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A LOW-COST, HIGH-PERFORMANCE SOUND CAPTURE AND ARCHIVING SYSTEM FOR THE SUBTIDAL ZONE

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1. INTRODUCTION

Installation and use of hydrophone arrays in the subtidal zone has grown as interest in the acoustics of this area has intensified. This interest ranges from acoustic characterization [1] and physical modeling [2] to bioacoustics of endemic species: snapping shrimp [3], midshipmen fish [4,5], harbor seals [6], and many others. Making sound recordings in the subtidal zone presents several unique engineering difficulties caused by the harsh effects of the environment. Wave action, currents, animals and plants, and even electromagnetic fields can be sources of problems.

Recently, interest has increased in long-term acoustic monitoring of animal species [7-10], especially for tracking and studying behavior [11] and responses to noise [12]. Long-term monitoring and tracking requires the use of a fixed hydrophone array, coupled with a high-capacity sound collection system. The engineering goals of such a system include installing a hydrophone array that stays fixed for months or years, coupled with a sound collection system with many-channel sound acquisition, high-bandwidth data transfer, and high-volume data storage.

A subtidal-zone hydrophone array and a high-capacity sound collection system were installed earlier this year at Hopkins Marine Station (HMS), Monterey, California. The system is used to monitor and track harbor seals (*Phoca vitulina*). The array has a 190 m active section containing eight hydrophones, with a lead-in cable of 100 m (Fig. 1).

This paper presents the problems that were encountered using this array and data-collection system, and discusses the practical solutions that were devised. Problems with the "wet end" — the array — are discussed first, followed by solutions. Then problems for the "dry end" — the sound-collection system — are covered, followed by solutions.

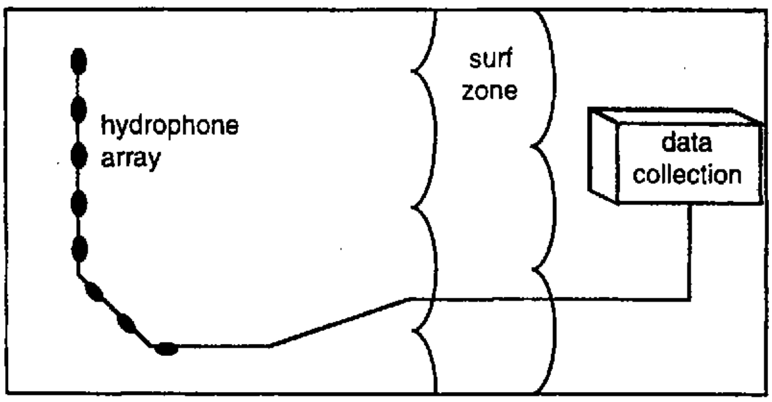

Fig. 1. Schematic of the "wet end" (the hydrophone array) and the "dry end" (the data-collection and archival system)

2. THE WET END: A SUBTIDAL-ZONE HYDROPHONE ARRAY

For long-term acoustic monitoring in the subtidal zone, the foremost engineering goal is to make the hydrophone array survive in the harsh environment. Quite a few forces work toward damaging or destroying a hydrophone array. The strongest, most constant force is of course wave action and its corresponding water motion on the sea floor, called surge. At almost all near-shore sites, surge is present at all times; during storms, it can become quite large. The hydrophone array typically comes out of the water through the surf zone at some point, and it is here that the force of the waves is strongest. Even in deeper areas not exposed to breaking waves, the water flow from surge can be quite noisy, potentially causing flow noise over the hydrophones or cable, and causing cable strumming as well.

The hydrophone array site at HMS is protected by near-shore rock islands and reefs, but still two-meter-high waves are not uncommon, with bigger ones during large storms. With waves of only 1.5 m, the surge moves surface objects back and forth more than 10 m; objects on the bottom (where hydrophone arrays are usually anchored) are not moved as much, but they are still subject to strong, continual forces.

