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NEW TECHNOLOGIES FOR MARINE MAMMAL ACOUSTIC DATA CAPTURE

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1. INTRODUCTION

The study of marine mammals is generally characterised by individuals or small teams working on a very tight budget. The use of advanced electronic technology to assist these studies has traditionally been severely limited by funding. However, the trend in microelectronics, driven by the demands of the personal computer and home entertainment markets is to continually reduce the cost of technology and to make more powerful systems available to the mass market. The marine mammal research area can now benefit from this advanced technology to provide a number of useful tools.

This paper will explore the advances made in recent years to demonstrate the level of technology now available and conceptually design a number of systems that could be assembled to aid cetacean research.

2. BACKGROUND

Cetaceans are generally one of the more difficult groups of animals to study. They inhabit a medium very different from our own and traditional land-based study methods can only be partially applied. Visually our only contact with them is during the brief periods when they surface to breathe or by diving in order to join them in their medium. In both cases, unless underwater visibility is exceptional, we only get a brief snapshot of their lives and it is very difficult to piece together what else they may be doing below the surface. Visual techniques are also limited to daylight hours and to relatively calm water conditions. In order to improve our knowledge of cetacean behaviour one possibility is to use acoustics to listen to the sounds they make and to attempt to track the animals as they move around. The volume coverage needed to achieve this ranges from a few hundred cubic metres for the smaller animals to whole ocean basins for the larger baleen whales.

Listening to the sounds the animals make can give an insight into behaviour patterns, although validating the relationship between sound patterns and behaviour patterns is not always easy, Herzing [15]. Detection of cetacean sounds can also be used to alert visual watchers to the presence of animals and allow the visual watch to be more complete than it may otherwise be.

The use of acoustic tracking systems has recently become more popular as military systems have become available to some cetacean researchers, Clark [1], Spikes [17] and the technology has become more generally available to all researchers, Woodward & Coggrave [2], Clark [3], Cummings [16], Connolly et al [18]. Acoustic tracking systems provide much behavioural information but the temperature structuring of the water can make accurate location difficult to determine.

3. RESEARCH SYSTEMS

All acoustic systems rely on using hydrophones to convert low-level pressure variations in the water within the frequency range 10Hz to 300KHz to electrical voltage or current and then amplifying and filtering the signals. The human ear can only distinguish the frequency range 50Hz to 20KHz at best, Kinsler & Frey [4], so sounds outside of this region need to be processed electronically in order to extract useful information.

One way of transposing the higher frequency signals into the part of the spectrum that we can hear is to use a click detector. The output of such a circuit traces the envelope of the incoming signal. This works well for listening to echolocation clicks since relative amplitude and time is maintained and current consumption is low making it very suitable for lightweight battery-operated equipment for behavioural studies in the field.

The use of the human ear in conjunction with the human eye to perform behavioural studies in the field is acceptable, but more detailed investigation of the acoustic signals needs more sophisticated systems to aid the human operator. Virtually all such systems rely on converting the analogue signals to digital signals and then processing them further using some form of computer.

One obvious use of advanced processing is to transform the data to the frequency domain and then to display the spectrum of the frequency range of interest. This data can be displayed as a continuous Z-scan display (fig 1) or as a single A-scan displaying instantaneous or averaged spectra (Bottom of fig 1).

Tracking systems take a number of forms. Arrays of hydrophones can be clustered together, as in a towed array to give the bearing of any sounds detected, or can be spread across a volume to give range and bearing of the sounds. In both cases the sounds detected are processed in a way that searches time-delay space to give a best-fit result for each sound. The smaller systems will consist of a small number of hydrophones, perhaps as few as two, which are towed behind a survey boat, Leaper et al [5], or fixed to the sea-bed, Mellinger [6]. On the grand scale military surveillance systems may be several hundred kilometres long and contain many hundreds of hydrophones.

Automated cetacean detection systems which use acoustic signals to detect the presence of animals can be a powerful tool to aid researchers. Systems that detect cetacean/no cetacean present are currently feasible but the reliable identification of individual species is less advanced.

