A PC/Linux Software Toolkit for Coastal Swath Mapping

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Abstract

Assembly of a PC/Linux based data acquisition and processing software toolkit for coastal (shallow water) multibeam and sidescan swath mapping sonar systems has been undertaken by the URI Ocean Mapping Development center (OMDC) in collaboration with government agencies and industry. This toolkit integrates existing software developments with a powerful menu driven Real Time Geographic Information System (RTGIS). This paper represents a progress report on this effort along with examples of some of the software tools.

1. Introduction

The OMDC (directed by Dr. Tyce) is part of the NSF/Industry sponsored Ocean Technology Center of the University of Rhode Island (URI). Members include NOAA, NAVOCEANO, USGS, SAIC, Raytheon, Datasonics and Sea Beam Instruments. This software effort is supported by NOAA, NSF and industry members (particularly SeaBeam Instruments). With the software originally intended for workstations running UNIX, more recently we have moved to PCs running Linux, a public licensed UNIX operating system. The intent is not really to develop completely new tools but to integrate compatible software tools for multibeam and sidescan sonar surveying with a powerful Real Time Geographical Information System (RTGIS), utilizing the diverse set of software packages already developed for related applications.

The toolkit is built around the following public software tools:

- Linux public licensed UNIX for PC's
- Xfree86 Xwindows display software for Linux from The Xfree86 Project
- Tcl/Tk graphical user interface software
- Ghostscript and Ghostview public domain Postscript software from The GNU Project at MIT
- GRASS 4.1 GIS and data base software developed by the USACE CERL
- Xsonar and Mini Image Processing System (MIPS) Sidescan Sonar processing packages from the USGS
- Multi-Beam System (MB-System) and Generic Mapping Tools (GMT) from LDEO and NOAA researchers
- netCDF data management software from UNIDATA
- Data Transfer Mechanism (DTM) IPC messaging software from National Center for Supercomputing Applications

The toolkit also makes use of the following proprietary software tools for those with licenses:

- Motif graphical user interface software
- OpenGL graphical display language for Linux
- Maptech Professional PC Helm guidance software from Resolution Mapping
- SeaView/ SeaSurvey multibeam processing enhancements to MB-System from SeaBeam Instruments
- Swathmap Realtime multibeam tools from the University of New Brunswick
- RTGIS Real Time extensions to GRASS GIS software from URI OMDC

During the past 15 years, personnel from URI's OMDC have developed and installed hardware and software to support multibeam and sidescan sonar operations aboard more than 15 ships from the National Oceanic and Atmospheric Administration (NOAA), the U.S. Naval Oceanographic Office (NAVOCEANO), Woods Hole Oceanographic Institution (WHOI), Lamont–Doherty Earth Observatory (LDEO), URI and private industry. From 1990 to 1992 the OMDC worked with the USGS and the British IOS to integrate shipboard data collection and processing of combined sidescan sonar

imagery and bathymetry from the GLORIA sidescan sonar aboard the research Vessel Farnella. As part of this effort we introduced the GRASS GIS to the shipboard environment for monitoring survey progress in real time with such success that we concluded that the next generation of hydrographic / oceanographic survey data acquisition and processing system should be built around a Real Time GIS (RTGIS) [1] [2].
In 1994 we began the development of an RTGIS software package as a project under URI's newly formed NSF/Industry sponsored Ocean Technology Center. The GIS software chosen for our RTGIS effort was the Geographic Resource Analysis Support System (GRASS) written primarily by the United States Army Corps of Engineers [3]. The GRASS GIS package was chosen for this work because of its low cost, because the source code is included with the distribution, and because its raster based origins make it particularly good at dealing with swath sonar data.

The GRASS system is written in C and runs under UNIX operating systems. GRASS has been ported to a variety of computer systems ranging from 386 PC's to high-end workstations and the only specific system requirement is that GRASS must be run under UNIX. Our original multibeam processing software development was VAX/VMS based in Fortran. With the conversion to UNIX as the operating system of choice for swath sonar data processing in recent years, new tools needed to be developed. A number of government, university and industry organizations have undertaken to develop UNIX based tools for multibeam and sidescan (swath) sonars, with impressive results.

