Near real-time transmission of reduced data from a moored multi-frequency sonar by low bandwidth telemetry

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Abstract— **Moored, internally-recording acoustic instruments can acquire continuous profiles of echoes throughout the water column, thus providing a low-cost method of studying the behavior and abundance of fish and zooplankton in oceans and lakes. Calibrated sonars with several frequencies allow some information about species composition and abundance to be deduced from acoustic backscatter data. The same instrument can be configured to look up from the bottom, down from the surface, or horizontally from a CTD cage. In this presentation we describe additional capabilities of this low-power, battery-operated, multi-frequency sonar capable of autonomously collecting data at high temporal and spatial resolution for periods of up to a year. The AZFP instrument (Acoustic Zooplankton and Fish Profiler) supports up to four frequencies in a single housing. The available operating frequencies are 38, 67.5, 125, 200, 455, 769 and 2000 kHz. The transducers are co-located, with the same nominal beam widths of 7° or 8°, except at 38 and 67.5 kHz, where the beam width is 12°. The standard AZFP can be moored at depths up to 300m, and with modified transducers as deep as 600m.**

The AZFP can store up to 32 GB of this data internally. The user can specify averaging in time and/or range to choose an optimum sampling scheme for the available storage. Because the AZFPs are deployed on moorings for long periods of time, there can be a requirement to monitor the data in near real-time. The volume of data collected is usually too great to allow monitoring of the results unless the instrument is connected by cable to shore. A capability to retrieve a subset of this data over low bandwidth satellite or other network links to provide this monitoring was developed. In this presentation we show how the stored data is further reduced to accommodate transmission over a low bandwidth network.

The AZFP data is acquired in logarithmic form so compiling data averages requires conversion to linear values if a true arithmetic average is desired. Because the instrument is designed for low power consumption to allow long deployments, the onboard microprocessor has limited processing capabilities. In particular, floating point calculations are not possible and all processing is done using integer arithmetic. Conversion to and from logarithmic form is therefor done using lookup tables, but limited internal memory limits the size of the lookup tables. We will describe how the tables are constructed to provide adequate resolution.

This capability is applicable to AZFPs deployed on AUVs and gliders as well as moorings where a surface buoy allows satellite or radio telemetry. If two-way serial communication is possible in a particular application, then the operation of the AZFP can be controlled by the platform or remotely by a communication link through the platform. Here we will give an example of a moored system where inductive modems are used to transmit data from the AZFP to the surface buoy for retransmission over a satellite link. In this case, because other types of data were to be transmitted over the satellite link, the fraction of the bandwidth available for the AZFP data was severely limited, so additional range averaging was required.

I. AZFP DESCRIPTION

The AZFP is an autonomous scientific sonar, designed for long-term collection of acoustic backscatter data from a mooring. It contains up to four acoustic channels; the frequencies available are 38, 67.5, 125, 200, 455, 769 and 2000 kHz. The transducers for the four higher frequencies (except 2000 kHz) are located within a single housing; the larger 38 and 70 kHz transducers require a separate housing. Figure 1 shows the configuration of the instrument with and without a low frequency channel, as well as an exploded view. Table 1 summarizes the AZFP's basic acoustic parameters for each of the available frequencies.

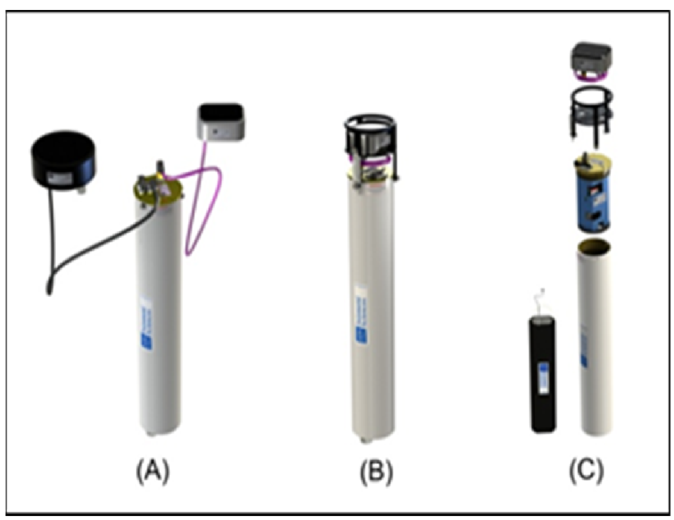

Figure 1 Configuration of the AZFP: (A) with the 38 kHz channel, (B) as a 4-frequency 125/200/455/770 combination, (C) as an exploded view.