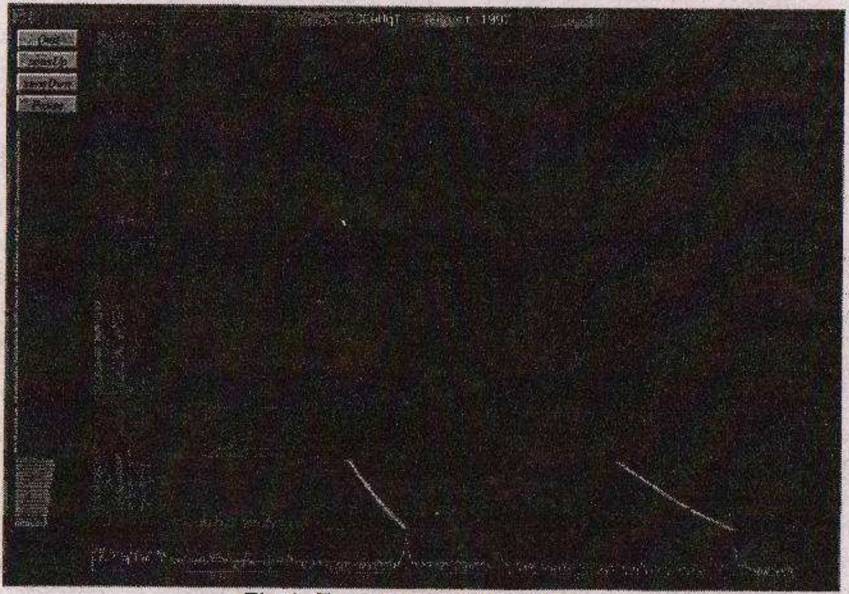

Fig 1. Z-scan spectrum display

4. HYDROPHONES

This is one area of technology where a breakthrough could make a significant difference to the cost/performance of acoustic systems for cetacean research. Regrettably there is no mass market driving this technology so costs have remained high and performance geared to the demands of more financially-endowed customers eg the military. However, for those on a severely limited budget it is possible to construct your own, Goodson [7], and some companies are prepared to supply lower quality units for use in research. However, within the UK, a good quality ball hydrophone still costs from £300 up to £1300, depending on size and quality, and these are essential for any detailed acoustic work. Cylindrical hydrophones suitable for behavioural work can be purchased for as little as £25.

5. ANALOGUE CIRCUITS

The first stages of amplifying the signals from a hydrophone require the use of low-noise amplifiers. Most hydrophones are high-impedance ceramic elements which need amplifiers with a very high input impedance and the best devices for this application are still junction FETs. Table 1 shows the basic specification for a typical device. Such devices, when used with appropriate hydrophones, can achieve system noise levels comparable with or below sea-state zero ambient noise levels. The 4nV voltage noise compares favourably with the 20nV one could expect to see from a typical 20mm ball hydrophone, ITC [10], at 1KHz in sea-state 0 conditions, Urick [11].

I/p noise voltage	4nV/√Hz above 10KHz
Noise figure	1dB
Current consumption	3.5mA

Table 1. Data for Junction FET

Later stages of amplification and filtering invariably use operational amplifiers. The design of these versatile building blocks has improved dramatically in recent years. Devices such as the LM6142 or LM6162 (table 2), NS [12], can now operate over the whole frequency range of interest to cetacean research and with supply currents that make them suitable for battery-powered equipment. Other parameters such as slew-rate and noise performance have also improved during this period and the requirements of the hifi market have resulted in operational amplifiers with very high dynamic ranges eg OPA2604, BB [13]. Performance of analogue systems for cetacean research are now no longer limited by available and affordable technology, only by the imagination. For comparison, the same data for the 741 operational amplifier, TI [14], which was the workhorse of the electronics industry for a number of years are also listed.

Device	LM6142	LM6162	741
Gain-bandwidth product	17MHz	100MHz	1.5MHz
Full power bandwidth	200KHz	1MHz	10KHz
Power supply current	0.65mA	5mA	3mA
noise	18nV/√Hz above 10Hz	10nV/√Hz above 1KHz	Not quoted
Slew rate	25v/μSec	200V/μSec	0.5V/μSec

Table 2. Data for operational amplifiers

6. ANALOGUE TO DIGITAL CONVERTORS

The demands of the digital hifi market, eg CD, DAT and mini-disk, have resulted in the availability of cheap very high performance analogue to digital convertors covering the frequency range 10Hz to 22KHz and with 18 and 20 bit outputs. This covers the requirements of cetacean researchers working with the baleen whales and looking at the tonal sounds from the odontocetes. The next generation of hi-fi systems is now producing A/D convertors with frequency ranges to 48 and 96KHz. In addition, the instrumentation market is producing A/D convertors capable of conversion at up to 1Mword/sec rates and using 12bit accuracy. These are ideal for capturing the full range of sounds made by cetaceans. For both types of A/D, battery-powered systems are feasible as current consumptions have dropped considerably in recent years as production geometries have shrunk. A comparison of typical current and obsolete convertors is shown in table 3.

