Postprocessing system for echo sounder data

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Echo sounding is a powerful and widely used technique for remote sensing of the marine environment. In order to enhance the power of the echo sounder, a postprocessing system has been designed and realized in standard software that is essentially machine independent. This has been done by adhering to the following international standards: UNIX operating system, C programming language, X Window Systems, Structured-Query Language (SQL) for communication with a relational database, and Transport Control Protocol/Internet Protocol (TCP/IP). Preprocessed data are transferred from the echo sounder to the postprocessing system by means of a local-area network (LAN), namely Ethernet. Development of the postprocessing system, for analysis of such diverse scatterers as plankton, pelagic, and bottom fish, and the bottom itself, is documented in the following way. The history of echo integration is summarized. User requirements for the new system are listed. Reasons are given for the choice of the particular computing environment, including both hardware, software, and external communications. The system design, consisting of data flow and graphical user interfaces, is described. Implementation of the system is defined through integration techniques and a discussion of performance issues. Operating procedures and the first field trials of the system are described. Several features characteristic of and perhaps unique to the postprocessing system are, for example: (1) user definition of arbitrarily shaped integration regions, including non-constant-depth intervals, by means of interactive graphics; (2) preprocessor error correction, e.g., adjustment of the noise threshold or redefinition of the detected bottom; (3) use of several color map techniques in order to extract such information as signal strength and shape; and (4) the scheme of interconnections of graphical user interfaces, database, and data files. This work does not introduce a set of computer instructions. It does describe a design philosophy and method of realization that may have broader applications in acoustics than that ostensibly concerned only with the quantitative estimation of fish abundance.

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INTRODUCTION

A major application of echo sounder data is in the estimation of fish abundance, as for monitoring fish stocks to establish fishing quotas, thence regulate fishing. Echo integration is the most widely used of several techniques to perform this estimation.[1,2] It proceeds in the following way. A ship with calibrated hull-mounted or towed transducer makes absolute measurements of the acoustic density of scatterers along transects crossing the survey region. The density is commonly expressed through the mean volume backscattering coefficient[3] or strength,[4] or the integral of the volume coefficient over depth, the so-called area or column backscattering coefficient or, in the logarithmic domain, column backscattering strength.[5] The area backscattering coefficient has units of square meters of backscattering cross section per unit surveyed area, e.g., square nautical mile or square kilometer. Vital information about the object organisms, namely, species and size or age-class composition, is generally derived by direct physical sampling by trawling or other catching means. This is used to allocate the measurements of acoustic density by species and size group or age class. By dividing the area backscattering coefficient by the mean backscattering cross section of the object fish, the number density is determined along the transects. The overall abundance is then estimated by statistical combination of the transect data.

Typical survey areas of marine fish stocks may vary from about 1 km^2, as for herring (*Clupea harengus*) in local fjord stocks[6] or in larger, oceanic stocks when hibernating in fjords,[7] to 10^6 km^2, as for walleye pollock (*Theragra chalcogramma*) in the Aleutian Basin.[8] A typical pulse repetition frequency (PRF) used in making acoustic observations is 50 pings per minute per transducer. Total survey times vary roughly from several hours to several months. It is often desirable, if not necessary, to measure scatterer density with 1-m depth resolution over a range of 100–500 m or more, as for blue whiting (*Micromesistius poutassou*).[9] If a measurement of acoustic density, such as the mean volume backscattering strength over a 1-m depth interval, requires two eight-bit words or bytes to maintain adequate precision, then characteristic data quantities to be digested from a single fish-stock survey are of the order of 1 Mbyte–10 Gbyte for the simultaneous use of one to three transducers. Given that these data must be processed in the course of a survey, in order that the resulting abundance estimate be timely, and that fish capture data and auxiliary data such as salinity–temperature–depth (STD) profiles are required to interpret the acoustic data, the magnitude of the task is evident.

Solutions to this problem, in the form of digital echo integrators, have been commercially available for about ten years. The status of major American, French, Japanese, and Norwegian systems per 1984 is summarized in a single volume edited by Mitson.[10] These echo integrators have inevitably become antiquated because of rapid advances in data technology. A specific shortcoming of some of the described systems is that the processing is irrevocable: The data are integrated over predefined depth channels and intervals of sailed distance, without storage of raw or preprocessed data. In another case, the data must be stored, on magnetic tape, before integration, which, while allowing adjustment of integration limits, is still cumbersome because of the manner of definition of limits and their conformity to rectangular boxes, not to mention the time and labor required by postprocessing of such data. Some newer digital echo integrators[11–13] suffer from similar limitations.

The Bergen solution to the problem of echo integration owes its origin to the work of G. Vestnes and Dragesund and Olsen,[14] as assisted by I. Hoff. This work was indeed seminal to the entire development of echo integrators. An early, necessary adjustment of the manner of integration, from that of the detected signal to that of the squared detected signal,[15] resulted from a pronouncement by R. E. Craig. J. E. Ehrenberg verified the correctness of this.[16,17] The Institute of Marine Research based its first digital echo integrator on the Norsk Data ND-1 computer.[18] This was later upgraded to the ND-10 computer.[19] While this was quite effective in the context of early 1970s data technology, it quickly became obsolete, depending as it did on a command of ND-10 machine language and hardware that went out of production in 1979.