In 1995 the OMDC undertook a project for NOAA to develop a UNIX-based software toolkit for hydrographic data collection and processing from coastal (shallow water) multibeam and sidescan sonar systems. The intent was to build a set of compatible software tools specific to U.S. multibeam and sidescan sonar hydrography out of the diverse set of software packages already developed for related applications rather than developing a new set of tools. Central to this effort were our prior efforts to develop RTGIS tools. This paper represents a progress report on this project.

Our software toolkit effort began first aboard Silicon Graphics UNIX workstations, the platform of choice for most multibeam software developers, and it has proven to be a forgiving host. Our intention was to eventually migrate the code to workstations from other vendors. However, from the beginning we hoped that we would be able to migrate the toolkit to a PC platform running some form of UNIX. Since the GRASS GIS had already been ported to the PC-based public licensed Linux operating system, this became our platform of choice early in 1997. This choice was made primarily for cost (low cost computer and zero cost operating system) with performance improving with time. Porting to Linux has been surprisingly straightforward for most of our tools, in part due to the wealth of support code available for standard user interfaces and graphical environments. The work described here was done on a Gateway 133 MHz Pentium with 32 Mbytes of memory. One 1.6 Gbyte disk was used for Windows 95 operations and one 4 Gbyte disk for Linux operations. Graphics were provided by an ATI Mach 64 PCI bus card. Peripherals included an 8 port RS-232 serial port card from Cyclades with Linux drivers, a PMI PCI bus ethernet card, an Adaptec SCSI adapter, an Exabyte 8200 tape drive, and an HP 650C large format color plotter.

2. Software Toolkit Contents

Software components of our toolbox include both cost free public software and proprietary code with licenses available either commercially or through special arrangements with the developers or their clients. The first type of public code includes the operating system (Linux) with TCP/IP ethernet support, supporting graphics software (Xfree86), Graphical User Interface (GUI) widget software (Tcl/Tk), and public Postscript compatible printing software (Ghostscript and Ghostview). The second type of public code includes powerful general purpose GIS software (GRASS 4.1), special purpose sidescan sonar processing software (Xsonar), and multibeam processing software (MB-System) together with supporting display graphics (GMT) and data management (netCDF) tools.

The first type of proprietary software in the toolkit is low cost support software including the Motif GUI widget software and an OpenGL graphic library for Linux to provide maximum compatibility with different packages. The second type of proprietary code is commercial mapping products, which includes 1) the electronic nautical chart program Maptech Professional run on a second DOS/Windows PC for helm guidance and autopilot control (based upon routes and standard NMEA data messages provided by the RTGIS Linux system), and 2) a sophisticated commercial set of multibeam mapping tools (SeaView / SeaSurvey from SeaBeam Instruments Corp.) which build upon the MB-System tool set. The last type of proprietary software includes software developed at universities in consort with commercial and government clients who have the right to use and license the software. This last type includes components of the Swathmap multibeam mapping software developed by the Ocean Mapping Group at the University of New Brunswick, and RTGIS enhancements to GRASS and other tools developed by the University of Rhode Island. NOAA and SeaBeam Instruments are supporters of both these university groups. A summary list of software components is provided in Table 1.

3. Software Functions

The software packages above are part of either toolkit system software or toolkit user software. Each user software package has been selected for this toolkit because it satisfies a particular need, though overlap does occur in user functions with some tools. The RTGIS operator directly interacts with the user software to perform a specific task (i.e., data acquisition, processing, or display). The system software generally does not directly interact with the user. It is provided as necessary support for the user software. Table 2 presents a list of toolkit modules along with a brief summary of the functions performed by each software module.