Device	20 bit hi-fi	12 bit fast	Old 12 bit
Power	370mW	240mW	1000mW
conversion rate	48KHz	800KHz	22KHz
Dynamic range	108dB	69dB	68dB
Accuracy	+/-1dB	+/- 2 LSB	+/-2 LSB
Size	10 x 7.5 mm	18 x 7.5 mm	28 x 28 mm

Table 3. Comparison of A/D convertors

7. COMPUTER SYSTEMS

The drive to improve personal computers has yielded a number of benefits for research systems. Memory sizes have increased steadily over the last 20 years as also has the amount of processing power available. The average lap-top today has the processing power of a typical mainframe of ten years ago. The typical lap-top now has 32Mbytes of memory with several Gbytes of hard-disk storage and a potential throughput of around 20MOPs. Regrettably the architecture of the average PC is not optimised for the real-time processing of signals but nevertheless a current Pentium-based PC can perform a single channel rolling Z-scan spectrum analysis task with a bandwidth of 10KHz without too much stress.

One useful source of computing power is the burgeoning palm-top market where machines such as the Psion 3 or 5 can be used for data collection tasks in the field.

The top-end of the PC market yields machines that can be used to process many channels of data and to assemble complex databases. Machines in this category include the top-end of the Power-PC range from Apple and other manufacturers. The performance of Pentium-based PC's can be improved by moving away from the WINDOWS operating system to an operating system such as LINUX. Performance when calculating 1024 point FFTs can exceed 60 MFLOPS.

8. DIGITAL SIGNAL PROCESSORS

Specialised processors optimised to process signals in real time made an appearance some fifteen years ago and have been further developed into very high performance units capable of performing 80 MOPS ie 80 million operations per second, and of operating in arrays to perform at 2 GOPS. This allows very complex processing of signals in real time. By using such high performance processors either as co-processors on standard PC's or as stand-alone processors the system performance can be significantly improved.

This type of processor is now routinely used to perform multi-channel FFT or correlation operations. In cetacean research they could be used to analyse multiple acoustic channels or to implement tracking or recognition algorithms in real-time.

However, the programming of DSP's is not a trivial exercise and except for some of the simplest tasks is best left to the specialists in the field. Some system manufacturers now offer symbolic design languages for DSP systems and there is hope that as these become more mature it will be possible for non-specialists to more effectively utilise complex DSP systems.

9. TYPICAL RESEARCH SYSTEMS

Let us now consider the design of some possible systems that would be useful to cetacean researchers. Firstly consider the problem of collecting acoustic data in the field. A useful unit to achieve this would contain the following functions:-

- Hydrophone and low noise preamplifier
- Gain control to allow for varying ambient noise and signal levels
- Selectable low-pass and high-pass filters to optimise signal-noise ratio
- Click detector
- Audio mixer
- Drivers for tape recorder
- Drivers for headphones
- Sound level metering
- Calibration tone generator

Such a unit should be battery-powered with a battery life of at least several days, be easily portable, preferably pocket-sized in order not to get in the way when using small boats, and should be water-proof in case it is dropped. A block diagram of such a unit is shown in fig 2. A microphone input allows comments to be added to the tape. The CAL oscillator allows a tone of known level to recorded on the tape to facilitate the measurement of absolute acoustic levels during tape replay.