During the time that a replacement to the ND-10-based system was being discussed, a number of new echo integrators entered the market. However, the pace of development of data technology, including both hardware and software, has been so rapid that when the Institute eventually decided to replace its echo integrator, in 1987, it also decided to gamble, in a manner of speaking, on recent developments in data processing and graphics display techniques that appeared to be attaining standards-status. In fact, the decision was taken to free the echo integrator from hardware to the extent that all software should conform to such international standards as UNIX operating system,[20,21] C programming language,[22,23] X Window System,[24,25] Structured-Query Language (SQL) relational database,[26] and Transport Control Protocol/Internet Protocol (TCP/IP).[27]

Colleagues in other fields at the Institute, observing this development, saw the power of the new system for processing their own cruise data. This confirmed the envisaged extended scope of the system to include biological and chemical oceanographic data, hydrographic data, meteorological data, plankton data, and other data on fish biology, e.g., stomach-content data for use in multispecies modeling.

It is the aim of this paper to document the development of the new postprocessing system, especially apropos of its potential for analyzing echo sounder data. Because of the importance of such data to the system, this has been named the Bergen Echo Integrator (BEI).[28] Both biological scatterers, e.g., fish, shrimp, squid, and plankton, and the bottom itself, fall within the purview of the acoustic part of BEI.

Formal documentation commences here with description of user requirements and the consequent choice of the computing environment. The system design is described by specifying the data flow and graphical user interfaces. Implementation of the system is defined through the various integration techniques and a brief discussion of performance issues. The first field trials of the new system are described.

It is emphasized that the present work is not intended to introduce a set of computer instructions. Rather, it aims to describe a system design philosophy and method of realization that has been found successful in the quantitative measurement of fish density and that may be useful in other domains of acoustics.

I. USER REQUIREMENTS

User interpretation of echograms is an essential part of the fish stock assessment procedure. This makes stringent demands on the man–machine interface. Recognition of this at the outset of the development work is reflected in the design goal, namely, development of a flexible, open, and user-friendly system in software for postprocessing and displaying data from an echo sounder preprocessor and other on-board systems, as shown in Fig. 1. This should make possible reassessment of survey data in the light of current biological knowledge of the target species.

Requirements imposed by users on the system are the following: (1) ample capacity for processing, displaying, and manipulating data from an echo sounder preprocessor and other units indicated in Fig. 1; (2) machine independence; (3) programming in a high-level language; (4) modular construction; (5) database; (6) Ethernet local-area network; (7) full documentation; and (8) user friendliness.

These requirements are grounded in certain very basic needs. First, the system should indeed be user-specified. That is, the user, not the system, should make all the important decisions in the course of interpreting the data. An example is that of discrimination of bottom fish from the bottom itself. Based on the echogram appearance, the user should be able to override the detected bottom and literally redraw the bottom contour. Second, the system should be easy to use. Difficulties in using the system must inevitably interfere with the interpretation process and jeopardize the quality of this. Data interpretation can also be subjective or, at the least, idiosyncratic on the part of the user. The system should not automatically display auxiliary data that may be useful in interpreting echograms, but be able to readily access these if wanted. Third, since all applications of the system cannot be foreseen, it must be capable of expansion. In computerese, the architecture must be extendable and scalable. Thus, to help and not hinder future expansion, the system must also be fully documented, from the functional to coding stages.

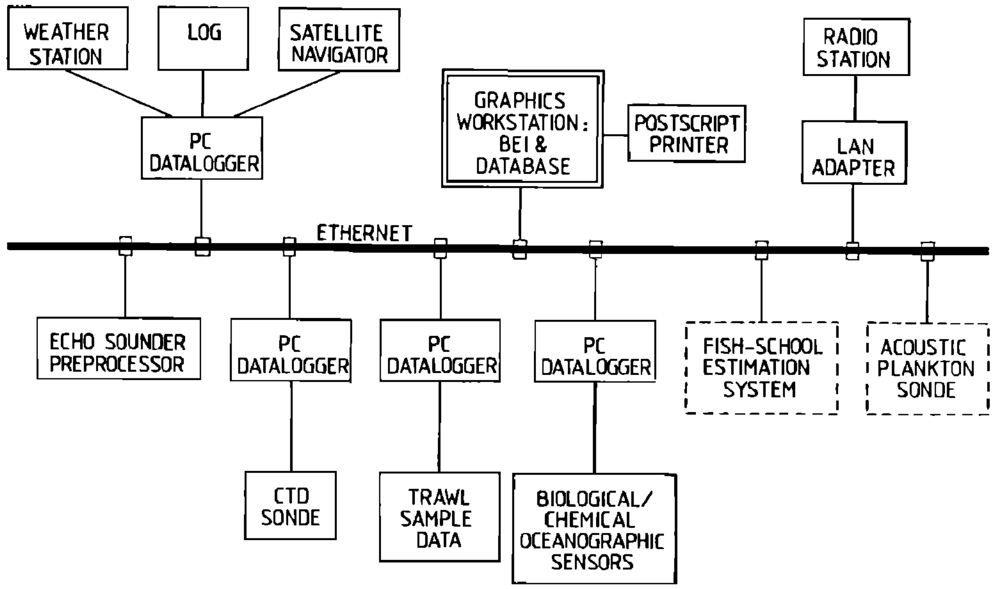

FIG. 1. Data network for research vessels.

The processing capacity is partly determined by the need to receive and manipulate data from the echo sounder preprocessor. These data are sent in formatted blocks called datagrams. Preprocessed acoustic data consist of values of the detected bottom depth, mean volume backscattering strength, and resolved single-scatterer target strength, as determined, for example, by split-beam echo sounding systems.[11,29,30] Dual-beam echo sounding systems[12,30] are also convenient sources of measures of both acoustic density and single-scatterer target strength.