Table 1. Toolkit Software Components

Package	Description	Source	Information	Restrictions
Linux	Public UNIX for PCs	ftp://ftp.cdrom.com/pub/linux/slackware	http://www.linux.org	Free public licensing with terms included
Xfree86	X windows for UNIX	ftp://ftp.xfree86.org	http://www.xfree86.org	Free public licensing with terms included
Tcl/Tk	X Windows GUI development system	ftp://ftp.smli.com/pub/tcl/	http://www.smli.com/research/tcl	Free public licensing with terms included
Ghostscript	Postscript interpreter	ftp://ftp.cs.wisc.edu/ghost/aladdin/	http://www.cs.wisc.edu/~ghost/index.html	Free public licensing with terms included
Ghostview	Postscript viewer	ftp://ftp.cs.wisc.edu/pub/X/	http://www.cs.wisc.edu/~ghost/index.html	Free public licensing with terms included
GRASS4.1	Geographic Information System	ftp://moon.cecer.army.mil/pub/grass/grass4.1/release/	http://www.cecer.army.mil/grass/GRASS.main.html	Public domain No license required
XSonar	Side scan sonar processing system	ftp://boomer.er.usgs.gov/pub/sonar/	ftp://boomer.er.usgs.gov/pub/sonar/xsonar.ps.Z	Public domain No license required
MB-System	Multibeam sonar processing system	ftp://lamont.ldeo.columbia.edu/pub/swath_data/	http://www.ldeo.columbia.edu/MB-System/MB-System.intro.html	Public domain No license required
GMT	Generic Mapping Tools	ftp://kiawe.soest.hawaii.edu/pub/gmt/	http://www.soest.hawaii.edu/wessel/gmt.html	Free public licensing with terms included
netCDF	Common data exchange utility	ftp://ftp.unidata.ucar.edu/pub/netcdf/	http://www.unidata.ucar.edu/packages/netcdf/	Free public licensing with terms included
DTM	Data Transfer Mechanism for Interprocess Communication	ftp://ftp.ncsa.uiuc.edu/DTM/	http://xtc.ncsa.uiuc.edu/DTM/Documentation/DTM2.4/dtm.tp.html	Public domain No license required
Motif 2.0	X Windows GUI programming system	Metrolink, Inc.	http://www.metrolink.com holly@metrolink.com	Proprietary $199 license per installation
OpenGL	Graphics programming system	Metrolink, Inc.	http://www.metrolink.com holly@metrolink.com	Proprietary $199 license per installation
Maptech Professional	Helm Guidance Electronic Nautical Chart program	Resolution Mapping	1-617-860-0430	Proprietary $500-1000 license per installation
SeaView / SeaSurvey	Multibean collection and processing software	SeaBeam Instruments Corp.	mkt@seabeam.com 1-800-732-2326	Proprietary commercial licensing
Swathmap	Multibeam collection and processing software	Univ. of New Brunswick Ocean Mapping Group	jhc@atlantic.cs.unb.ca	Distribution limited to supporting members who can license
RTGIS	Real Time Extensions to GRASS	URI Ocean Mapping Development Center	tyce@oce.uri.edu	Distribution limited to supporting members who can license

4. Real Time Geographic Information System (RTGIS) for Swath Mapping

Real time in the context of mapping generally means aboard ship. Figure 1 represents our RTGIS shipboard mapping configuration with sensor data being concentrated and time stamped, then passed on for collection, processing, and display. Both before and during surveying, line planning and trackline selection generally occurs, based upon previous operations. The tracklines are then supplied to a track-following system which provides helm guidance (preferably on an electronic nautical chart or ENC) and autopilot control if so equipped. Our present PC toolkit configuration uses two PC's to accomplish the tasks in figure 1. The first PC runs the Linux toolkit with RTGIS capability and performs all functions except helm guidance. The second runs an ENC based helm guidance system (e.g. Maptech Professional) in DOS or Windows. The helm guidance system is provided a single RS-232 interface with multiple NMEA 0183 format messages containing time, position, depth, heading, course and speed. Track lines to follow are provided via ethernet file transfer. The RTGIS system allows for line, track and coverage displays on top of any number of GIS data layers from previous surveys, including nautical charts. GIS data layers are one of the end products of all the processing tools. An example of GIS data layers which might be used by the RTGIS is shown in figure 2, which includes NOAA chart, coastline, sidescan mosaic, sample sites and sidescan imagery draped over bathymetry [4].

