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A MICROCOMPUTER-BASED SONAR DATA ACQUISITION SYSTEM FOR FISH AND PLANKTON RESEARCH

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ABSTRACT

This paper describes a microcomputer based data acquisition system developed for collecting and analyzing sonar data to study the concentration and distribution of fish and zooplankton populations in lakes.

The system consists of an IBM PS/2 model 30 microcomputer powered by a lead acid battery through a DC/AC inverter, a Data Translation DT-2801A Data Acquisition board, a modified Lowrance echo-sounder, high frequency narrow beam sonar transducers, an IBM WORM Optical Disk Drive, and custom software for data acquisition, display, and analysis.

The system software controls the A/D conversions using the DT-2801A DMA transfer capability. A color rendering of the digitized echo signal intensity data is displayed in real-time. The digitized data is saved to disk for post process analyses.

This system is unique in that it integrates off the shelf products to provide a low cost (total cost comparable to the cost of a research microscope) system that allows the researcher to easily see the abundance and spatial distribution of both fish and plankton in real-time. It is particularly valuable for sonar studies in lakes because it can be quickly assembled and used in a small boat.

Echo intensity data collected with the system is presented with additional temperature and oxygen measurements.

INTRODUCTION

Accurate quantitative information about the abundance and spatial distribution of fish and their zooplankton food supply is needed to improve our ability to manage lake ecosystems. This information can be used to assess the impact of pollution from waste water, acid rain, and runoff on lake ecosystems, to evaluate the effectiveness of restorative measures, and to develop new and innovative biological manipulations for improving water quality.

The high degree of spatial and temporal variability in the distribution of zooplankton make gathering accurate quantitative data on their size and abundance extremely difficult with traditional sampling techniques (collecting organisms with a pump and filter and performing manual counting). High concentrations of zooplankton occur in relatively narrow depth bands that vary seasonally due to changes in the thermal stratification of the lake. It is also known that zooplankton rise to the surface waters at night, and return to moderate depths at dawn [1].

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With traditional sampling methods, it is easy to miss depth layers where the zooplankton are concentrated. The zooplankton also can move away from sampling apparatus. It is therefore difficult to get reliable estimates of zooplankton abundance even if a large number of samples are taken.

Seasonal variability in the abundance of zooplankton also needs to be accounted for when studying the impact of pollution on the lake ecosystem and when evaluating the effectiveness of lake restoration measures. The zooplankton population can diminish dramatically when the juvenile fish emerge in the spring [2].

Currently estimates of zooplankton abundance in lakes are generally made by taking samples and counting the number of organisms in a known volume of water. Information on the size distribution of the zooplankton is obtained by using filters of various mesh sizes to sort organisms according to diameter [3]. These techniques are slow and yield a limited amount of information due to the non-uniform spatial distribution of zooplankton.

An alternative method for observing zooplankton is to use sonar. Acoustic methods have been used for decades to study fish [4-10]. More recently, acoustic technology has been applied to the study of zooplankton [11,12]. Although the acoustic echo from an individual zooplankton organism is too weak to be detected, a number of studies have shown that backscattering of high frequency sound from depths is strongly correlated with concentrations of zooplankton.

However, most existing sonar systems use relatively expensive custom hardware and are limited in their data storage and display capabilities. Recent advances in microcomputer processing speeds, color graphics, and data storage capacities make it feasible to develop a low cost system to collect, analyze, and display sonar echo intensity data in real-time using off-the-shelf hardware. The data is also saved for use in analyses that cannot be performed in real-time or that were not available at the time of data collection, and in the development of analysis methodologies.

This paper will describe the development of a microcomputer based sonar data collection and analysis system used for studying zooplankton and fish populations in lakes.

HARDWARE

The system hardware consists of an IBM PS/2 model 30 microcomputer powered by a lead acid battery through a DC/AC inverter, a Data Translation DT-2801A Data Acquisition board, a modified Lowrance X-16 echo-sounder, high frequency (192 kHz) narrow beam sonar transducers, and an IBM WORM Optical Disk Drive.