In developing the echo integration function of the postprocessing system, the echo sounder data are assumed to be preprocessed to the extent of specifying values of the mean volume backscattering strength. These data, and accompanying target strength data from a split-beam transducer, if available, are assumed to derive from a particular configuration of the SIMRAD EK500 echo sounding system.[11,31] This constitutes no essential limitation, however, with respect to either data quantity, transducer, or echo sounder preprocessor.

Mean volume backscattering strength: For each ping and each transducer, 650 values of this quantity are transferred to the postprocessing system in datagrams. The first 500 values of each such datagram are uniformly distributed over a predefined depth interval, e.g., 0–50, 210–310, 180–430, and 100–600 m, with respective depth resolutions of 0.1, 0.2, 0.5, and 1.0 m. The last 150 values of the same datagram represent values uniformly distributed over a predefined expanded bottom channel, e.g., from 10 m over the detected bottom to 5 m under the same, hence with 0.1-m resolution in this case. One, two, or three transducers may operate simultaneously. A typical ping rate or PRF is 50 pings per minute per transducer.

Single-scatterer target strength: Values of resolved single-scatterer target strength are transferred together with the corresponding echo strength, detected alongships and athwartships angles, range, and identifying data such as the time of pinging. These data are transferred asynchronously in datagrams of variable size.

Other data may be sent from the echo sounder preprocessor to BEI through a system of datagrams. These data, like the acoustic data, are formatted according to acknowledged principles for machine–machine communication.

II. CHOICE OF COMPUTING ENVIRONMENT

A. Hardware

Specifying hardware that is marginally adequate for a particular task is always hazardous, especially if additional functionality must be incorporated in the system in the future. The hardware technology should therefore not have architectural constraints that may limit software development. Such a technology is generally embodied in the workstation-class of machines.

BEI has been dimensioned for storing raw data at the collection rates outlined above for at least 24 h, hence of magnitude 100–400 Mbytes, before cleanup procedures must be initiated. Computation-intensive interactive operations, such as setting a new noise threshold and recomputing area backscattering coefficients, should be done within 5 s. Loading a new 650×1000-pixel echogram, including transformations, computations, and visualization, should be done within 10 s. The raster graphics should be able to render the echogram derived from the echo sounder preprocessor data without information loss. The graphics system should, therefore, include a frame buffer that can display 256 colors simultaneously from a modifiable color palette.

In order to meet the response time constraints on the system, a workstation is required with speed of at least 10 million instructions per second (MIPS), 2 million floating-point operations per second (MFLOPS), and input/output (I/O) bandwidth of 2 to 3 Mbytes per second. At the start of the project, Reduced Instruction Set Computer (RISC) architecture could satisfy these requirements. Because of the short development time of RISC-architecture machines, these remain the most promising scalable machine architectures.[32]

B. Software

In order to satisfy the requirement of an open architecture, the following international, nonproprietary standards were selected.

Operating system: The operating system UNIX[20,21] was chosen for the following reasons. (1) Portability: It is implemented under different machine architectures. (2) Multitasking: Several processes can be run concurrently. (3) Virtual memory: This allows programs to be run that require memory larger than that physically available in the machine. (4) Nonsegmented memory: This allows large programs to be designed without considering the underlying memory architecture. (5) Networking: This powerful mechanism enables user-designed code to interact with other network peripherals.

Programming language: The language C[22,23] was chosen for the following reasons: It is sufficiently high-level to support structured programming, it is sufficiently low-level to support efficient coding, and it has a powerful interface to UNIX.

Database: A relational database was chosen for ease of use and maintenance, while avoiding the complexities of graph-oriented databases.[26] A standard database query language, namely, Structured-Query Language (SQL), was chosen because of the availability of SQL-based tools for further processing of data.[33]

Window system: In order to provide a user-friendly interface, a graphical user interface (GUI) is essential. The only windowing system that is both nonproprietary and portable is the X Window System.[24,25,34] This windowing system provides a mechanism for implementing GUI applications.

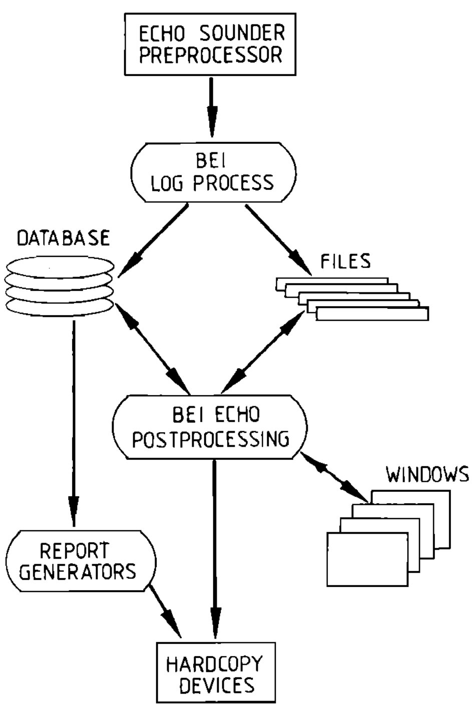

FIG. 2. Data flow model.