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There are 32 GB of data storage available, and the standard battery pack of 200 A-Hr allows the instrument to sample on four channels to 100 m range, pinging every 2 seconds for 150 days. The pulse width is selectable between 100 and 1000 µs, and averaging over range or time is available. The instrument can be installed looking upward, either from a bottom frame or in a taut-line mooring, or it can be deployed looking downward from a surface buoy. The standard AZFP can be moored at depths of up to 300m, and with modified transducers as deep as 600m.

Frequency (kHz)	Nominal -3 dB Beam Angle (°)	Nominal Source Level (dB)
38	12	208
67.5	12	205
125	8	210
200	8	210
455	7	210
769	7	210
2000	7	212

Table 1 Acoustic parameters of the AZFP channels.

Figure 2 illustrates the sampling schematically for an instrument with four channels. Sampling may be regularly spaced or in bursts; in either case, averaging in range or in time is optional. When a ping is to be emitted, transmission occurs from the highest frequency transducer first. After the listening period for that channel (determined by the maximum sampling range selected) has elapsed, the next channel down in frequency transmits, and so on until listening is complete for the last channel. The sequence is repeated at the selected ping rate; if burst sampling has been selected, transmissions cease after the number of pings per burst is reached, and the sequence starts again after the burst period has elapsed. The maximum sampling range, pulse length and range bin size may be set independently for each channel.

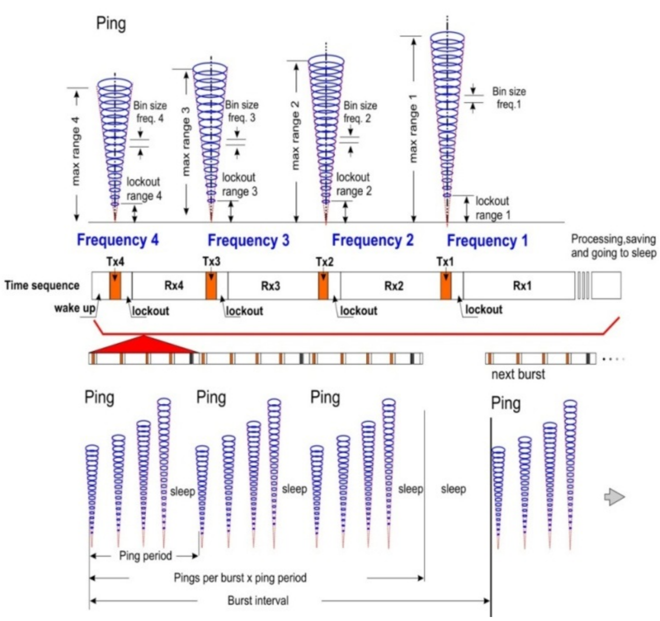

Figure 2 Schematic of the instrument sampling scheme showing the timing for individual pings and bursts.

Echoes arriving at the transducer pass through an amplification and band-pass filtering stage to a detector whose output is a DC voltage linearly related to the logarithm of the input signal power with an effective dynamic range between 80 and 90 dB. The detector output is digitized by a 16-bit A/D and then stored to a 32 GB compact Flash card. Calibration is performed in a test tank using a reference hydrophone and target spheres of known target strength.

II. Data Formats and Averaging

Frequently, considerations of data storage space or power consumption make it advantageous to store averaged data rather than the individual digitized values. The user may specify averaging over a specified range interval or number of samples, or time-averaging over all the pings in a burst, or a combination of the two. Since the digital values output by the detector are on a logarithmic scale, they cannot be averaged directly, as that would result in a geometric rather than an arithmetic average. The AZFP performs a true arithmetic average of the signal amplitude data and stores the result as the data are being collected. The individual raw samples are not saved. Because of the limitations of the on-board processor (CPU speed, power, memory and integer arithmetic) the conversion between logarithmic and linear values is done using a look-up table, which has a resolution of 0.013 dB.