Table 2. Toolkit Software Functions

Module	Software	Functions
System Software		
Computer Environment	Linux 2.0.0	UNIX operating system- host for all other system and user software
	Xfree86 3.2	Xwindows implementation- host for all Xwindows-based user applications
	TCP/TP	Complete TCP/IP implementation- host for networking applications, ftp, telnet and ethernet data acquistion.
	Motif 2.0	Port of OSF/Motif for Linux, includes Motif window manager and all Motif libraries and headers for support of Motif-based application GUIs
	OpenGL	Fully SGI-compliant port OpenGL for Linux, includes software double buffering, depth buffering, accumulation buffering, anti-aliasing, texture mapping, fog, lighting, etc. Supports OpenGL-based graphics applications
	Tcl/Tk	System for developing and using GUI applications. Provides the top level RTGIS interface, or "Toolkit"; menus provide consistent interface to all other Toolkit user software
	netCDF	Data structure to support GMT and MB-System user software
	DTM	Interprocess Communication to supports RTGIS real time extensions
	Ghostview	Postscript map viewing
	Ghostscript	Postscript hard copy map output to user-selectable printer or plotter
	GMT	High quality map creation of user defined data overlays and multibeam data / MB-System support
User Software		
Survey Planning	RTGIS	Historic data browsing, Sidescan sonar coverage display, Survey line layout, Survey line export to Helm Guidance Digital Terrain Model creation from raster NOAA chart data layers
Data Acquisition	RTGIS	Serial data acquisition and logging of multiple navigation sources, gyro heading, magnetic heading, and single beam bathymetry via 8-port serial port extenders Sidescan sonar data acquisition and logging of digital output from EG&G 960 Deck Unit via PC parallel port Multibeam data acquisition and logging via PC Ethernet port
Survey Monitoring	RTGIS	Real time text and graphical monitoring of data logging, Real time ship track display Real time swath coverage display
RTGIS	RTGIS	Real time output of reconstructed NMEA messages to Helm Guidance for line steering and autopilot control
	Maptech Pro	Laptop display of NOAA chart with ship navigation overlay Display of current survey line, Output to autopilot
Data Management	GRASS4.1	Provides geographical data base structure and interface to an RDBMS
	RTGIS	Post-survey data reporting, CD-ROM writing of raw and processed swath data for storage and on-line reference
Sidescan sonar	RTGIS	Data acquisition and logging, Import of Xsonar raster output to GRASS raster coverage
	Xsonar	Complete sidescan sonar processing and gridding
	GRASS4.1	Swath mosaicing, translation, and rubbersheeting
Multibeam sonar	RTGIS	Real time data acquisition and logging Import of MB-System raster output to GRASS raster coverage
	MB-System	Complete multibeam sonar processing, gridding, and mosaicing
	SeaSurvey	Produce realistic geological views of multibeam data in real time
	SeaSwath	Produce waterfall, profile views of multibeam data in real time
	SeaMapper	Interactive, graphical processing and mapping of multibeam data
	Swathmap	High performance multibeam sonar monitoring and editing software

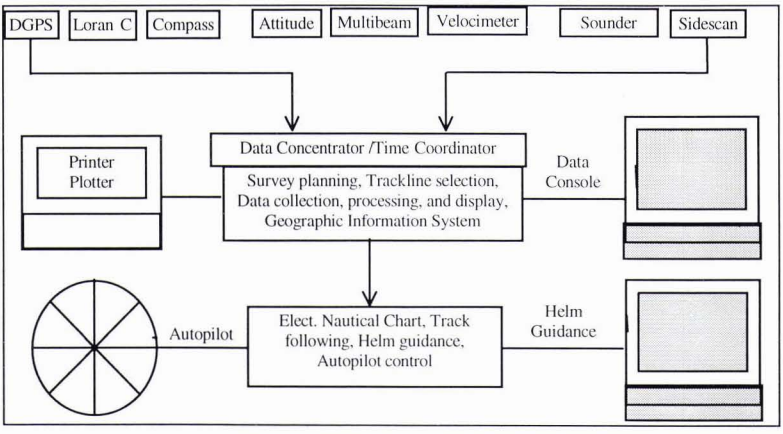


Figure 1. RTGIS shipboard swath mapping configuration

5. RTGIS Real Time Extensions to GRASS

GRASS 4.1 is a fully functional GIS consisting of over 300 programs for displaying and analyzing geographic data. There are more than 46 display programs, 18 general management programs, 72 raster manipulation programs, 68 vector manipulation programs, 20 site manipulation programs, 32 imagery processing programs, 5 photo processing programs, 8 printing/painting programs, 3 postscript interface programs, 32 miscellaneous programs, and 18 shell scripts. There are also numerous related programs included with the GRASS4.1 distribution, such as PROJ4 from USGS for coordinate transformations and PBMPlus for image file translation. However, GRASS has historically been used for land-based applications where the databases are well

populated and real time data acquisition has not been a necessity. Thus, GRASS4.1 by itself is not well suited for real time operations.