C. External communications

In contrast to traditional, vendor-specific solutions, in which peripheral instruments are attached directly to the central processing unit (CPU), a local-area network (LAN) provides a well-defined data interface. This allows peripherals to be attached at will, without influencing CPU operations. The most widely used LAN interface consists of Ethernet and Transport Control Protocol/Internet Protocol (TCP/IP).[27] A specific subset of TCP/IP, namely, User Datagram Protocol/Internet Protocol (UDP/IP), is particularly well suited for data acquisition. This protocol allows data to be sent even if the receiver process has a temporary overflow problem. Possible loss of data in the system is not critical, however, since the all-important statistical characteristics are not affected by the occasional random loss of single pings.

III. SYSTEM DESIGN

A. Data flow

The flow of acoustic data is illustrated in Fig. 2. Acoustic data from the echo sounder preprocessor are sent through the Ethernet network to the BEI logging process. Raw acoustic data and other high-volume data are stored in files, while access to these is organized in the database. Postprocessed data and other low-volume data, like navigation data and time signals, are stored directly in the database.

BEI displays and processes data accessed from both the database and files. During the interpretation process, the operator sets various parameters that specify the quantity and quality of observed data. Upon completion of the formal postprocessing operations, so-called report generators summarize the results. The reports are usually printed, presently by means of a PostScript laser printer.

B. Graphical user interfaces

A special window has been designed to specify cruise configuration data. These data are stored in the database, and represent database settings that identify the data to be collected during a cruise. These data can be verified by the operator and corrected if necessary.

Postprocessing of acoustic, fish-station, STD-station, and other data is performed by manipulating window-based applications.

1. Configuration Window

The Configuration Window is used to set the key data in the database. In almost all tables in the database, nation, vessel name, and cruise numbers are used to associate data. Descriptive information about the cruise, such as purpose, plan, sea area, and cruise personnel, may be entered through this window.

Channel depths for echo integration of pelagic and bottom fish are also specified through the Configuration Window. These include both pelagic or surface-referenced channels, and bottom-referenced channels. It is customary for purposes of comparing data collected on different cruises or over long periods of time to use certain standard channels. For pelagic fish these are contiguous layers of 50-m thickness beginning at the surface or at the transducer depth. For bottom fish, exemplary layer thicknesses are 1, 2, 5, and 10 m, as reckoned from the bottom for each ping. These or any other desired channel depths are defined through the window.

The basic interval of sailed distance over which echo integration is performed is also specified in the Configuration Window. Like the channel depths, certain standard distances are used. These are 5, 1, 0.5, and 0.1 nautical miles.

Species or species groups needed in the Interpretation Window are also defined through the Configuration Window. These are generally determined by selecting a subset of the species names in the database. This list can easily be expanded to include new names.

2. Survey Grid Window

The Survey Grid Window displays the location of the cruise data stations. Among these are stations where echo sounder, trawl, oceanographic, and other data are collected. Echo sounder stations are visualized by the survey grid as superimposed on a map of sea area, coastal region, or fjord, as indicated by geographic coordinates and positions of land masses. Other stations are visualized by various symbols, e.g., PT821 for pelagic trawl station number 821.

After a station is selected by the operator, by means of the mouse, data from the same are displayed in the corresponding window. Echo sounder data are divided into storage units that are selectable along the cruise path. Active, or displayed, stations are marked in boldface.