The lookup table has 8192 entries in long integer form, each entry in the table corresponding to a group of eight A/D values. A count of 65535 corresponds to the detector's full scale output of 2.5 volts. The response of the detector is a volts/dB (nominally a = 0.023), so full-scale output corresponds to 2.5/a dB relative to the theoretical output at 1 count. If the count from the digitizer is N, then the lookup table index is

$$I = N/8$$

I takes values from 1 to 8192, and the corresponding amplitude value entry at index I is

$$V = 10^{[I/(65535a) + 2.5]}$$

In normal operation, the averages are stored on board in unsigned long integer form with an additional byte to count overruns, and conversion from the averaged value V_{av} back to decibel format is done after the data are downloaded by the interface program as

$$N = [\mathrm{Log}_{10}(V_{av}) - 2.5]*8*65535*a$$

The increment in V between any successive values of the index is equivalent to 0.013 dB.

III. Near Real-Time Data Transmission

In a number of applications for the AZFP, it is often desirable to have some near real-time telemetry of the data, to monitor instrument operation, as partial data backup or to assess and possibly modify sampling schedules for the AZFP and other instruments that may be deployed with it. If the AZFP has a high bandwidth connection to shore (as part of a cabled observatory, for example) then all the data collected can be sent out in near real time. However, in many cases, such as on board a glider or AUV, or as part of a mooring with a surface buoy and radio or satellite communication to shore, the bandwidth is usually limited, and only a condensed subsample can be sent.

A procedure called Profile Condensing Feature (PCF) was developed in the AZFP firmware to condense the data stored by the AZFP for such bandwidth-limited applications, which included converting the averaged values back to logarithmic form. Due to processor, power and memory limitations, directly performing that computation is not possible in the instrument, so a procedure to do an inverse lookup of the anti-log table was used to do the conversion.

The procedure is illustrated using an example of a moored system as shown schematically in **Figure 3** where inductive modems are used to transmit the data from underwater sensors to a surface buoy for retransmission over a satellite link. In this case, because other types of data were to be transmitted over the satellite link, the fraction of the bandwidth available for the AZFP data was severely limited, necessitating additional averaging.

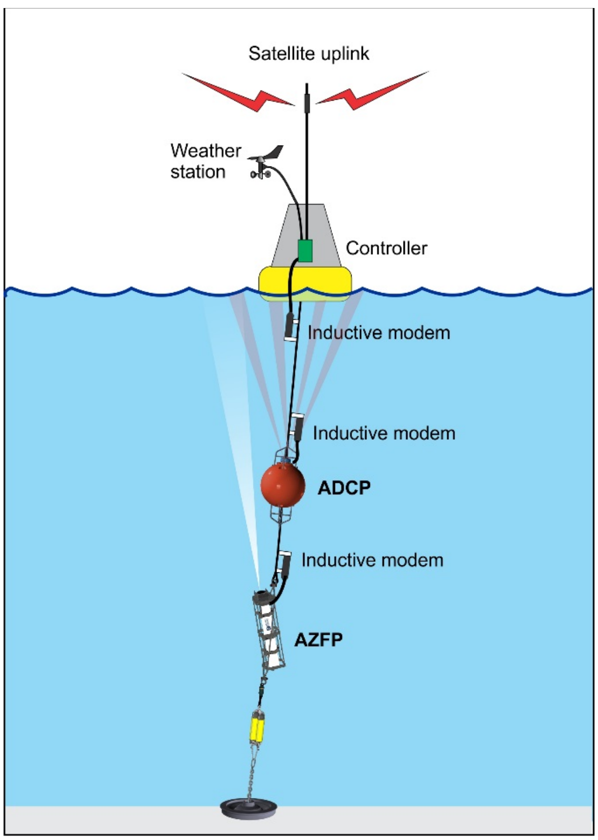

Figure 3 Mooring with Inductive Modems

IV. PROFILE CONDENSING FEATURE

The Profile Condensing Feature (PCF) reprocesses selected AZFP profiles as they are acquired and condenses them down to a manageable size for output over the limited bandwidth communications link. The user has control of the degree of condensing by programing the instrument with the number of bins to average in a profile. The condensing of profiles is not a reversible process (this is not data compression), therefore the original profiles are stored to the internal FLASH storage and can be retrieved when the instrument is recovered to provide the full resolution data. In the example mooring the AZFP is run on an internal battery supply so as well as the bandwidth issues there is a power cost to performing the PCF. Although the PCF is designed to minimize the amount of CPU time to create the condensed profiles, it is generally only done on a subset of the data.