The IBM PS/2 model 30 was selected for its small size, light weight, low cost, and compatibility with suitable data acquisition boards. The model 30 chosen has a 20 MB hard disk and was equipped with a VGA graphics adapter. VGA graphics permits display of the echo intensity data in 16 colors at a resolution of 640 x 480 pixels or in 256 colors at a resolution of 320 x 200 pixels. The IBM 12 inch PS/2 color monitor is used.

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The Lowrance echo-sounder was modified to provide an analog output of the signal echo intensity used for the strip chart recorder and a TTL level output of the signal used to trigger the transmitter to emit a ping. The analog output signal is input to one of the Analog to Digital (A/D) channels of the Data Translation Board. The start of ping trigger signal is input to the external trigger line of the Data Translation board to start the A/D sampling for each ping.

Sonar systems require time varied gain amplification to compensate for signal intensity losses due to spherical spreading of the acoustic wave and absorption losses in the water. The Lowrance echo-sounder implements time varied gain by providing 8 possible selections of "Surface Clarity Control". Measurements of signal strength from fish bobbers at various depths indicated that the time varied gain offered by the Lowrance is capable of compensating for the loss in signal intensity with depth in the range of depths typically encountered in lake biological research.

The Data Translation DT-2801A is a high speed data acquisition board with 12 bit Analog to Digital (A/D) resolution. The echo signal from each ping is digitized by the A/D converter at up to a 28 kHz sampling rate. The external trigger line on the data acquisition board is used to synchronize data collection with the start of each ping.

The DT-2801A can be programmed to make use of one of the IBM PC Direct Memory Access (DMA) channels when performing A/D data conversions. The computer's DMA channels allow data to be transferred directly to or from the computer's system memory without intervention from the host CPU. DMA transfer is commonly used when higher sampling rates are required. In DMA operation, the application software initializes the PC DMA controller by loading registers with the values of the DMA channel number, memory start address for storing the digitized samples, and number of samples to be converted. The data acquisition board pacer clock is configured to the desired sampling rate and the analog channel(s) to be converted are indicated. Once the initialization has been performed, a single instruction to the data acquisition board causes the digitizing of the echo signal to commence when the start of the next ping sets the external trigger line high. The sampling then occurs at the desired rate without the need for software to initiate the conversion of each individual sample. The application can attend to processing and display of the data while the A/D conversions occur in the background.

An IBM Optical Disk Drive is used for data storage. This technology allows data to be written once and then read many times and is capable of storing 200 MB on a \$65 cartridge. Data sampling during a transect typically results in the collection of 0.5 - 2.0 MB of data per minute. The high storage capacity of the optical disk media permit all of the raw digitized data samples from a transect to be saved for later data analysis. In practice, the data is generally saved to the computer hard disk during the transect and then copied to the optical disk at the end of the transect.

SOFTWARE

Software was developed to control the A/D conversions using DMA transfer, display the data in real-time, and save the digitized data based on user specified criteria.

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A double buffered DMA data collection technique is used to permit display of the data in real-time. Two data arrays are allocated for collection of digitized echo intensity data, with each array sized to store the data from a single ping. While the data for a ping is being digitized to buffer 1, the software processes, displays, and stores the data in buffer 2 that was collected from the preceding ping. When buffer 1 has been filled with data from the current ping, the DMA controller is re-programmed to collect to buffer 2 during the next ping.

Assembly language routines were developed to display a color rendering of the digitized echo signal intensity in real-time, with each color corresponding to a different range of signal intensity. The pixels on the color graphics display are colored to show the signal intensity as a function of depth and distance along the transect. The data may be displayed in 320 x 200 resolution with 256 colors or 640 x 480 resolution with 16 colors.