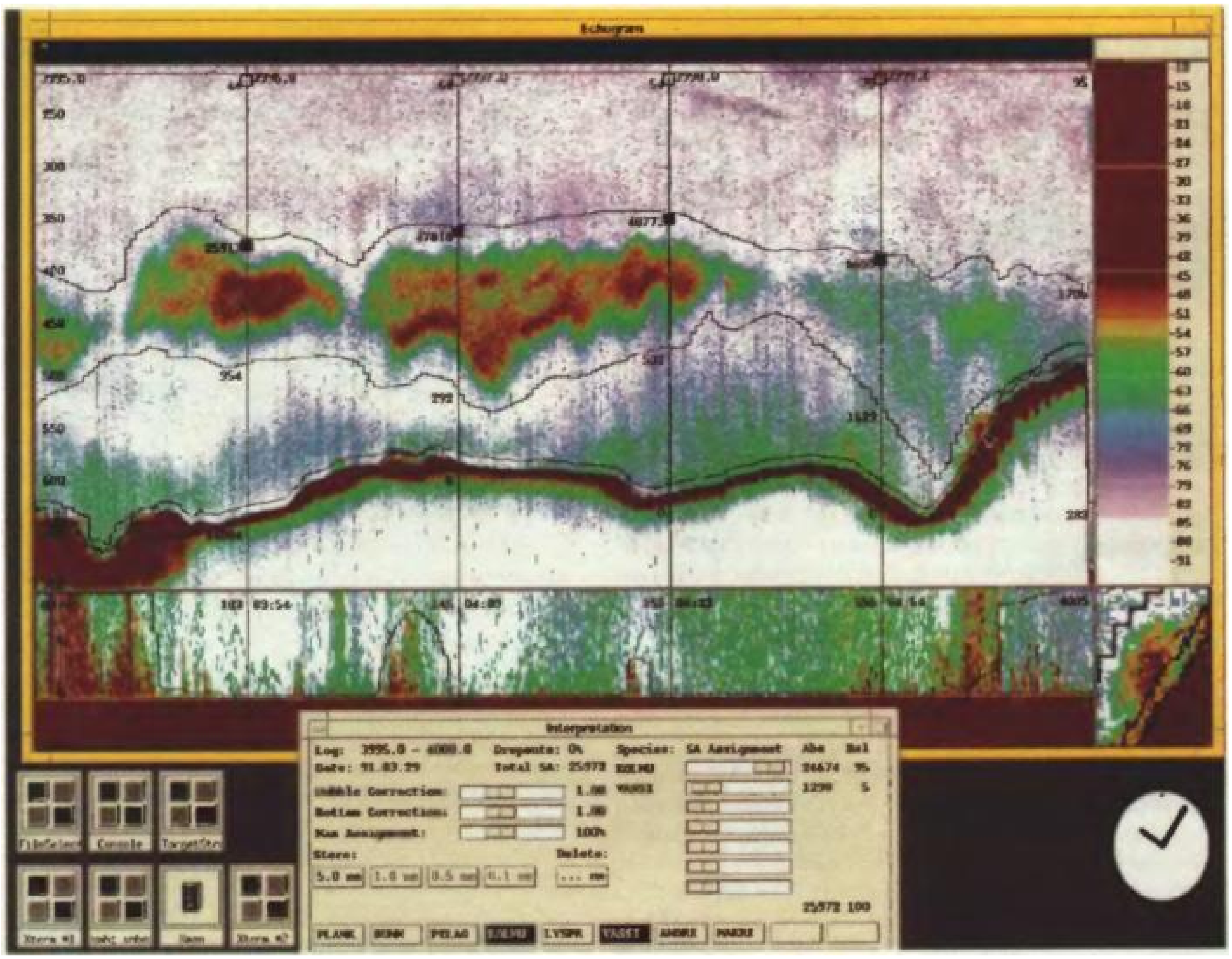

FIG. 3. Echogram Window and Interpretation Window.

3. Echogram Window

The Echogram Window consists of four different subwindows: those of the main echogram, expanded bottom channel, color map, and zoom. The first two subwindows are displayed with markers specifying depth range, vessel log, and layer limits. New layers and school-bounding rectangles can be inserted, moved, deleted, or redrawn at will.

Layers in the Main Echogram Subwindow are not required to lie within constant-depth intervals, giving the operator the opportunity to partition the echogram into homogeneous areas such as schools, shoals, bottom fish, and like aggregations. The cumulative area backscattering coefficient is computed for each of these partitioned echogram areas or regions. Modifying layers or school bounds results in recomputation of the cumulative area backscattering coefficients.

The Expanded Bottom Channel Subwindow displays an expanded echogram around the detected bottom, shown as a horizontal line. This is designed for distinguishing fish from the bottom. Drawing functions enable the bottom line to be redrawn, for example, to include fish lying under the apparent detected bottom or to exclude bottom features lying over the same. These functions are exceedingly useful in two not uncommon situations: those of dense fish aggregations causing false bottom detection, and rough bottom topography, with integration of local peaks in fish channels or layers.

The Color Map Subwindow is effected as an adaptable, operator-steered color scale in which the operator can set threshold levels and associate colors with values of the mean volume backscattering strength displayed on the workstation screen. The general aim is to preserve both shape and signal strength information in the echogram, but the availability of three different color maps in the BEI allows enhancement of shape or signal strength separately as well as together. These maps are those of the gray scale, red–blue color scale, and combined dark red–light blue scale, respectively.

Gray scale: Work done on human perception shows that the gray scale, such as used in traditional echo sounders, is ideal for observing shape in data.[35] Estimating signal strength by gray levels is, however, difficult.

Red–blue color scale: Signal strength is easily gauged by coding signal strength values according to the ordinary spectrum of visible solar radiation. Red is associated with strong signals, while blue is associated with weak signals. Estimating shape by the red-blue scale is relatively difficult.

Dark red–light blue scale: This combines the advantages of the gray scale and red–blue color scale.[36] It is the recommended color map for ordinary applications, and therefore serves as the default color-map setting in BEI.

For more detailed examination of the echogram, the Zoom Subwindow allows expansion of arbitrary individual sections of the Main Echogram Subwindow or Expanded Bottom Channel Subwindow. The expansion is initiated by positioning a small box over the section to be expanded.

An example of the Echogram Window, provided by K. A. Hansen, is shown in Fig. 3. The Main Echogram Subwindow shows a characteristic echogram of an aggregation of spawning blue whiting on the edge of the continental shelf west of the British Isles on 29 March 1991. The depth range is from 200 to 700 m relative to the sea surface. Operator-drawn layer limits embrace the aggregations for ease in assigning cumulative values of the area backscattering coefficient to the target species. The Expanded Bottom Channel Subwindow is immediately below the Main Echogram Subwindow. The combined dark red–light blue color map is shown to the right of the main echogram. Numerical values attached to this indicate absolute values of mean volume backscattering strength in decibels. The color spectrum shown here can be compressed or expanded over the indicated range from -91 to -12 dB. To illustrate the Zoom Subwindow, a portion of the main echogram is shown in the lower right corner.

4. Interpretation Window

Prior to storage of the computed cumulative values of the area backscattering coefficient for the various automatic or mouse-drawn partitions of the echogram, the values must be assigned to one or more fish species or groups. This is done through the Interpretation Window, also illustrated in Fig. 3, which presents candidate species or groups of species in a table representing the appropriate subset of the comprehensive listing in the database. The computed coefficients may be additionally adjusted for effects due to air-bubble absorption, the dead zone near the bottom, and other medium effects. Upon completion of the described processes, the adjusted and assigned values of area backscattering coefficient are stored in the database.

