DESIGN OF A MARINE GEOGRAPHIC INFORMATION SYSTEM FOR SEABED MAPPING AND CLASSIFICATION

Geoffrey Shippey (1), Klas Vikgren (1), Anders Elhammer (2) and Rustan Finndin (1)

(1) Chalmers University of Technology, Department of Underwater Technology, Gothenburg, Sweden
(2) Geological Survey of Sweden, Uppsala, Sweden

ABSTRACT

A preliminary description of the spatial database under development for the ESMAC (Environmental Seabed Mapping and Classification) project is presented. The system has the working name of GISMO (Geographic Information System + MOsaiccing). The paper outlines requirements and key features of the design. It is required to handle side-scan data from Geological Survey of Sweden, and multibeam data from Simrad Subsea A/S of Norway. However the multibeam data is subject to considerable processing in any case to generate the bathymetric terrain model, which simplifies the GISMO task. Hence the paper is more concerned with processing of digital sonar data. A main requirement is to support hydroacoustic classification experiments by mapping "ground truth" showing the distribution of bottom sediments and bentos over selected regions of the seafloor. Within the project, ground-truthing of shellfish habitats and sea-weed is carried out by video-camera using a remotely operated vehicle. A new procedure is described for generating strip-charts of the seabed from video-sequences, to enable them to be handled in a similar manner to side-scan records. Current facilities for sonar preprocessing and mapping are outlined, giving an example of the mosaiccing technique.

INTRODUCTION

ESMAC survey is carried out by M/K Simrad, S/V Ocean Surveyor, and R/V Ancylus, equipped with different instrumentation for multibeam, sidescan, ROV (Remotely Operated Vehicle), and bottom survey. Four key areas of a few square kilometers with different bottom types have been selected in the Oslo Fjord, Skagerrak, and Kattegat. A main purpose of the database is to enable survey records from the different instruments to be compared with each others to facilitate classifier training and evaluation of classifier performance. "Ground truth" obtained by grab samples at discrete points on the seafloor, and by video-camera survey using the "Sea-Owl" ROV, is used to evaluate this performance. In the future, survey charts derived using the system should enable viewing of seabed changes over time, as a vital tool in the task of environmental monitoring. A common geographic frame of reference is required to support these comparison studies, and to enable geologists, biologists, and other marine scientists to apply their interpretation knowledge to the data. Since individual side-scan records are of limited use for scientific assessment, the system should enable them to be "mosaicced", i.e. selected, rectified, and integrated into charts covering larger areas. Although ground coordinates are needed for data comparison, classification itself must usually be carried out on "raw data" in instrument coordinates, since conversion destroys much of the statistical information employed. This poses the requirement to move easily between large volumes of data stored in different coordinate systems, and at different scales. These different requirements together add up to a form of marine GIS, incorporating mosaiccing facilities for much of the data.

GENERATION OF SURVEY DATA ON OCEAN SURVEYOR

S/V Ocean Surveyor is a 38 meters long, 509 GRT, twin hull sandwich constructed vessel, with built in:
- large survey/instrument room,
- dynamic positioning system (Simrad Albatross ADP 100, modernized 1992),
- attitude sensor (Datawell Hippy 120B),
- ultra shortbase acoustic positioning system (Simrad HPR 309T),
- hydrographic echo sounder (Simrad EAA 200),

making it ideal for mapping operations.

The survey system comprises:
- Qubit Trac V survey computer system complemented with a real time position extrapolation unit, a PC for logging water depth and magnetometer data to diskettes, printer and HP 7580B plotter.
- GeoAcoustic SE 881S workstation, dedicated to side scanning sonar work and connected to one of three Klein side scan sonars (50 kHz, 100 kHz or 500 kHz).
- GeoAcoustic SE 881S workstation dedicated to high resolution seismic work, equipped with 7 input channels and connected to a six channel Teledyne streamer and a Teledyne source receiver. Depending on the aim of the survey an EG&G Uniboom or an EG&G sparker is used as sound source.
- GeoAcoustic SE 881S workstation dedicated to subbottom profiler work, connected to an Edo Western 3.5/7 kHz subbottom profiler built into the hull of the ship.
- Intergraph workstation dedicated to description of sediment samples, connected via a frame grabber to a video camera mounted above a sample tray.
- Intergraph workstation dedicated to description and storage of video images of the sea bottom. This workstation is connected via a frame grabber to an underwater video camera system.