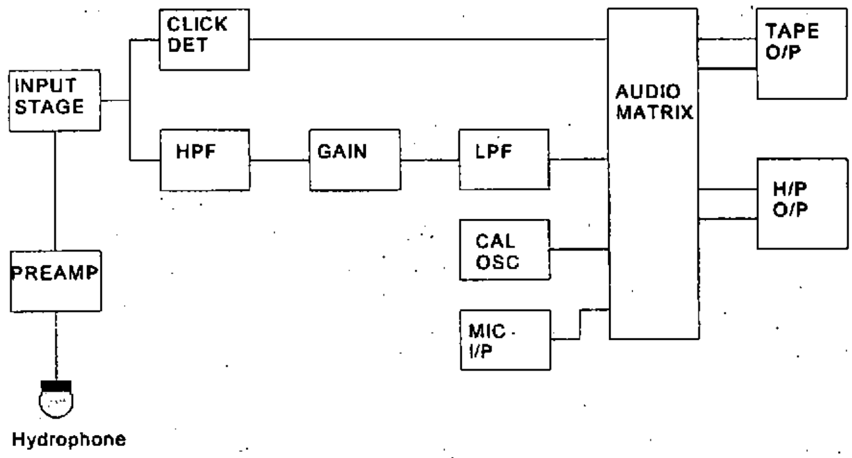

Fig 2. Field acoustic monitoring and data collection unit.

Using readily available components such a unit can be built in a box 4.5x7x11cms, powered by a single PP3 or two AA batteries. It is possible to fit the electronics into a smaller box, but the ultimate limit is determined by the size of the controls and the above size is about the limit for normal-sized fingers! Units similar to this are now in use by a number of research groups within the UK and Australia. Typical component costs for a one-off unit are around £50, excluding the hydrophone and cables.

Consider now a more advanced system for field use. This would allow the operator to display continuous rolling spectra over the normal audio range and to display captured waveforms. By using the unit described above as the analogue conditioning unit we can use a standard lap-top PC with off-the-shelf plug-in hardware to perform the data conversion. A high-speed Pentium-based unit is capable of doing all the computations necessary to display real-time spectra and to capture and display waveforms. The programmable nature of a PC means that it is possible to run programs designed to automatically recognise the presence of cetaceans. The captured data can be stored onto hard disk when later analysis is required.

For field systems designed to track cetaceans a number of possibilities exist. For surveys, a towed array gives the best volume coverage and examples already exist of groups using such system, although they are generally assisted by the military, Spikes [17], Pavan [8], [9]. However, the technology now exists to manufacture a civilian system. The number of hydrophones used will depend on funds available as this parameter is the primary determining factor of costs. Reasonable performance should be obtained with arrays of between 8 and 32 hydrophones. The main problem is choosing the element spacing in order to cover the required frequency range. Various compromises can be chosen depending on the precise need. All such systems with a significant number of elements will need to digitise the signals in the array and then multiplex the signals up fibre-optic or coax tow cables. If we take the example of a sixteen element array with a bandwidth of 200KHz and 12 bit sampling at 500KHz, this results in a data rate of:-

$$12 \times 500{,}000 \times 16 = 96\text{Mbit/s}$$

This is manageable using more expensive cable drivers but the data rate can be reduced either by partially processing the signals in the array or by limiting the bandwidth. If we limit ourselves to listening to tonals only in the band up to 20KHz, sampled at 50KHz, the data rate becomes:-

$$12 \times 50{,}000 \times 16 = 9.6\text{Mb/s}$$

This is manageable using cheap and readily available components. By using a click-detector to compress the bandwidth of the echolocation clicks this can be passed up the data-link and time-difference of arrival used to assess the bearing of the animal. An alternative method of compressing the bandwidth required on the data-link is to utilise burst mode. In this mode the data is recorded at the high sample rate to capture the full bandwidth but for a limited period. The data is then transmitted up the cable at a slower data rate than would otherwise be required. By using this techniques the costs of cables and line drivers can be reduced but at the expense of loosing continuity of the data. A typical 16 element system may transmit only 10% of the data. However, for some applications this may be a small price to pay in order to get the highest quality data. The main limitation to burst mode operation is the size of the memory that can be packaged into the array.

For static systems a number of distributed hydrophones, either in a bottom-deployed line array or as a number of independently deployed single hydrophones, can be used. Again burst-mode can be used to minimise costs but the memory size limitation of the towed array is effectively removed.

10. CONCLUSION

This paper has demonstrated that new technologies driven by the consumer and business markets are opening many new opportunities to cetacean researchers to capture and process data in new and exciting ways that will allow us to expand our knowledge of these animals in ways that have not been previously possible.

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