5. Target Strength Window

Target strengths corresponding to resolved single-fish echoes are collected in a histogram that is displayed in this window. Associated statistics include the number of observations and the depth range. The basic data are extracted from either of two kinds of regions, a rectangular box of operator-set-and-controlled limits or a horizontal layer indicated by the operator using the same.

6. File Selection Window

This provides an alternative means of selecting acoustic data, as when navigation data are lacking, for example.

7. Fish Station Window

Biological data collected during trawling or other fishing operations are summarized and displayed in this window, which is accessed from the Survey Grid Window. Presentations are made of the length distribution and number of measured specimens for each selected species captured by fishing.

8. STD Window

The dependences of salinity and temperature on depth, as measured by an CTD-sonde, are displayed in this window. Like the Fish Station Window, the STD Window is accessed directly from the Survey Grid Window. If indicated, the window will interpolate between two STD stations according to a linear model.

IV. SYSTEM IMPLEMENTATION

To implement a multifunctional system as described, the method of integration is important. One operator may, at a given time, be interested in inspecting data through the Survey Grid and STD Windows. Another operator, at the same time from a second workstation or at a different time, may want to inspect data through the Echogram and Survey Grid Windows. Both operators are therefore served by a modular system, whose separate parts can be activated and deactivated independently, as required.

A. Integration techniques

In order to optimize user resources, it should be possible to activate a subset of the system functionality without having to activate the whole. A monolithic design, in which all parts of the system are integrated into a single process, is consequently contraindicated. Instead, the system ought to be broken down into a set of processes, each of which can carry out its own task independently of the others. Communication among these processes is thus essential to integration.

The traditional way to interconnect independent processes has been to let processes communicate through files or operating-system-specific interprocess mechanisms. An alternative method, as employed in this system, is to use the communication mechanism available in the window system itself, as illustrated in Fig. 4. This mechanism allows processes to announce their entrance to and departure from the other window-based processes. Once a process has announced its entrance, it will exchange messages with other active processes defined in the system.

A typical scenario is that the Survey Grid Process instructs the Scrutinizing Process to display a particular echogram after its selection in the Survey Grid Window. In case the STD Process has also been activated, this process would be activated to display the STD data nearest to the selected navigational position.

Decomposing the system into such loosely coupled processes allows the operator to load a subset of the entire system. From a developer's point of view, the system is also modularized into manageable pieces that can be maintained and tested with minimal side effects to other parts of the system.

B. Performance issues

Ideally, all data, including raw data, should be maintained in the database. Since most databases have been designed primarily to handle low-volume related data, mechanisms for fast transfer of blocks of unrelated data have not been standardized. Available mechanisms for database I/O simply lack the bandwidth required for loading large echograms in a reasonable time. As a consequence, data used to manage and access high-volume data are kept in the database, whereas high-volume data are stored in files. Refined data resulting from postprocessing are stored in the database.

CPU-intensive sections of the system, like noise-thresholding of the echograms, is heavily optimized by precalculating mathematical expressions and storing the results by means of index tables when possible. An example of this involves the conversion of values of volume backscattering strength (S_v) to values of area backscattering coefficient (s_A) for the respective depth interval. An S_v value, which is expressed as a logarithm to base two, is used as an index to a vector of pre-calculated s_A values.

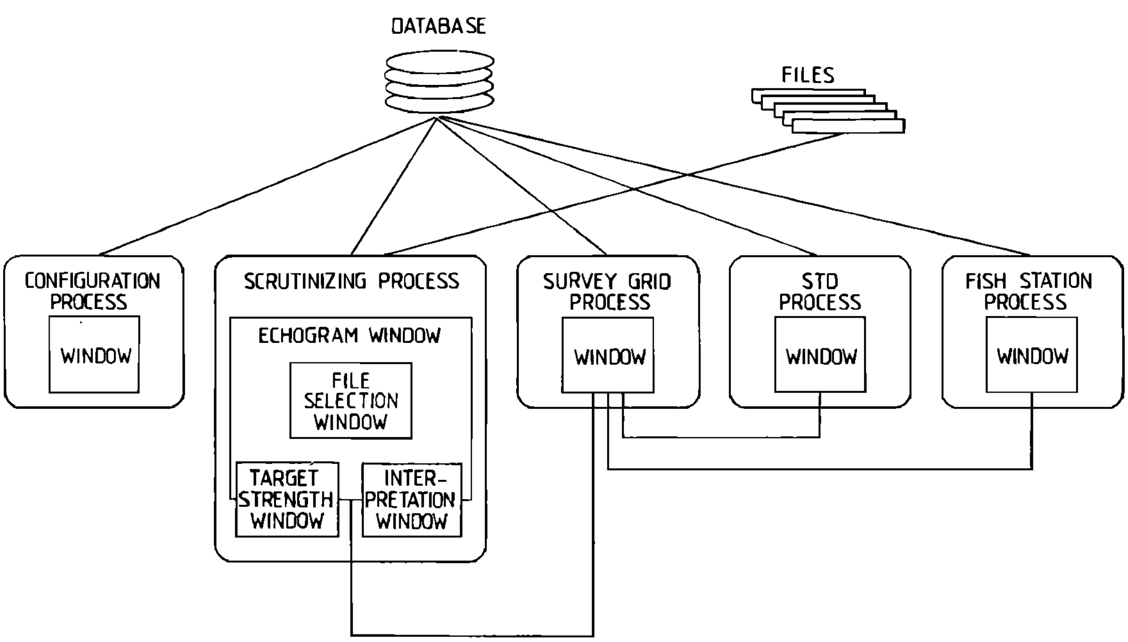

FIG. 4. Interconnections of graphical user interfaces and stored data.