In order to give GRASS Real Time capabilities, a 3 component system was created. The first component consists of a modification to certain GRASS library routines. GRASS4.1 uses a resource file which defines a set of variables to define the GIS environment, similar to UNIX environment variables. GRASS uses the state of these variables as a form of Inter-process Communication (IPC). However, the library routines provide no mechanism for controlling access to the resource file. This is highly inadequate for real time operations, when many background processes write and read the resource file asynchronously. To control access to the resource file in real time mode, the standard GRASS4.1 library was modified to use semaphore file locking which guarantees that only one single process will have access to the resource file at any one time.

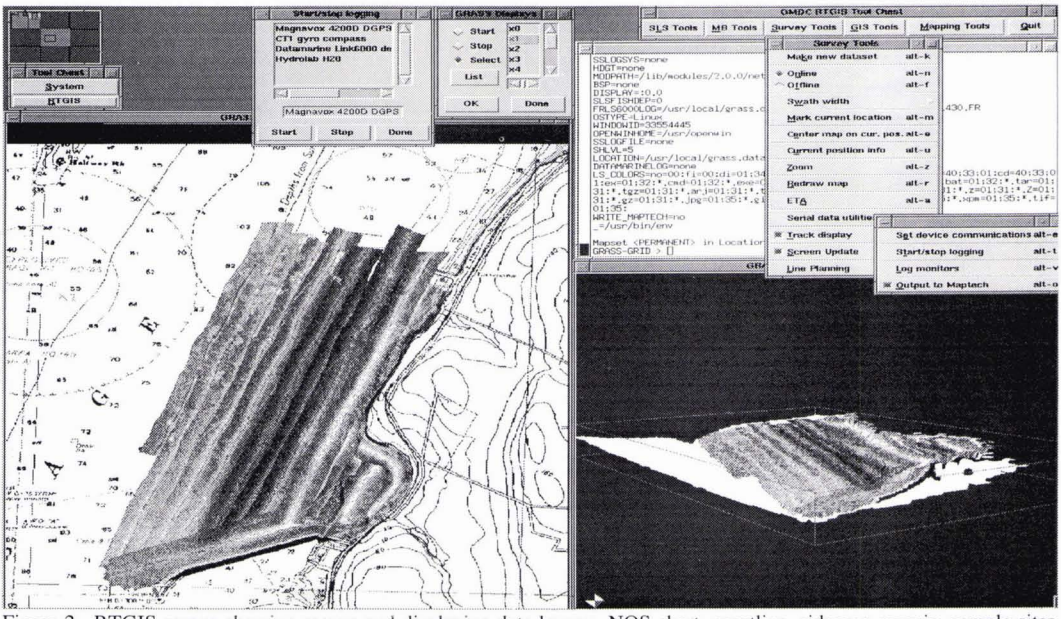


Figure 2. RTGIS screen showing menus and displaying data layers: NOS chart, coastline, sidescan mosaic, sample sites, and 3-D bathymetry draped with sidescan mosaic.

The second component for providing real time capabilities consists of a message passing facility to simplify the IPC. The Data Transfer Mechanism (DTM) from the NCSA fulfills this task. DTM provides a highly simplified interface to Berkeley sockets for IPC. The third component goes hand-in-hand with the DTM implementation. It is simply a C header file which coordinates the DTM port addresses for all real time modules. By including this centrally located header file, each real time module is provided with coordinated access to all other real time modules via message passing to the predefined ports. Using this 3 component real time extension to GRASS4.1, any module may request data from the loggers and respond accordingly in real time. While the toolkit is aimed at support for swath sonar operations (sidescan and multibeam), the comprehensive nature of the GIS allows support for single beam hydrography, sampling programs, bottom photography, survey data management, etc.