The survey computer system recalculates the position of the ship and each sensor every second from information supplied by a Syledis B interrogator (radio navigation), a Magnavox MX 200/MX50R GPS/diff GPS receiver (satellite positioning). Attitude data is supplied by the main gyro compass and by a Datawell Hippy 120B attitude sensor; Ship's speed is supplied by a Sperry SRD 421S Doppler log. It keeps track of the ship's offset from preplanned run lines or sample stations and feeds this information to the dynamic positioning system and helmsman's displays. A Simrad HPR 309T is provided for underwater acoustic positioning. Via the position extrapolator, the survey computer manages the triggering of the hydro acoustic/seismic systems and supplies a telegram containing line number, date, time, course over ground, sensor position(s) and water depth to the relevant SE 881S workstation. It also handles logging to hard copy and track plotting.

The SE881S workstation manages conditioning, digitizing, processing and recording of the received hydroacoustic/seismic signals. The conditioning stage comprises frequency filtering functions and several gain functions, including a useful "Optimum gain control" which automatically keeps the maximum signal level reasonable on a shot to shot basis. Processing facilities include bottom tracking and slant range correction for side-scan sonar. Digitized signals from all used channels, including position information supplied by the survey computer system, are output in SEG Y format to Exabyte cassettes.

The Intergraph workstation serves several purposes including:
- coarse geographic, geometric and grey-level processing of side-scan sonar records,
- side-scan sonar mosaiccing,
- interpretation of side-scan sonar mosaics as regards bottom structuring,
- compilation of geological and contour maps.

Digital map design and reproduction is also carried out by Intergraph software. Prepared map manuscripts are transformed to the stage of colour separated raster files that may be plotted on a laser film plotter.

AUTOMATIC GENERATION OF STRIP-CHARTS FROM ROV VIDEO SEQUENCES

The ROV used, a Sea Owl MK II from SUTEC, is unmanned, tethered and can be operated to a depth of 350 m. It is equipped with a control system and 7 thrusters that enable it to swim in any direction with very good stability, weighs 95 kg in air, and is 1.4 m long, 0.8 m wide and 0.6 m high. Sequences from a video camera mounted on this vehicle enable sea-bed features to be observed at a scale between conventional sea-bed coring and sonar survey. In environmental studies of the seafloor, this scale enables shellfish communities and the extent of sea-weed to be recognized even in turbid costal waters. Compared to film cameras operated by divers, an ROV-mounted camera is less restricted in terms of depth, velocity and time. However the evaluation of underwater film sequences is an ardous job; hard copy documentation is typically restricted to isolated frames of poorer quality than a still photograph. One solution to this problem is to assemble the isolated frames into a mosaic along the ROV-track. The preferred procedure is to fly the camera with the focal axis approximately perpendicular to the bottom. However angles up to 45 degrees may be necessary in turbid waters with low visibility for piloting purposes. The technique described below was designed to handle such oblique views.

A program has been written [1] to merge strips representing the areas travelled between frames into a continuous strip-chart of the sea floor (Fig. 1). Patches representing common features in the overlapping areas of successive frames are compared. The displacement giving minimum norm or maximum cross-correlation enables ROV movement between frames to be calculated. Estimated movement of the different patches varies considerably, but the mean values are good enough to estimate ROV movement. A model describing the camera optics is needed, since coordinates on the screen must be converted into sight angles which, together with altitude information, give the distance to an object. Problems concerned with patch selection can be made easier if each frame is preprocessed in order to find textures (e.g. stones or sand with stones and shells) that are more suitable for matching than others (e.g. seaweed). Values for camera pitch and altitude, needed for rectification and calculation of scale were superimposed on the video data, and automatically read from the digitized frames. Heading and roll information is not yet included in the program.

Trial strip-charts have been made automatically (Fig. 2a-c and 3) with errors small enough not to be visible, provided that ROV heading was unchanged and the sea floor almost flat. The sequences were recorded in colour at 25 frames/s, giving about 90% overlap between successive frames. In order to save storage space, and decrease the error caused by the quantification of the picture into lines, every third frame were digitized. Features on the sea floor appear in different perspectives on different frames, so rectification is needed before merging into strips. In fact there is possibly enough information to estimate a 3D bottom model.