Wave action also has significant side effect: in soft-bottom areas of sand or mud, the waves re-deposit the substrate, moving it from one location to another. A fixed hydrophone array in such a location is in danger either of being buried, or of being raised up off the sea floor and exposed to powerful and noisy water movement. At HMS, variations in sand depth of 70 cm through the year are normal.

Marine life forms, both animals and plants, present another potential source of problems. Animals are dangerous because they may bite the hydrophones or cable. At HMS, the most threatening animal is probably the sea otter (*Enhydra lutris*) because of its long teeth and its behavior of feeding on bottom-dwelling invertebrates, which bear all too much resemblance to hydrophones. Harbor seals present a secondary danger: their teeth are not as sharp, but they are larger than otters [13] and presumably have stronger jaws.

Plants can be a problem either by growing over and shielding the hydrophones, or by growing stems upward from the hydrophones. At HMS, the most problematic plant is a kind of surficial algae that is quite difficult to remove; left unchecked, this plant quickly covers all hydrophones and introduces variable unknown spectral distortion into all collected sounds. The other main threat comprises various kinds of kelp. By climbing to the array and growing toward the surface, a kelp stalk enters a region of great water motion where it can induce extensive flow noise.

Lastly, electrical noise can be an unexpected problem. AM radio frequencies can penetrate water to a depth of 5 m, so any part of a hydrophone array less than this depth must be well shielded. Also, the hydrophones are typically 100 m or more from the shore-based recording location, so they must have a high enough output level to drive a long cable. The cable itself is capacitatively coupled to sea water, so electrical isolation is needed where the cable connects to the recording system.

3. SOLUTIONS

The principal problem of attaching the hydrophone array securely to the sea floor must obviously be solved differently in soft-bottom and hard-bottom regions. In rocky areas, it can simply be bolted in place. Bolt holes are made using a pneumatically powered drill, then filled with putty-type marine epoxy. An eyebolt (10 mm diameter, 5 cm length) is inserted into the epoxy, and the epoxy is allowed to harden. It helps to keep the plane of the eyebolt aligned with the direction the cable will run, as the extra attachment distance can help reduce cable strum. After the epoxy hardens, the hydrophone cable is attached to the eye with cable ties. The distance between adjacent bolts determines whether cable strum will be a problem. At the HMS site, which is a relatively protected area, bolts were placed every 5 m, but a spacing of 2 m is suggested for areas that are more exposed to more direct wave action.

Attaching the array in soft-bottom areas requires different methods. The goal is to keep the cable close to the bottom or slightly buried, while keeping the hydrophones themselves slightly elevated. A variety of cable-weighting schemes were investigates, but were found wanting because they could not cope easily with changes in sand level. The best solution found is a combination of sand anchors and weights. Sand anchors (Fig. 2) are metal rods with an eye at the top and a helical plate attached near the bottom. They provide fixed attachment points for the hydrophones, or (at HMS) every 10 m along the cable when hydrophones are not spaced that closely. They are easily screwed into the substrate—each takes about two minutes to install—and the cable is attached to the eye. When the sand level changes, the cable is detached, the anchor is screwed in or out to change its level, and the cable is reattached. These sand anchors are surprisingly strong: when screwed only about 25 cm into sand, they cannot be pulled out by hand, and when screwed all the way in, they can be used to anchor boats. In between the sand anchors, weights are attached to the cable to keep it on or slightly below the surface. At HMS, these weights are 1.5 m steel rods (rebar) strapped to the cable every 3 m. The weights keep the cable close enough to the bottom that flow noise has not been a problem.

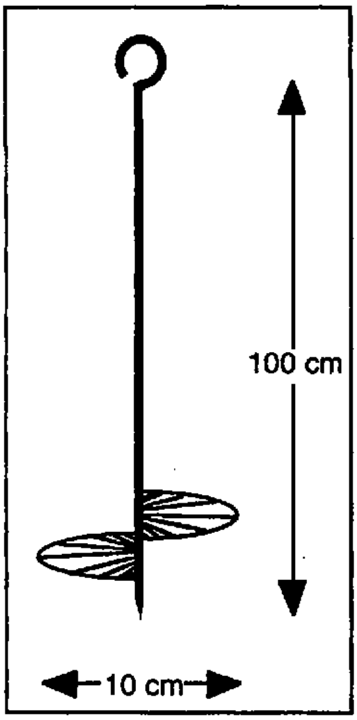

Fig. 2. A sand anchor: a metal rod with an eye at one end and a corkscrew plate near the other end.