6. Sidescan Sonar Processing with Xsonar

The Xsonar software package was developed by Bill Danforth at the Woods Hole office of the U.S. Geological Survey for shipboard processing of sidescan sonar data [5]. This software has been integrated with our RTGIS environment and provides standard sidescan data processing including automatic and manual bottom tracking and water column removal, geometric and radiometric corrections and filtering, track integration and geo-referencing, and multi-swath mosaicing via cut and paste of hardcopy output to a thermal printer.

Figure 3 shows some of the menus and beginning screen displays for Xsonar. In the upper left hand corner is the main setup window. This window is used to select a sidescan sonar file for processing, configure its input parameters, and select the processing function. Here we have selected the input file 13-14.dat. We have selected latitude/longitude navigation input, a navigation filtering interval of 0.41 minutes (time), 100 meter swath width, and 16 bit input with only the lower 12

bits being significant. The process frame shows that we have selected slant range correction, destriping, and beam pattern removal processing. In addition, Xsonar provides file translation from several common sidescan sonar file formats to the Xsonar internal format, interactive navigation editing and smoothing, linear stretch and equalization image processing, histogram generation, and gridding of sonar imagery.

The Showimage window at the lower right hand corner of figure 3 is used to view the sidescan sonar imagery, either raw or at any one of the intermediate processing steps. Showimage may also be used to obtain per ping information from the sonar file. The Showimage Telemetry window at the upper middle of Figure 3 contains pertinent information for the ping currently selected with the middle mouse button. A significant and powerful feature of Showimage is the ability to interactively correct bottom tracking using the Showimage Zoom Window shown at the lower middle of figure 3.

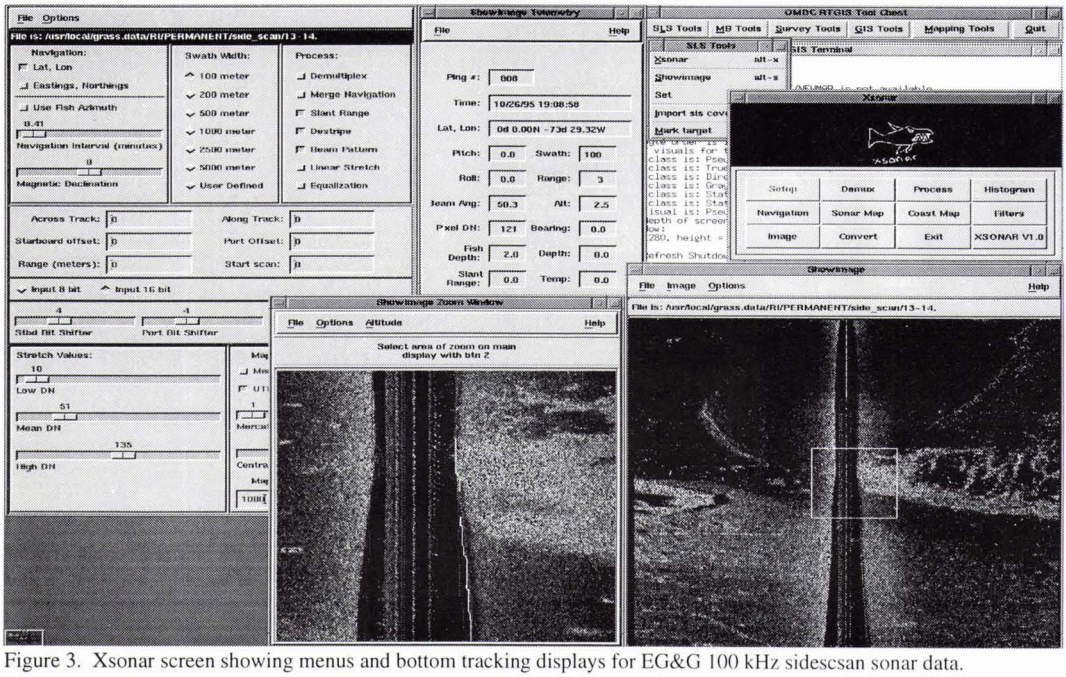


Figure 3. Xsonar screen showing menus and bottom tracking displays for EG&G 100 kHz sidescsan sonar data.