MAPPING AND MOSAICCING

WOOLZ Data Representation

Rectified sidescan survey records are bent strips, typically one or more km long and a few hundred meters wide, depending on frequency. The tracks of the survey vessels themselves, and echo-sounder and sub-bottom survey lines, have zero nominal width. Rectified ROV video strips cover up to 100m by a few meters. Each rectified survey record is therefore an irregular patch covering a small section of the survey area. A data format is needed to handle such patchy data, plus vector data defining ship's track etc. This data format must support geometrical transformation of each patch, as well as the "cut and merge" operations involved in making a mosaic. The problem of handling patchy data is not new, and has been extensively studied in medical image analysis. Each patch is handled as a raster image, with each line of data termed an "interval". The data structure for the patch holds both the set of interval start/end points defining the patch boundary, and the table of pixel values filling the interior of the patch. This is termed a "Woolz Object" [2]. Chalmers computer scientists have used WOOLZ within an X-Windows environment [3]. One particular problem which WOOLZ helps to solve is rapid data retrieval, i.e. determining whether a certain patch includes or intersects an area of interest. Using the interval representation, boundary information is held separately from the data itself, so can be processed rapidly.

The User Interface: X-Windows

GISMO users may be marine scientists requiring a simple, convenient interface at sea. Pixel resolution for stored and displayed data is quite variable depending on the source of the data and the purpose of the display. Different types of record which were originally surveyed at different scales need to be compared on the screen, demanding a powerful zoom facility (including "negative zoom" or subsampling). Interactive operations for classification include the selection of training areas, and display of results, both in feature space and on the seachart. Methods of presentation should exploit the colour possibilities of the computer screen, for example to display sonar data and machine classification at the same time. For mosaiccing, the interactive operations include selection of common landmarks in overlapping patches, tracing of the boundary to be used for patch merging, and interactive "shade correction". Some of these interaction facilities are automatically provided in the X-Windows Environment which is available under the UNIX Operating System. The X-Windows facilities in GISMO are at three different levels:
- OPEN WINDOWS software biassed towards text display,
- software to handle grey-scale and colour windows, particularly pan, zoom, and intensity control,
- special software to handle underwater data, programmed by Chalmers.

Data Conversion

A SEGY file of sonar data from a particular survey line consists of a file header and a sequence of port and/or starboard traces. The file header contains descriptive information concerning the survey and the instrumentation recorded. Each trace is proceeded by a trace header which contains descriptive information, such as the digital sampling rate, plus a time stamp and navigation information such as position and course over ground derived from Syledis. The data-reading program breaks this data up into three files, a Descriptor File, a Navigation File, and either or both Sidescan Files. The port and starboard sidescan files contain a short header enabling the data to be displayed immediately as an X-Windows image. The data reading program also contains a number of options which permit selected sections of the data to be read, either completely or sub-sampled along and across-track. This data-structure is convenient in a number of respects. Most of the pre-processing operations can be carried out on the Side-scan Files regarded as computer images, with little or no reference to the remaining data. The Navigation File plus Descriptor File contain sufficient information to define and plot the sonar coverage of each survey line without accessing the full sidescan data. The Descriptor File contains the information necessary for non-geographic data retrieval, and approximate geographic retrieval. The Navigation File also plays a key role in the rectification task, and subsequent cross-referencing between rectified and unrectified data.

<u>Sonar Pre-Processing Operations</u>

<u>Artifact Removal</u>. The usual way to eliminate noise artifacts due to power supplies or other instruments is to estimate their spectral composition, and filter in the frequency domain. However this procedure is unacceptable when the spectrum is used for sea-bed classification. An alternative time-domain technique has been developed, which automatically extracts a template for the noise contamination and correlates this with successive trace to compute the best gain and shift for cancellation. This and other computationally intensive operations, exploit the image processing facilities of the ContextVision GOP 300 computer hosted by one of the SPARCstations.