In some cases, time consumption has been reduced to 7/45 of that of the nonoptimized version. Such optimizations sometimes increase the complexity of the code. Occasionally, in some parts of the system, this has been necessary to achieve acceptable response times.

V. OPERATING PROCEDURES

At the beginning of a cruise, the Log Process is started. This controls reception of echo sounder data without requiring active interference by the operator.

When echo sounder or other data are to be processed, BEI is started, and the Survey Grid Window is opened, showing locations of various data sources. The desired data source is identified, and the corresponding window is opened. In the case of STD data, for instance, this is the STD Window.

Echo sounder data, which are of preeminent interest here, are processed through the Echogram Window. Initially, this displays the selected portion of the echogram, as sent by the echo sounder preprocessor, in either of two modes: log-based or ping-based. In the particular example in Fig. 3, data are shown over the depth range 200–700 m, relative to the sea surface. A total of 1000 pings over a sailed distance of 5 nautical miles is shown. The vertical or depth resolution is 1 m, since the 500-m range is represented by 500 pixels. The color of a single pixel corresponds to an absolute value of the mean volume backscattering strength according to the color map shown immediately to the right of the echogram. From experience, including knowledge of sea area and season, the operator has concluded that the bulk of the fish concentration in the central zone is homogeneous with respect to fish species. This is reflected in the irregular, mouse-drawn layers embracing the echo structure.

Below this so-called Main Echogram Subwindow is a second echogram, presented in the Expanded Bottom Channel Subwindow. This presents the region about the bottom, as detected and specified by the echo sounder preprocessor and represented here by a straight line. In the example in Fig. 3, the range from 10 m over the bottom to 5 m under the same is shown with the maximal resolution of 0.1 m available in the preprocessor function associated with the 38-kHz frequency of the particular transducer. In total, the acoustic data occupy a matrix of 650×1000 elements.

This echogram duplicates the presentation by the echo sounder preprocessor. Before interpreting this, several different corrections may be applied. These allow removal of all values of mean volume backscattering strength lying under the operator-specified threshold, correction for possible absorption by air bubbles in the surface layer, and adjustment of echo values in the bottom region due to unavoidable shortcomings in the bottom detection algorithm. If the operator believes that the bottom itself is integrated or that fish echoes are excluded, as because of false bottom detection by powerful scattering layers or schools, the bottom line may be redrawn by means of the mouse. This has been done in Fig. 3 to avoid three evident cases of integration of bottom features in the bottom fish channel. The monotonically increasing line running from the lower left to upper right corners of the particular subwindow is a visual display of the cumulative echo integration result. Discontinuities or rapid increases in this may be clues to the presence of the bottom in the integrated result.

The Zoom Subwindow has also been exercised in Fig. 3. This shows a small section or box of the main echogram in enlarged state in the lower right corner, immediately below the Color Map Subwindow. Specifically, the region near the arrow is examined to help discriminate between an aggregation of fish and the bottom.

Several thresholds have been applied in the Color Map Subwindow shown in Fig. 3. These have been chosen by the operator, by admittedly subjective criteria, in an attempt to minimize the appearance of noise or reverberation due to scatterers regarded as extraneous for the cruise aim of surveying blue whiting, and to draw out structure in the distribution of fish in the aggregation.

Interpretation of the arbitrary echogram is performed within the context of the Interpretation Window. Important auxiliary information is obtained by calling the Fish Station and STD Windows. Selected Fish Station Windows, for example, describe the content, by species and size or age groups, of appropriate trawls. In Fig. 3, these suggest that the relative echo proportion of species in the dense aggregation layer are 95% kolmule or blue whiting and 5% vassild or greater silver smelt (*Argentina silus*). The STD station is frequently called, as characteristic features of the salinity and temperature profiles, such as minima, maxima, and sharp gradients, are commonly associated with vertical separations in fish species, not to mention plankton.

Under the surveying conditions present while the echogram data in Fig. 3 were being collected, it was not felt necessary to correct for absorption by air bubbles in the surface layer, hence, the indicated factor of 1.00. The bottom is sufficiently regular to allow the mentioned exclusion of integrated bottom features, without additional compensation, hence, the indicated bottom correction factor of 1.00.

In order to minimize operator specification of parameters in the Interpretation Window, settings are carried over to the following echogram. It is generally quicker to modify these than to enter the settings anew each time.

Values of area backscattering coefficient are interpreted, or assigned to target fish species or groups, throughout a survey. This is generally done within a day of their gathering. During and at the end of a survey cruise, report generators may summarize the cumulative results by transect segment, if not entire transect length, in printed form. Following interpolation of these between transects, which is an operation performed outside of BEI, the resulting mean area backscattering coefficients may be converted to absolute quantities of fish. This is done simply by dividing the assigned area backscattering coefficients by the corresponding average fish backscattering cross section.[15]

VI. FIELD TRIALS

The first field trials of the new postprocessing system were conducted on board R/V G. O. SARS, 5–15 December 1988 and 6–10 March 1989. A number of different intersystem comparisons were performed at 38 kHz, both on calibration objects and on biological scatterers.