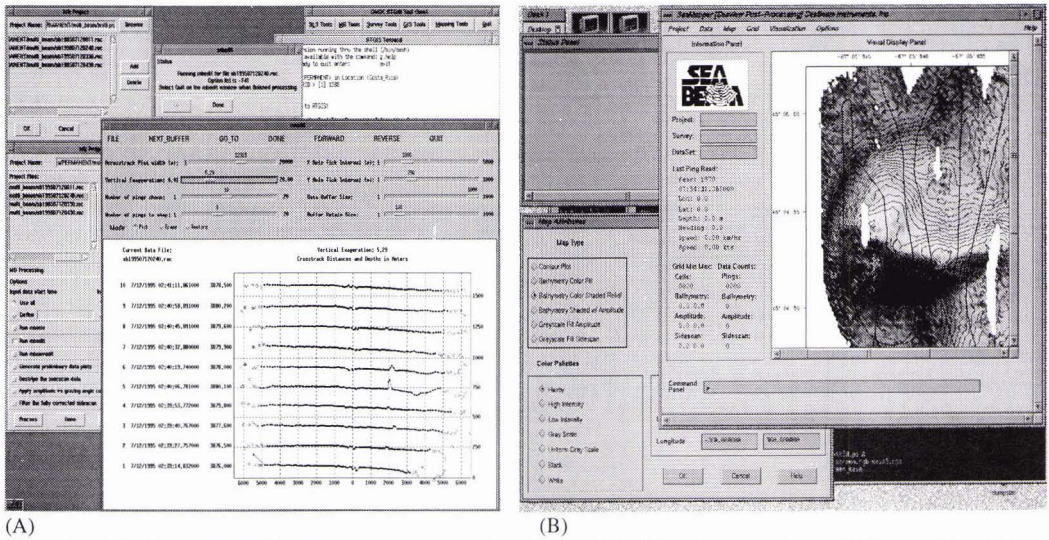
When all sidescan sonar processing is complete, the Sonar Map function is used to grid the sonar imagery for a user-defined region and resolution. The geo-referenced raster imagery file is then provided to the RTGIS using the Import sls coverage function. GRASS is then used for mosaicing the swath imagery. Included is the ability to translate and rubbersheet the swath imagery for full control of the final mosaic. The sidescan sonar mosaic in figure 2 above was created with XSonar and its interface to GRASS.

7. Multibeam Sonar Data Processing

Multibeam sonar processing is accomplished with the public licensed MB-System [6] and a subset of SeaBeam's proprietary SeaView package which includes SeaSurvey, SeaSwath, SeaMapper, and SeaVisualize [7][8]. Figure 4 shows multibeam sonar data processing sessions using MB-System and its interface to the RTGIS. The MB Project window at the upper left of figure 4A is used to define a set of multibeam sonar data files to include in the current Project. Each multibeam Project is uniquely named and has an associated Project File which stores the complete processing history of all sonar data files in the Project. Included in the Project history is information about all sonar processors who have worked with the Project.

At the left middle of Figure 4A is the MB Process window which provides interactive control of MB-System processing routines. Processing may be applied to all files in the project or any subset thereof. MB-System contains a large set of programs for various processing tasks. The RTGIS interfaces to the subset of processing routines suggested by the MB-System documentation. The RTGIS interfaces to multibeam sonar processing include generating and viewing file statistics, beam editing (fig. 4A), navigation editing, sidescan destriping, beam angle and grazing angle sidescan corrections, bathymetry and sidescan gridding, user-selectable 2D and 3D plot generation to user-selectable printers and plotters (fig. 4B), and import of geo-referenced grids to GRASS.

SeaSurvey is a new SeaView software package from SeaBeam Instruments. A subset of this package has been adapted to the toolkit. This product provides screen-based tools for viewing and analyzing swath sonar data in real-time. A variety of map and 3D perspective views of bathymetry and sidescan data are generated as the sonar data are collected. The underlying data i/o is modular and supports many sonar data formats. The displays can be interactively queried to show data values at particular locations, the sizes of targets of interest, or the distance and heading between two points. Survey or cable routes can be entered and adjusted interactively. Sections of data can be selected and loaded into several analysis tools. If one or more sections of ship tracks have been selected, users may launch various data analysis tools which work with the selected data.



