a lot more in the sonar signal than what is seen in just these 8 bits – information equivalent to the subtleties of a whisper and the crackle in the roar of the jet.

Side-scan sonars have traditionally relied on front-end time variable gain (TVG) and automatic gain control (AGC) to do a lot of this adjustment and zooming in order to represent the sound on the screen. The TVG compensates for the huge differences in sound levels returned from a target immediately below the sonar and one at the edge of the swath, while the AGC tries to adjust the signal level as the sonar goes over rock and then mud patches. On traditional side-scan sonars, there are usually two stages to this: firstly, from the raw data (possibly 130dB dynamic range) to a 12-bit number stored on disk (72-bit dynamic range), and, secondly, when displaying this 12-bit number on a computer screen with 8-bit resolution.

However, all this adjusting and zooming of the signal must make assumptions about the signal levels. What if there is a rock pile (or mine) in the middle of a soft seabed? Here, the AGC will not be able to adjust fast enough and the detail in the strong signals will be lost. What if the sonar is going over a slope? Is the TVG going to adjust the raw data properly? If the sonar goes over a rocky crag and then mud, how long does it take the AGC to adjust appropriately? Get any of this wrong, and useful information can be lost in the digitisation and large signals can get clipped. When going from the stored data to the screen, a user can repeatedly adjust the settings to try to improve things, but errors made by the TVG and AGC applied prior to storing the raw data cannot be recovered.

Another problem with applying front-end TVG and AGC is that the stored data do not directly represent the signal level received. A sonar shadow at near range will have a different intensity to a sonar shadow at far range, and the absolute difference in signal level between two identical objects on different sea floors at different ranges will not only be from the change in range. This can be a big problem in machine interpretation of sonar images, computer-aided classification of objects and the neural-network machine perception systems now being researched for sonars.

The new digital side-scan technology developed by GeoAcoustics gets around this by recording the raw signal levels using a 24-bit number. This corresponds to a 144dB dynamic range, the highest dynamic range of any commercial sonar raw data. When this problem was first posed, it was noticed that this is similar to a problem seen with mobile telephone signals: your mobile might be 10m or 10km away from the base station, which also results in a huge dynamic range. The technique used to solve this is to use very rapid over-sampling of the raw signal, combined with digital signal processing. A similar technique is used in the dual-frequency 100kHz/410kHz GeoAcoustics Digital Side Scan Sonar (DSSS); a 40Mhz front-end sample rate is digitally processed to give 24-bit data at a 50kHz sample output rate, and this 50kHz data stream is the data that are stored to disk.
The digital processing of the over-sampled signal gives three other key advantages:

1.The digital filters applied can be much better than any electronic filter. In the DSSS, a filter with out-of-band rejection of over 100dB is used. This reduces the sea noise that gets into the system, extending the range and the ability to see soft targets. It also allows simultaneous (even asynchronous) use of the two frequencies.

2.The digital filters are all in the processing code, and so can be adjusted at will. This means that the sonar can dynamically trade range for resolution, optimising the pulse length and signal-to-noise ratio for the range selected: long pulses with wide filters for long-range 'search' surveys, short pulses and tight filters for the 'classify' pass.

3.The response to changes in signal level is virtually instantaneous. The detail seen on a fish in the water column or a small, hard object on a soft seabed will not depend on the phase response of the electronics – the signal can go from 0 to 16 million in one sample.

The machine interpretation of side-scan images has been helped a lot by this digital processing technique: the signal can be directly related to the sound intensity at the transducer, and the signal levels have absolute repeatability.
The transmitting and storage of full raw data is a new proposition for commercial side-scan sonars. A major consideration in the -implementation of this digital technology was how to get this mass of digital data, generated on the towfish or remotely operated vehicle, back to the surface. Again, commercial off-the-shelf solutions were chosen using ADSL technology or ethernet connections.

The final link in the chain from sonar to surveyor is, of course, the display of the data. While the standard techniques of post-processing TVG and gain level shift can be applied to the 24-bit DSSS data in order to put it on the screen, new techniques are being developed in the conversion of the 24-bit numbers to the 8 bits of the screen, which improve the image content and help the interpretability of the sonar images. These techniques can be made much more consistent using the full raw data that is now available. The development of sonar data collection and processing tools to handle the full dynamic range of the data is well underway: for example, Coda-Octopus can now provide a digital interface to the GeoAcoustics DSSS using both the Coda DA Series and Coda GeoSurvey Geophysical Interpretation Suite.

The images accompanying this article demonstrate what can be achieved using 24-bit side-scan sonar technology in terms of range, resolution and dual-frequency operation. These images were all collected using the GeoAcoustics DSSS operating at 100kHz and 410kHz. Of course, the printed images cannot show the full signal dynamic range – TVG has been applied in processing to bring out features for the eye.

This article has described how much more information there is in the raw data behind a sonar image than was ever previously available, and how the surveyor (be he man or machine) will be able to do much more with the survey data now being collected. While this is not the end of TVG and AGC, as a surveyor still needs to generate the pretty images for his reports, it is the end of the evils of badly set TVG and AGC, which can throw away the information that is needed.