COMPUTER TECHNOLOGY

A computerized method of analyzing and playing back vibratory animal signals

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In water striders or other animals that communicate with vibratory or oscillatory signals, surface wave signals can be recorded, analyzed in digital form by computer, then played back accurately by oscillating a magnet, glued to the animal, with electromagnetic fluctuations from a coil driven by the computer. Signals can be played with great flexibility through a normally behaving animal, in laboratory or field.

The need to collect, analyze, and play back specific signals quickly and with flexibility is a major problem in research on animal communication. Researchers have typically used magnetic tape recorders for storage of signals, and indirect methods of playback such as loudspeakers, vibrators, or similar electromechanical devices. These playback systems usually require extensive preparation in the laboratory to edit and analyze signals and to prepare playback recordings or tape loops before an experiment can be run. They also often force the experimenter to use relatively inflexible and limited playback sequences. Such techniques make it impossible for real-time recording, analysis, and playback to be conducted in either laboratory or field. The system described herein was designed to enable us to conduct real-time playback experiments in the laboratory and field in such a way that we could reproduce signals directly through the animal without disturbing its normal behavior. At the same time, we did not wish to interrupt the flow of behavioral interactions among the animals involved.

The experiments dealt with surface wave communication in aquatic insects, water striders (Hemiptera, Gerridae). These insects produce signals by oscillating their legs up and down on the surface, producing patterned sequences of waves that have communicative significance in the general contexts of mating and spacing behavior (Wilcox, 1972, 1979). Surface wave signals were played back through individual water striders by gluing a miniature samarium cobalt magnet on the foreleg of a strider, which was allowed to swim freely inside a large-diameter horizontal coil of magnet

wire located at or near the water's surface (Figures 1 and 2). The coil was connected to a computer-

Figure 1. Water strider producing computer-generated surface wave signal by oscillations of a magnet glued to the top of the right foreleg.

Figure 2. Foreleg of a water strider with a thin magnet glued on top of the femur. Magnet N-S poles are oriented horizontally in line with the longitudinal axis of the femur. Orientation of the magnet with N-S poles laterally would result in the leg's rocking from side to side as well as up and down, since as the polarity of the electromagnetic field changes, the magnet rocks around the central axis midway and at a right angle to the line between poles.

We will be glad to respond to inquiries about aspects of the system and to provide programs. We thank Kris Kafka, Tom Apalanek, and David Gelbman for computer programming and equipment building, Tom Apalanek (in addition to Wayne Kashinsky) for suggesting the coil and magnet idea, and Sue Darlington for the drawings. This research was supported by NSF Grant BNS77-24708 to Robert Stimson Wilcox, who is with the Department of Biological Sciences. Wayne Kashinsky is with the Department of Psychology.

controlled A/D and D/A converter system that generated a particular surface wave signal by causing magnetic fluctuations similar to those in loudspeakers, resulting in vertical oscillations of the magnet and, consequently, to the foreleg.

THE ANALYSIS AND PLAYBACK SYSTEM

The following system is drawn schematically in Figure 3. Signals are recorded from a surface wave sensor (Wilcox, Lucas, Lazay, & Gelbman, Note 1) through a Vetter FM recording adapter onto a Uher 4400 IC audiotape recorder. The FM conversion was necessary since the frequencies of some signals of *Gerris remigis* (and of other water striders studied) are lower (down to 3-5 Hz) than the 40-Hz minimum frequency response of the recorder. The signals are then played back through the FM unit, and the output is sampled by an 8-bit Cromemco D+7A A/D converter on an IMSAI 8080 microcomputer. The computer samples a signal at a rate of 8,000/sec and writes signals into adjacent 8K blocks of static memory. The sampling is done using a machine language program called from BASIC, allowing high-speed data collection. Once the signals are in memory, the BASIC program allows each to be edited, scaled, analyzed for waveform and peak-to-peak frequencies, titled, dated, and labeled with other information before being written to disk for permanent reference. Storage is on one of two North Star 5.25-in minifloppy-disk drives, which are also used for programming storage.

Each minifloppy disk can hold 180K bytes of information. Since each signal is 8K, more than 20 1-sec signals can be resident on a single diskette. The Cromemco D+7A interface card provides seven analog input and seven analog output conversion channels with 8-bit resolution. We found that 8 bits was enough for our purposes and that we could use the same interface for input and for output to a storage scope, strip-chart recorder, and the coil without appreciable cross talk. All playbacks are handled by a BASIC program that can load any signal resident on a disk into memory.

Figure 3. Schematic of surface wave signal recording, analysis, and playback system.

As each signal is loaded, the title information can be displayed for reference. The signal can be graphed on the Tektronix terminal and edited prior to playback.

In playback mode, the program allows up to N signals to be read from disk into memory, then played into the amplifier. Since our system has 24K memory available for signal storage, three signals ($N = 3$) can be resident in memory at once. By specifying parameters upon input, each signal can be started and ended (or reversed), accurate to hundredths of a second, anywhere within the 1-sec signal. Since N signals are resident in RAM at a time, sequences on command or programmed sequences of playback can be set up. The playback routine can switch between RAM-resident signals within milliseconds or load and play a disk-resident signal in .25-2 sec average access time on a disk. In addition, if $N - R$ signals are used, the program can play back signals and then automatically record up to R surface wave signal responses from test animals. Actual playbacks of signals are done by a BASIC call to a machine language routine. Thus it is possible to record, analyze, and play back a signal, all within minutes. Another program mode allows direct playback while it is being produced by a strider, by inputting the signal to the A/D converter, then immediately outputting through the D/A converter on a sample-by-sample basis.

The samarium cobalt magnet (available from Permag Central Corporation, Elk Grove Village, Illinois) was glued distally on top of the femur of a strider's foreleg with contact cement so that the magnetic poles were oriented horizontally and in line with the longitudinal body axis (Figure 2). To affix the magnet, the glue should be put on first with the tip of a pin, then the magnet should be positioned with non-ferrous forceps.

The coil was made by winding Number 26 magnet wire around the circumference of a circular plastic form 3 cm high and 28 cm in diameter, leaving the two wire ends free. It was then waterproofed with fiberglass cloth. Since the strength of an electromagnetic field inside such a coil varies greatly with increase or decrease in diameter, the amount of wire used to create a particular electromagnetic field will vary according to the relationship among magnet size and desired amplitude of oscillation, coil diameter, and power output from the amplifier. For practicality of amplifier design, it would be sensible to keep the resistance of a coil below 100 ohms. The size and specific orientation of the magnet and the coil will be dictated by the particular animal species being studied. The coil requires at least 60 W for proper operation. Since the frequency of water strider playback signals can go down to near dc, a direct-coupled Darlington amplifier was used. Signals were input to the amplifier by an 8-bit D/A channel on the microcomputer or by the output of the FM converter for direct playback.

The strength of the electromagnetic field inside a coil decreases from the edge toward the center, resulting in decreasing playback amplitudes toward the center. If exact amplitudes are critical, relatively uniform amplitudes throughout the inside of the coil can be obtained by constructing an identical coil to the first and sandwiching the animal between the two, thus making a Helmholtz coil system.

The electromagnetic fluctuations produced during playback tend to "drown out" recordings of playback signals, making it difficult to record playbacks for calibration. This problem can be circumvented by placing the sensor far enough away from the magnet-bearing animal so that surface waves arrive at the sensor after the electromagnetic fluctuations cease.

The IMSAI 8080 is designed around an S100 bus, making it software/hardware compatible with over 30

computers currently available. A complete micro-computer system of this sort can be built for under \$3,500.

REFERENCE NOTE

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