The final attachment problem is the surf zone, with its constant waves and changing tide level. The solution here is to provide a fixed structural member to attach the cable to. At HMS, this consists of steel pipe bolted to the rock, with the hydrophone cable strapped to it roughly every 10 cm. If the pipe were large enough, it could hold the hydrophone cable inside it; at HMS, this was not possible because of the logistics of deployment.

Protecting the array against animal bites involves cable protection and hydrophone protection. It is necessary to shield the cable with a bite-proof layer, usually metal or kevlar. This layer must be on the outside of the waterproof layer. This adds substantially to the cable's thickness and stiffness (and cost), but it cannot be avoided, as one bite is enough to let sea water invade and make the hydrophone array worthless.

For protecting a hydrophone, it is necessary to have a shield that keeps animal mouths out but lets sound in. One good method is to build a cage, a set of radially symmetric bars that extend around each hydrophone with a circumferential reinforcing member around the mid-section (Fig. 3). The cage is made of steel rod material; the rod itself must be smooth on the surface to minimize flow noise, and must be strong enough to withstand the jaw strength of fishes (including sharks, if present) and mammals, and the spacing of the bars must be sufficiently close to prevent animals from biting between them. The cage is fabricated in two halves so that it can be clamped around the hydrophone at the time of array installation. At HMS, each cage is made of eight rods of 6.5 mm thickness; this has proven adequate.

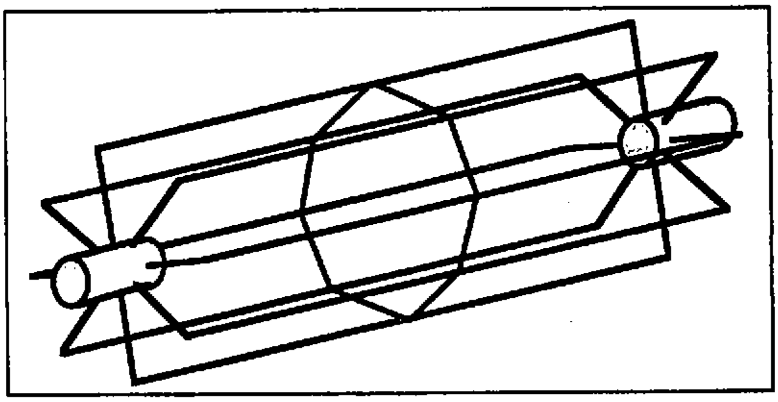

Fig. 3. A hydrophone cage, consisting of two hollow metal cylinders connected by eight bent metal rods. The hydrophone cable will run through the centers of the cylinders, while the hydrophone itself sits in the center of the cage formed by the rods.

Preventing algae from growing on the hydrophones has been a challenge. Mainly this is done by periodic maintenance, scrubbing off the algae with mild abrasives. This is only partially effective, and some algae colonies have appeared that are extremely difficult to remove. The best approach at HMS has been prevention: by making weekly maintenance dives, it has been possible to remove incipient algae before it has become permanently attached. Recently, the author has heard that applying a film of "baby lotion" to the hydrophone will prevent algae growth. This has been tried but the results are not yet available.

Finally to prevent electrical noise from interfering with the sound signals of interest, several steps are needed. Of course, each signal must be carried on its own shielded twisted pair of wires. The separate shielding is necessary because crosstalk is a problem with long, closely-packed wires. The shielding also prevents radio noise from interfering with the signals. (Hopefully, hydrophone arrays will soon be made with optical fiber, removing such electrical problems.) Also, for each hydrophone to drive a several-hundred-meter cable without significant electrical noise, the hydrophones must have a pre-amplifier to boost signal level. At HMS, a hydrophone+preamp sensitivity of -160 dB re 1V/Pa proved adequate.