In each of the calibration exercises, computations of the area backscattering coefficient in the BEI were compared with those derived directly from the SIMRAD EK500 scientific echo sounding system.[11] The results cannot be independent, since the EK500 performs the preprocessing for both its own echo integrator and the BEI. However, the EK500 internally operates with absolute physical quantities, and its calibration was confirmed to within ± 0.2 dB for a series of standard targets. These included a 38.1-mm-diam ball bearing made of tungsten carbide with 6% cobalt binder,[37] 60-mm-diam copper sphere,[38] and 50-cm-diam 12-mm-thick copper disk,[39] with nominal target strengths of -42.3, -33.5, and 14.0 dB, respectively. Echo integration was performed at anchor by simulating a vessel speed of 10 kn through a special command, or programming instruction, while pinging at the nominal rate of 50 pings per minute. Theoretical expected values of the area backscattering coefficient agreed with the respective results from the two echo integrators to within the cited calibration accuracy. Results from the two echo integrators were indistinguishable for each of the measured targets.

Several different aggregations of biological scatterers were measured by the BEI with EK500 preprocessor, by the EK500 echo sounding system with separate integrator, and by the ND-10-realized echo integrator coupled to the EK400 scientific echo sounder.[40] These included a stable aggregation of krill, shrimp, and blue whiting under 200 m in Storfjord on 7 December 1988 and a dense school of herring of 32-cm mean length in Vinjefjord on 11–12 December 1988. The results were essentially identical for the BEI and EK500 echo integrators, and were similar for these and the older EK400-coupled system. Differences in these third-system comparisons may be attributed to ordinary differences in scatterer concentration due to changed course and time, since the third system could not be operated simultaneously with the first pair. The attempt was made to repeat the previous course track and to match log-keyed starting positions, and it is to differences in these that the different results are ascribed.

Intersystem comparisons have also been performed during the regular survey-cruise program in 1989. Results of echo integration by the BEI and other integrators, under both good and marginal conditions of registration, have consistently agreed. Results from occasional exercises performed with integrators on board different ships sailing together have shown a similar strong agreement.

VII. DISCUSSION

The postprocessing system BEI has become an integral part of the complement of scientific instruments carried on board Institute research vessels. It has replaced its predecessor. Some of its enlarged capacity is evident in user specification of, for example, arbitrarily shaped integration regions, noise threshold, detected bottom, and degree of horizontal and vertical resolution in the database within certain limits. Operator selection of the color map and control of its dynamic range further aids the crucial process of interpretation.

A. Applications

In the course of applying the system in routine survey work, a number of related problems may be addressed. These are briefly described.

(1) *Target strength:* Notwithstanding a substantial history of investigation,[41] many dependences of this key quantity remain unknown. The Target Strength Window will facilitate analysis by automatic extraction of target strength histograms from operator-specified regions of the echogram.

(2) *Fish behavior:* Reaction of fish to the passage of the survey vessel are well known.[42] BEI will aid quantification of these, as by analysis of echo traces identified in the Echogram Window.

(3) *Bottom-typing:* This may be accomplished by Orlowski's method,[43] whereby the energy in the doubly reflected or bottom-surface-bottom echo is compared to the energy in the single-bounce echo. Harder, rougher bottoms have a higher ratio than softer ones. Such information, which may be extracted from the Echogram Window, may aid in decisions on where to trawl on fishing grounds of marginal quality. It may also provide useful information on bottom-fish species and behavior, because of the correlation of fish occurrence with bottom type.[44]

(4) *Spatial statistical modeling:* When compounding line-transect measurements of fish density to compute fish abundance over an area, assumptions are made about the distribution of fish.[45] BEI may contribute to ongoing work that aims to make explicit use of observed structure along transects in interpolating between these.

B. Future developments

Development of BEI is by no means finished, nor is its completion anticipated, because in addition to being a standard survey tool, it is also a research tool. Several imminent or near-term developments are briefly described.

(1) *Bottom detection algorithm:* Automatic bottom detection is presently effected in the echo sounder preprocessor. Since this must be accomplished in real time, the amount of information available for decision-making is limited to the most recent pings. In BEI, the bottom may be determined both from antecedent and subsequent pings. Improvements in the discrimination of bottom fish from the bottom are also expected.

(2) *Correction for range compensation errors:* Insofar as the echo sounder preprocessor may not use the best sound speed profile in its range compensation function, this may be improved in BEI by using appropriate STD data.

(3) *Echogram catalog:* Interpretation of echograms is inherently subjective, as this involves making decisions about the nature of scatterers from an underdimensioned pictorial representation. In some situations, identification is unambiguous. It is the intention to arrange exemplary echograms from the Echogram Window in a catalog for ready reference during cruises. The same may be used for instruction, for examining the consistency of interpretation of different observers, and for testing classification algorithms.

(4) *Multifrequency echograms:* BEI can receive simultaneous echo data from several transducers. Combination or

integration of these should aid interpretation of echograms, as by disclosing the presence or absence of plankton.

(5) *Acoustic classification by discriminant analysis:* Applications of discriminant analysis[46,47] have already yielded promising results for several fish species. Its use in BEI should be straightforward.

(6) *Compensation for extinction in schools:* Extinction of sound within dense or extended fish aggregations is a recognized phenomenon. Given identification of fish species and size distribution during surveying, compensation is possible.[48] Postprocessing is essential in effecting this, because of its dependence on the manner of variation of fish density with depth.

(7) *Air-bubble compensation:* Acoustic estimates of fish density are affected by the presence of air near the surveying transducer.[49] While the best strategy for addressing the problem is avoidance, as by using a towed transducer,[50] this is not always possible or convenient. If the bubble distribution in the vicinity of the transducer can be determined,[51] compensation can be performed within the Interpretation Window.

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