(A) (B)

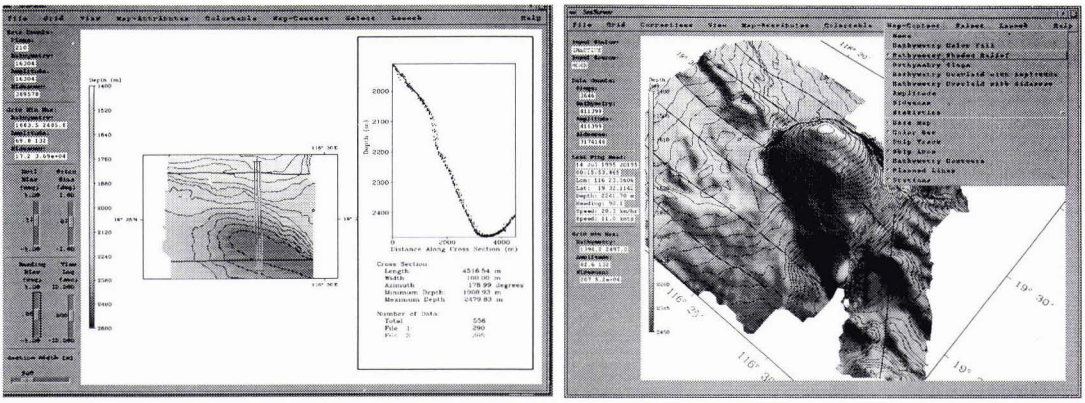
Figure 4. (A) MB-System multibeam sonar processing showing the RTGIS interface and the mbedit beam editor. (B) SeaMapper multibeam trackline and coverage display.

The bathymetry browser allows the user to inspect the swath bathymetry across track profiles several pings at a time, stepping forward and backward through the selected data as needed. This utility is valuable for verifying the quality of bathymetry data and identifying the nature of artifacts when problems occur.

The navigation browser shows the longitude, latitude, speed, heading, roll, pitch, and heave data as time series. The user may compare speed and course made good with the recorded values, helping to identify problems with the navigation. This tool also allows the user to correlate bathymetry errors with problems in the motion sensor or VRU.

The sound velocity analysis tool displays the current water sound velocity profile (SVP) used by the sonar, an SVP derived from a global database, and "bathymetry residuals" calculated using the current SVP. The "bathymetry residuals" derive from the average residuals of the across-track bathymetry relative to linear fits to each of the across-track profiles. If the seafloor is reasonably planar, the residuals are dominated by the "curl up" or "curl down" of the outer swath when the SVP is incorrect. Users can interactively modify the SVP and recalculate the residuals to arrive at an SVP which "flattens" the bathymetry swath.

The patch test tool (fig. 5A) displays the selected data in a fashion quite similar to SeaSurvey's 2D map mode. Users can drag the mouse to select a slice of bathymetry data, which is then displayed as individual soundings in a depth-distance section. If there are problems with the roll bias, pitch bias, heading bias, or navigation time lag parameters used by the sonar, mismatches between the data from different swaths will be obvious. The bias parameters can be interactively adjusted so that the data become consistent. If a proper patch test survey is done, the tool allows users to isolate and determine the errors in the bias parameters. For survey monitoring, SeaSurvey provides tools for real time viewing of data in 3-D from different perspectives (fig. 5B).



(A) (B)

Figure 5. (A) SeaPatch tool for roll, pitch, heading, time correcting (B) SeaSurvey 3-D real time bathymetry display

For NOAA multibeam hydrographic operations, a subset of the Swathmap processing tools developed by the University of New Brunswick, Canada, has been adapted to the toolkit for shipboard operations. Swathmap is a developmental set of tools particularly well adapted for processing data from very high data rate multibeams like the Reson Seabat.

8. Conclusions

Our toolkit effort has had considerable success migrating powerful UNIX workstation software tools for swath sonar mapping to the PC under the Linux operating system, in major part due to the depth and breadth of the operating system and supporting software. While some of the tools which support intense OpenGL graphics run slowly under our present software emulation, faster processors and dedicated graphics hardware are expected to be available soon. In the future we hope to be able to add NOAA sounding selection software tools to the toolkit along with much of the Hydrographic Multibeam Processing System software (HMPS) developed by the U. S. Naval Oceanographic Office.

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