4. THE DRY END: A SOUND COLLECTION AND ARCHIVING SYSTEM

The problems for building a data collection system for long-term acoustic monitoring arise chiefly from the large data volume needed. Ideally, monitoring is performed continuously, which implies that a large volume of data is collected each day. For instance, in recording the harbor seals at

HMS, a bandwidth of 6 kHz was required. Storing such sounds in analog format is impractical with any of the tape recorders currently available, so a digital format was needed. For just one hydrophone, this bandwidth requires storing 2.3 gigabytes (GB) (that is, 2.3 x 10^9 bytes) of sound data per day—a substantial amount, but not impossible with current technology.

Another consequence of the large data volume is that it becomes desirable to make the collected sound as accessible as possible. The fewer successive steps of playback, re-recording, or data transfer, the better. The large data volume necessitates some type of automated sound processing, for it is impractical for humans to scan this much data. Therefore, making the collected sounds as computer-accessible as possible is required. Ideally, it is stored it as sound files that can be accessed at random points to extract sounds of interest.

A final minor engineering goal is small physical size. The system will be installed at some field site, and the smaller the data-collection system is, the easier it is to place and to protect from the elements. For some locations, low power consumption is also a goal. Fortunately at HMS this was not the case, as access to the electrical power grid was possible.

5. SOLUTIONS

Fortunately, current technology is advanced enough to provide solutions to the problems outlined above. None of the components in the system here are especially new, but there is innovation in the way they are integrated into a functional system.

The solution is to use a PC-clone computer as a sound acquisition, data transfer, and tape recording unit (Fig. 4). The first step in collecting sound is acquisition—converting the analog sound signals from the hydrophone cable into digital samples in the computer's memory.

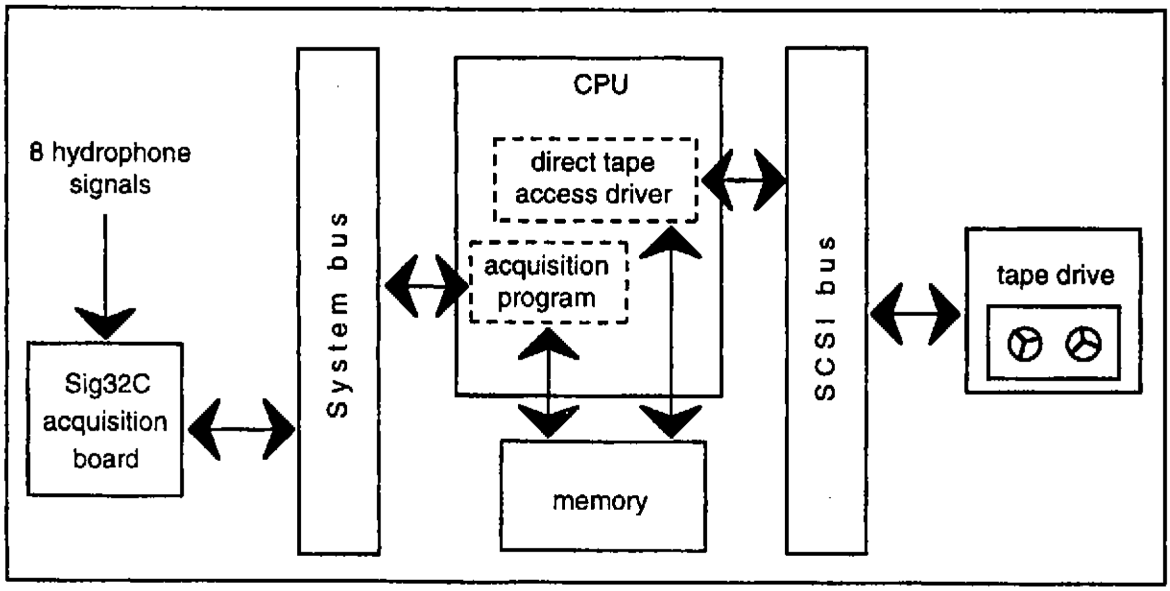

Fig. 4. Conceptual diagram of the main pieces of the data collection and archiving system. All components shown are physically housed inside the computer case.