<u>Slant Range Correction and Bottom Tracking</u>. Although it is eventually hoped to use a Digital Terrain Model to carry out slant- to horizontal-range correction, the standard bottom-tracking method is important for the time being. The automatic bottom-tracking facility provided in SGU instrumentation fails when bottom sediments are very soft, and also when the surface return overlaps the bottom return - a fairly common occurrence in shallow offshore waters. As a supplement, GISMO provides a semi-interactive facility in which the required bottom return is defined by a small number of points and then tracked accurately using a correlation window. Slant-range correction itself is carried out using difference equation techniques, with interpolation between pixels for the actual resampling.

<u>TVG Adjustment.</u> A mosaic is usually constructed from parallel survey lines with some overlap. Within the overlap area, the sea-bed is insonified from opposite directions on consecutive tracks. Systematic mismatch between echo strength on these adjacent records leads to a marked intensity discontinuity at the boundary in the subsequent mosaic, which adds to the difficulty of interpretation. A further problem is gain variation across the record due to instrument settings. Procedures are being investigated to enable the GISMO operator to correct the shading interactively. If all gain settings were recorded in the digital data, it would be possible to perform more systematic correction.

<u>Rectification.</u> Rectification is carried out on the echo files after slant-range correction, and requires an estimate of the position and heading of the sonar fish for each trace. In the SGU system, the towfish position relative to the vessel is estimated from the length of the towline. In the absence of direct monitoring, course over ground is considered to give the best estimate of towfish heading. The rectification method treats each pixel in the rectified image as a "bin" into which fall several samples of the pre-rectified image. The value assigned to the pixel can be the maximum, mean or median value. At longer ranges the number of samples is increased by allowing for the finite side-scan beamwidth. This helps to compensate for angle errors, which can cause holes in the rectified image. An efficient algorithm has been written to convert the unrectified sidescan echo into the interval-coded rectified WOOLZ Object.

<u>Mosaiccing</u>. Approximate alignment of overlapping records is already carried out by rectifying in a common frame of geographical reference. For more accurate alignment, previous research at Chalmers has investigated the use of large stones on the sea-bed as "landmarks", and also texture boundaries; it is planned to implement both facilities under X-Windows interactive control. In this way, the mosaiccing

task can exploit texture segmentation algorithms developed for classification. Interactive boundary delineation in the overlap area is carried out using a slave cursor in a second X-Window.

Example
Fig. 4 shows a simple example of mosaiccing, using two 50 kHz survey lines crossing at about 30 degrees. One of the raw records is shown in Fig 4a, with the tracked bottom echo superimposed (not difficult with this particular record). The pair of rectified port and starboard images from one survey line are shown in Fig 4b, and the other pair in Fig 4c. Rectification used the mean value of samples in each pixel bin. Gain correction proved quite difficult because gain variation appears to depend on bottom material, but some improvement was achieved which extended the useful range of each record. A mosaic derived from the four records is shown in Fig 4d, with one of the boundary cut-lines left visible. Merging of the records uses an averaging area around the cutline.

DISCUSSION

Even short experience with the ESMAC project has demonstrated that the requirement to support classification experiments places severe demands on all aspect of data acquisition and processing, from the accuracy of position information to the quality of images available for mosaiccing. Quality of ground-truth is of course fundamental to any classification experiment, and the ROV video survey described in the paper offers a significantly improved tool for this purpose. The section on Ocean Surveyor instrumentation indicated the investment needed to obtain high quality digital data, and a similar investment will be needed to make the best use of it. However the potential reward in terms of useful information are enormous provided that the classification techniques can be validated experimentally.

In terms of progress many of the basic facilities of GISMO are now in place, and a new set of problems require to be addressed, particularly data management. Semi-automatic mosaiccing is also a main target for the research, requiring careful thinking on the handling of sonar records collected from different directions.

ACKNOWLEDGMENTS

The ESMAC research has been carried out in close collaboration with other ESMAC Participants - ContextVision AB, Marine Research Institute in Lysekil, Norske Regnesentral, Simrad Subsea A/S whose assistance is gratefully acknowledged. Research funding has been provided by NUTEK of Sweden and the Nordic Industry Fund.
In the work reported here, the X-Windows and mosaiccing developments were made by Anders Bolinder and Lars Johanson of the Dept. of Applied Electronics at Chalmers.