Although the hardware time varied gain results in the same signal intensity of echos from discrete targets such as fish independent of depth, the signal intensity due to backscattering from plankton then increases with depth due to the larger volume entrained by the acoustic cone at greater depths. The software includes the option of normalizing the displayed digitized signal intensity data to a specified depth to correct for the effect of cone spreading. Since the echos from discrete targets are generally much stronger than from plankton, the normalization can be applied only to values below a user specified threshold so that the echos from fish continue to remain constant with depth.

Although data storage requirements are not a major concern when an optical storage system is available, the software has been designed to accommodate systems without optical storage by allowing the user to specify the data sampling rate, depth range, and number of pings per second to be saved. The data display and data storage functions have been programmed to be independent of each other. Thus the user can display data from one range of depths while saving the data from a different range of depths. The user can also continue to display the data while disabling data storage.

The user can output specified portions of a transect to an ASCII file for analysis with other computer programs. The output data can optionally be normalized to a specified depth to compensate for the cone spreading when analyzing plankton echo data.

The software uses pull down menus to allow the operator to easily set collection and display parameters. At any time along a transect, the operator may suspend collection to change the collection or display parameters.

DISPLAY AND INTERPRETATION OF DATA

An acoustic transect made during midday across a small lake in northwestern Minnesota illustrates some of the information that the system can provide about the abundance and spatial distribution of zooplankton and fish (Fig. 1). The highest concentrations of planktonic crustacea in this lake during mid summer are in the metalimnion. The metalimnetic zooplankton assemblage includes only two species. One of them is a copepod (*Diaptomus*) and the other is a large cladoceran, *Daphnia pulicoides*. The assemblage is displayed

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on the computer screen as a complex acoustic scattering layer in depths between 9 and 15 m.

The scattering layer consists of two sublayers along much of its length. The upper one is a rather diffuse band centered near 11 m depth. The lower one is somewhat more sharply delimited and centered near 14 m. Echotraces from large fish are most abundant near the upper sublayer.

A profile of echo strength (corrected for transmission losses) from one of the pings along the transect can be compared with depth profiles of environmental variables in Fig. 2. The acoustic scattering layer occurred in depths where water temperature decreased from 12 to 7 degrees Celsius. The top was located just below an oxygen maximum, and the bottom of the layer was near the lower limit of oxic water. Light levels decreased from about 10 $\mu\text{Einstein m}^{-2} \text{ s}^{-1}$ at the top to about 1 $\mu\text{Einstein m}^{-2} \text{ s}^{-1}$ at the bottom of the scattering layer.

The profile of echo strength also indicates that there was a layer of high acoustic backscattering in depths greater than 20 m. This is probably due to the insect *Chaoborus*, which has planktonic larvae that can inhabit anoxic water and are abundant during daytime near the lake bottom.

The echo profile shown in Fig. 2 indicates that zooplankton concentrations were highest at a depth of 14 m, with a secondary peak between 11 and 13 m at the time of this transect. This, together with the differences of light, temperature, and oxygen in the layers, suggests that the two sublayers may be inhabited by different proportions of Cladocera and Copepoda of different age classes.

CONCLUSION

Our first field studies indicate that lake wide distribution patterns of zooplankton and fish can be discerned quickly and studied efficiently with the microcomputer sonar system. The color display is especially valuable because it provides instant feedback and thus enables us to see which sonar operating characteristics are best suited to local conditions. Further, data from individual acoustic pulses are stored digitally and easily retrieved for numerical analyses and comparisons with environmental variables or they can be displayed as color echograms on the computer screen.

An important advantage of the sonar system is that it provides information instantaneously that is needed in order to select the depths of water to be sampled by conventional methods. For example, a carefully designed sampling program will be required to study the metalimnetic zooplankton assemblage shown in Fig. 1, because it is composed of closely spaced sublayers that would not be discerned by conventional methods without special sampling effort. Transects from other parts of the lake indicate that there is much spatial variation for the depth limits and and echo strengths from this assemblage. It would not be feasible to study such complexity with conventional methods alone. However, both the zooplankton and their interactions with fish can be investigated efficiently by combining acoustic sampling with conventional sampling methods.