Multi-channel data acquisition boards that sample sound at 14- or 16-bit resolution, and at rates of 4 kHz to 45 kHz, are available. Most do not have anti-alias filtering, which of course is necessary for sound sampling, but a few do. Some of these boards also offer the benefit of simultaneous sampling, which is greatly desirable for applications where time-of-arrival sound localization is performed. Some also offer external signal conditioning; if this is not used, then some kind of signal isolation devices (e.g. transformers) are needed.

At HMS, the board used was the SignaLogic Sig32C-8 board, which offers 8-channel simultaneous sampling at up to 48 kHz per channel. It also includes anti-alias filtering and adjustable input gain, removing two more potential headaches. The board has extra-cost software with functions for collecting sampled data and writing it to a sound file.

Once the sound data is acquired, it must be stored. A variety of storage media were examined: magnetic hard disks, magneto-optical disks, removable magnetic disks, magnetic tapes, and writeable CD-ROMS. The most cost-effective solution is data-grade 4 mm (DAT) or 8 mm (video) tapes. These media hold 4 GB and 7 GB, respectively, of uncompressed data, and larger amounts of compressed data, and cost about US$13 or US$45. (Costs for audio-grade tape are much lower, but these tapes are not reliable as digital archive media.)

With a tape format chosen, the final remaining obstacle is getting the data onto the tape. This is more difficult than one might think. Tape drives are normally sold as backup devices, and use proprietary software to store and retrieve data. The makes interfacing directly to a data-acquisition program impossible, and the only available method to get sound data onto the tape is to store the sound samples first as disk files, then transfer the files en masse to tape. Unfortunately, this transfer can take several hours, and recording is interrupted while it happens. Also, once the files are on tape, accessing parts of them is impossible, since the backup software allows only extraction of entire files.

Fortunately a better solution exists. A software system (Seagate Direct Tape Access) is available that makes a tape drive appear to the operating system as if it were a disk drive. One can write files directly from the sound acquisition program to the tape, view a directory listing of sound files, or open and read a sound file starting at an arbitrary point. This happen just as if the files were stored on disk, with the only difference being the slow seek time for tape access. But when writing files sequentially to tape, the data rate can be as fast as the tape drive can handle—typically several megabytes per second.

The data archiving system works as follows: electrical signals are received from the hydrophone array and converted by the acquisition board to sound samples in the computer's memory. The acquisition program then writes the samples to a sound file. The tape drive software receives the "write file" command and directs the file to the tape drive, where it is archived as a sound file. Once in a while, a person must remove the tape with the archived files and put in a blank tape. During later processing, the archived sound files are read directly from the tape as if they were stored as disk files.

At HMS, this system has been operating since April of 1997. For monitoring work, two hydrophones are recorded continuously; this requires changing a tape once a day. Except for power failures, the system has performed without errors.

6. CONCLUSION

Problems with using an acoustic monitoring system in the subtidal zone have been described and solutions outlined. In the wet end, the problems of anchoring in rock and sand were solved with bolts, sand anchors, and cable weights. The threats of animal and plant life were met with mechanical shielding, hydrophone cages, and periodic maintenance. Electrical problems were solved with pre-amplification and electrical shielding. At the dry end—the data-collection system—the problems caused by high data volume were met by using a high-bandwidth, multi-channel data acquisition system. Data is stored on 4 GB data-grade 4 mm tapes, allowing continuous data collection with little intervention needed. Special software allows data to be stored directly on tape as sound files; later, these are directly accessible to analysis software.

It is hoped that the practical advice presented here for using hydrophone arrays in the subtidal zone will make it easier for others to do acoustic work in this area. It is also hoped that the data collection system described here can be employed by other bioacousticians who wish to conduct long-term monitoring projects.

7. ACKNOWLEDGEMENTS

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