In the example mooring a profile is generally condensed and sent out once per day. The budget for the transmission of data over the satellite link was set to 2 kilobytes daily. The transmitted data had to include other sensor data such as ADCP data and weather station data. A typical sampling scheme for AZFP data collection would be 5 profiles per hour sampling 250 meters on four channels with a bin resolution of 0.1 meters per bin. This would result in a byte count of 55 KB for each ping or 6.5 MB per day of data. As described below, the AZFP data can be condensed by several factors but still retain features in the signals. Condensing one profile by a factor of 100 would bring the byte count of one profile to 668 bytes.

In normal operation when performing bin averaging in time (multiple profiles) and/or space (vertical bin averaging), the AZFP processor converts the acquired log data to a linear form by using the anti-log lookup table to convert the data to a linear form and summing it in 4 byte unsigned integers for each bin. An additional byte is used to track integer overflows. This is done in real time as the data is acquired.

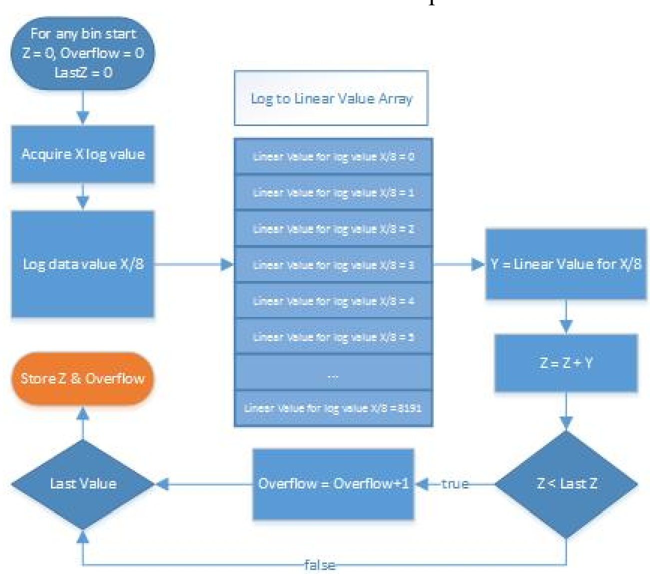

Figure 4 Log to Linear Conversion

Each bin of data consisting of a 4-byte sum and overflow byte are stored instead of converting them back to log form to save power. **Figure 4** illustrates the procedure for the summation of values for one bin of data.

The PCF performs the averaging in the same way by further summing up bins that are in linear form or converting non-averaged log data to the linear form then summing it up. To further reduce the amount of data to transmit the PCF converts the condensed data back to a log value. This is accomplished by computing the average of the condensed bins from the sum and doing a reverse lookup of the anti-log table for the closest element in the table that will give that averaged value. This reduces the number of bytes to transmit from 5 bytes to 2 bytes. The anti-log lookup consists of a binary search of the closest element in the table to the averaged values of each condensed bin as shown in **Figure 5**.

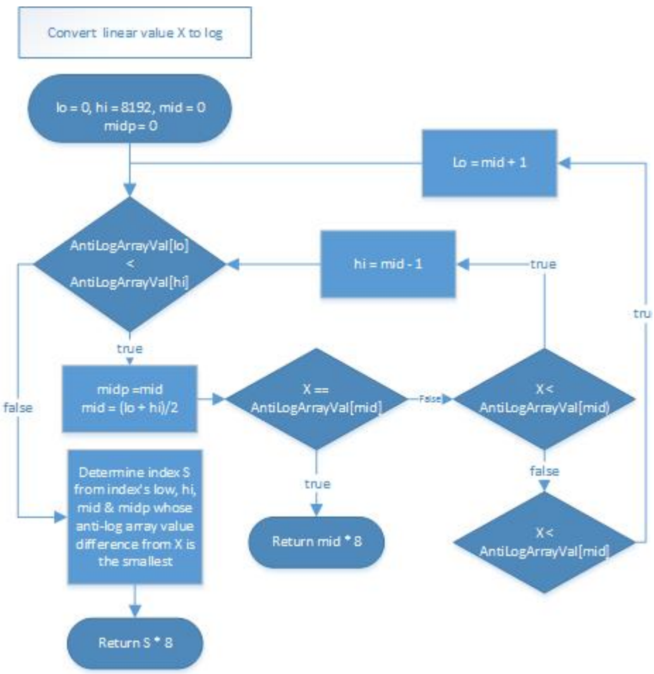

Figure 5 Anti-Log Binary Search

V. CONDENSED DATA EXAMPLE

Previously collected data was used to test the PCF algorithm. **Figure 6** shows an echogram of a data set with full resolution, **Figure 7** shows the same data condensed by a factor of 50 and **Figure 8** condensed by a factor of 100. Most of the features seen in the full resolution can be seen in the lower resolution echograms.