Our first objective has been to devise a system for studying lake zooplankton that 1) yields high frequency sonar data in a digital format for computer analyses and display, 2) is readily portable for use in small

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boats, 3) is easy to use, and 4) is low in cost so that acoustic technology can be more widely used in limnological studies. We are now turning our attention to comparing the acoustic data with conventional zooplankton samples, improving our understanding of how sonar data are analyzed, and refining the software. In the near future, we expect to incorporate a Loran C navigation receiver in the system so that we can prepare maps with the computer of the zooplankton and fish in lakes.

ACKNOWLEDGEMENTS

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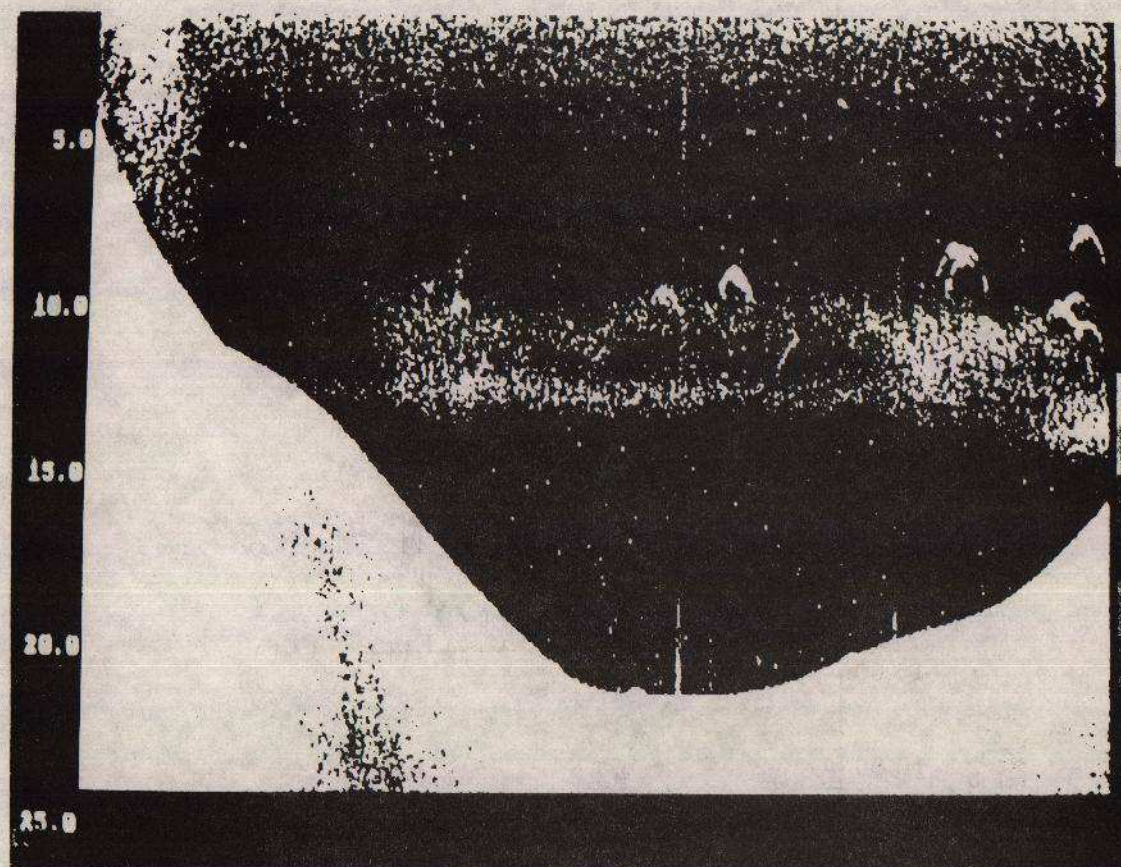


Figure 1. Acoustic transect across Long Lake in Clearwater County, northwestern Minnesota on 14 August, 1988.