REFERENCES

[1] R Finndin, 'Automatic Generation of Strip-Charts from ROV Video Sequences', M.Sc. Thesis, Department of Applied Electronics, Chalmers University of Technology, Gothenburg, Sweden, December 1992
[2] Y Piper, D Rutovitz, 'Data Structures for Image Processing in a C language and UNIX environment', Pattern Recognition Letters Vol. 3 (1985), pp. 119-129
[3] R Wikh, S Nivall, G Shippey, J Wahlström, T Gustavsson, 'X-Kary - A chromosome image analysis system based on X-windows', Swedish Conference on Image Analysis, Uppsala, March 10-11, 1992, pp. 245-248

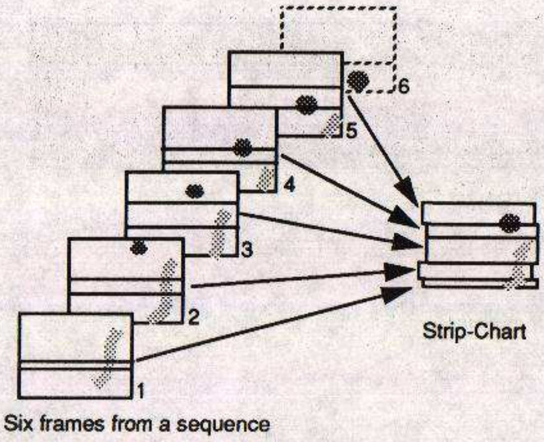

Figure 1 Schematic description of the strip-chart generation

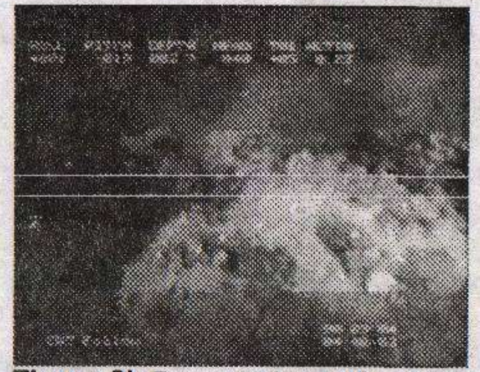

Figure 2b Frame #2 from strip-chart A with the strip marked

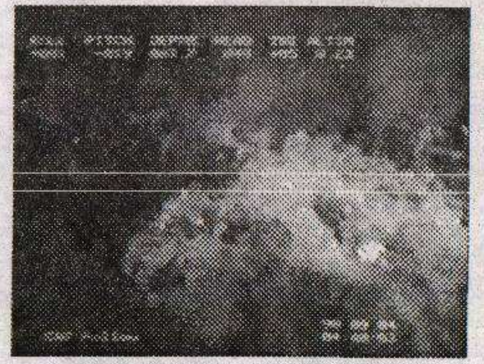

Figure 2a Frame #1 from strip-chart A with the strip marked

Figure 2c Strip-chart A made from 99 frames

Figure 3 Strip-chart B made from 99 frames

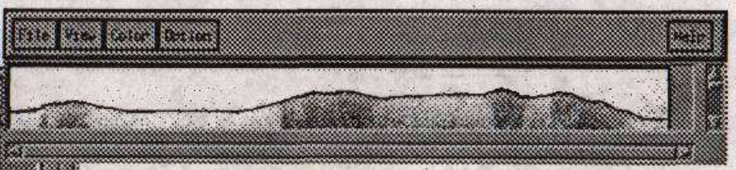

Figure 4a

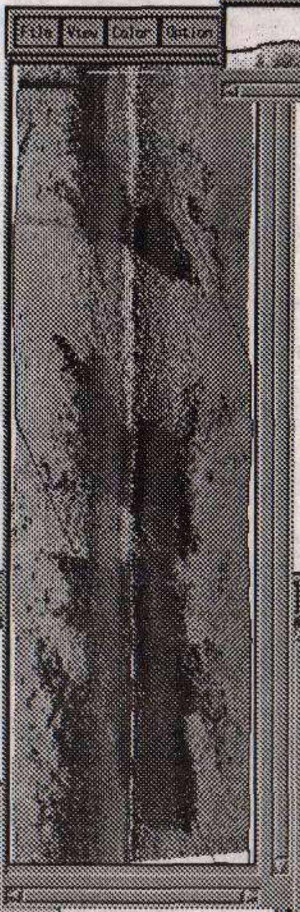

Figure 4b

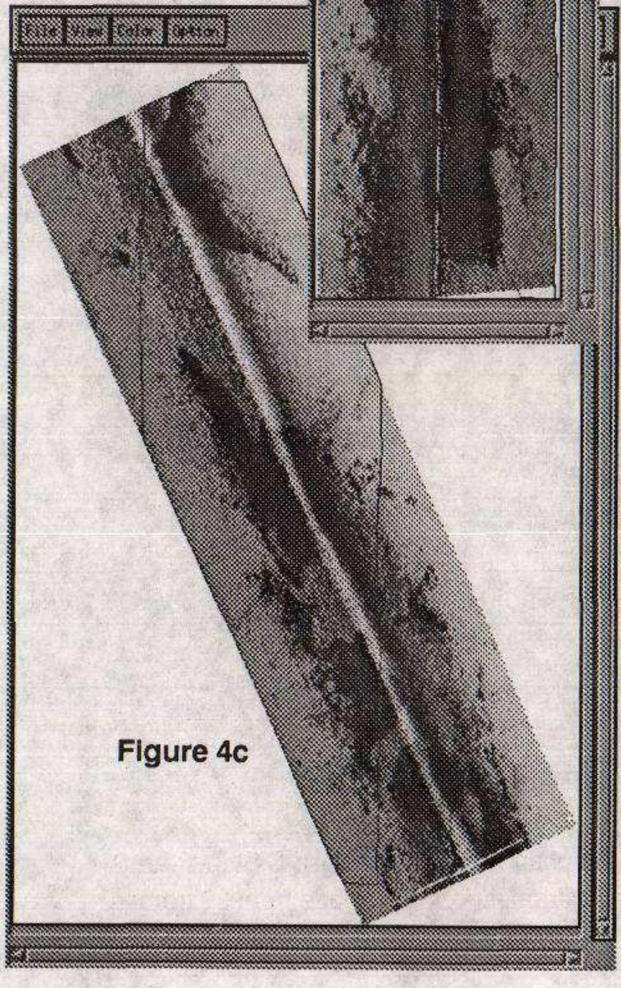

Figure 4c

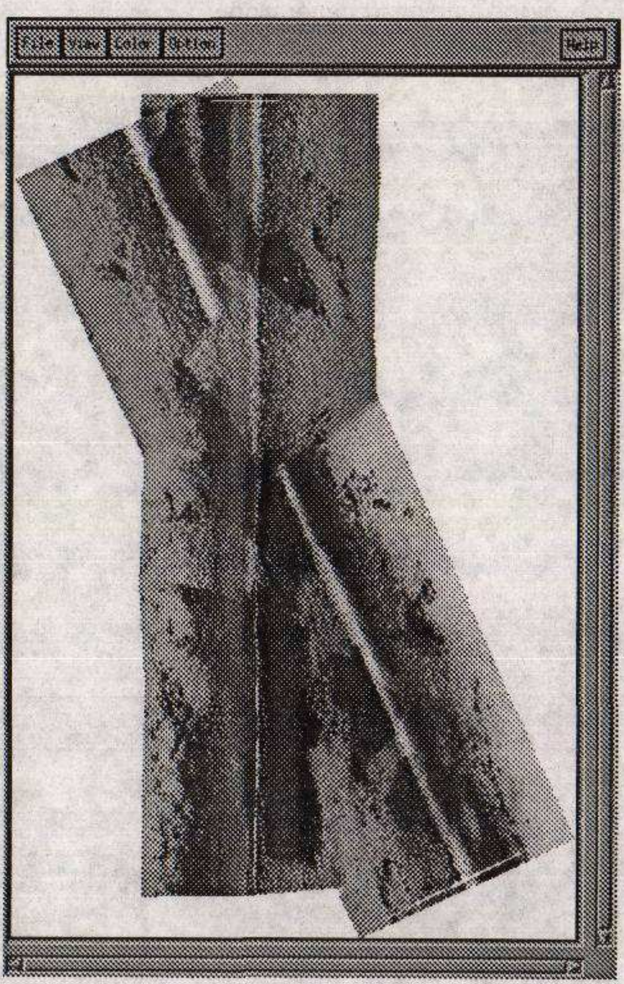

Figure 4d