The size of the full resolution data is 63.2 MB, the 50 times condensed file is 1.32 MB and the 100 times condensed is 782 KB. Note that at some point the size of the header information for each profile becomes more significant therefore increasing the condensation from 50 to 100 times does not decrease the data by half. The implementation of the PCF in the instrument does reduce the header information by removing some non-essential information to further reduce the number of bytes required for transport.

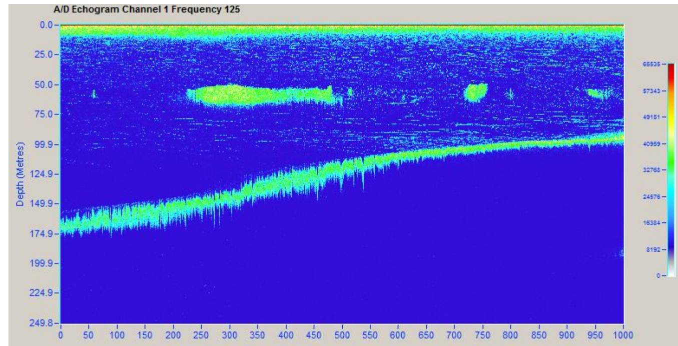

Figure 6 Full Profile Resolution

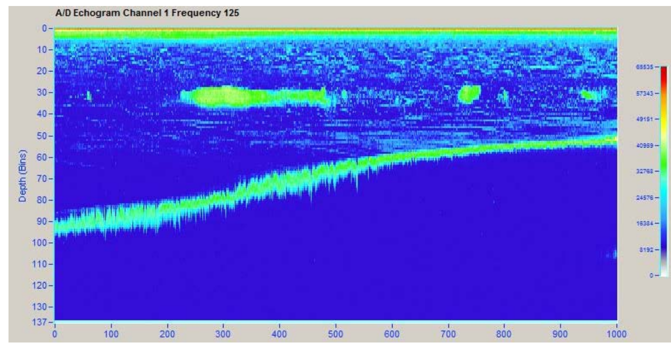

Figure 7 Condensed Profile to 1/50 Resolution

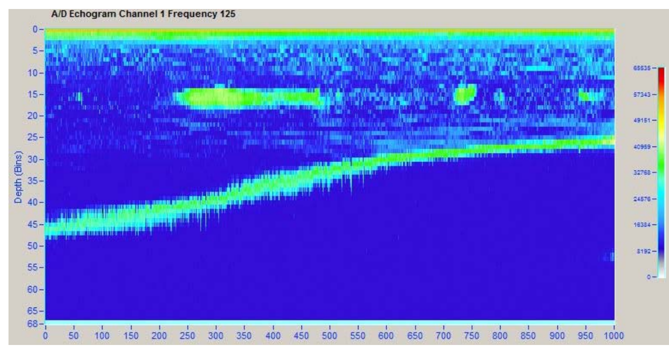

Figure 8 Condensed Profile to 1/100 Resolution

VI. INDUCTIVE MODEM COMMUNICATIONS

In the mooring example the communications between the AZFP and the control platform is performed using Sea-Bird inductive modems. In normal operation the AZFP shuts its CPU and communications down when not acquiring data to conserve battery power. This makes it impractical to have the platform computer directly communicate with the AZFP via the modems. To get around this limitation, the AZFP firmware was adapted to store condensed profiles as records in the memory of the inductive modem it is connected to. This allows the platform computer to interrogate the modem for new condensed profile records on its own schedule, retrieve them and package them with other data to be transmitted over satellite link.

VII. Conclusion

The development of the PCF feature allows for the monitoring of data from the AZFP over a low bandwidth data transmission system while maintaining the ability to store high resolution AZFP data for retrieval when the instrument is recovered.

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