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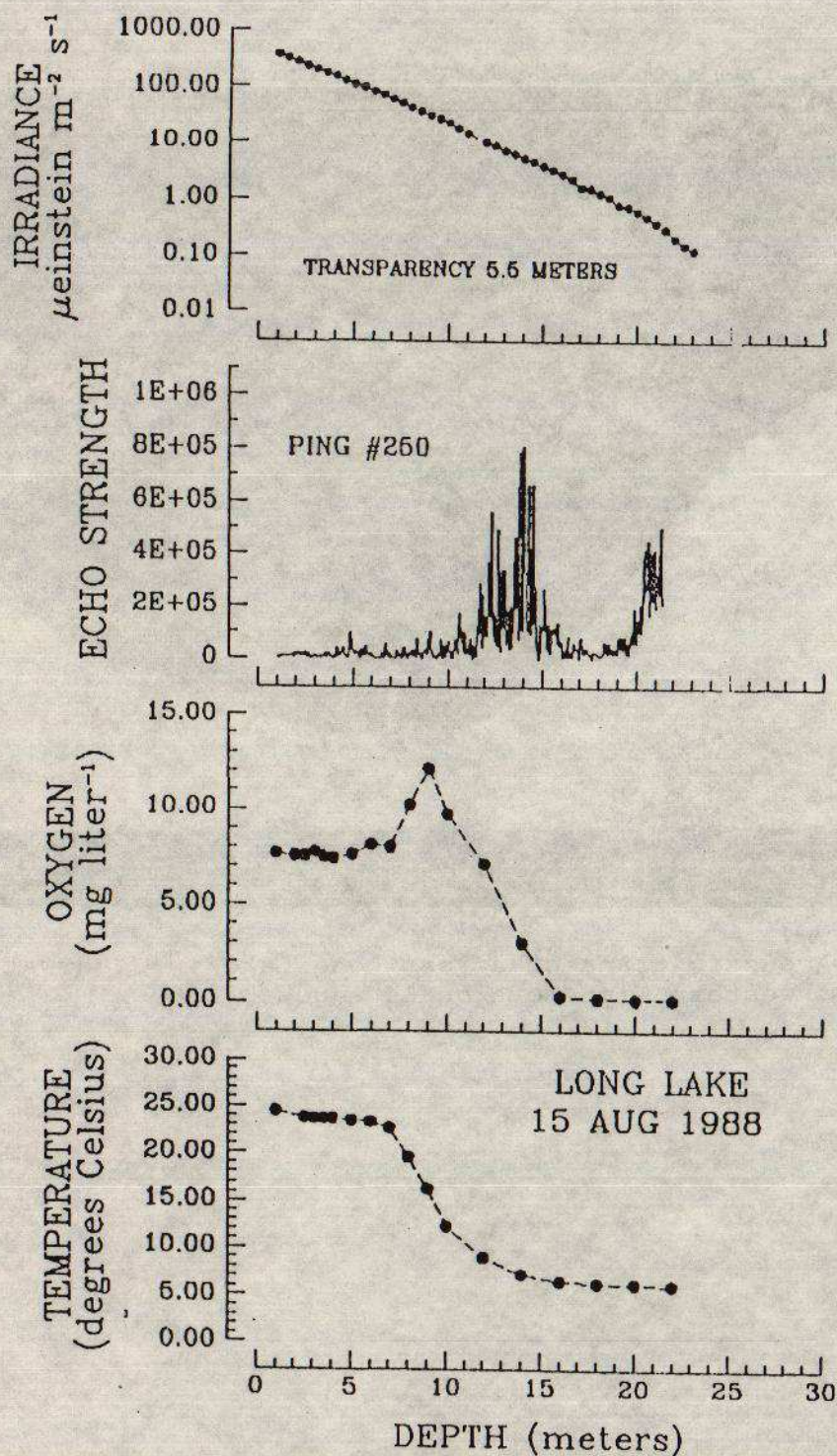


Figure 2. Depth profiles of irradiance, echo strength, concentration of dissolved oxygen, and temperature in Long Lake on 14 August, 1988.