DESIGN AND IMPLEMENTATION OF AN INSHORE HYDROGRAPHIC SURVEYING SYSTEM

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PREFACE

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ABSTRACT

Computers are now widely used in hydrographic surveys to take advantage of their ability to provide navigation function and data processing capabilities. The design parameters that play an important role when we try to create an automatic data acquisition and processing system are the accuracy with which sea bottom is represented, the reliability, the compatibility with existing hardware, the man/machine interaction, the modularity and the cost of the system.

In order to optimize the design parameters, an automatic data acquisition and processing system was built around the Apple IIe personal computer. The algorithms required to meet the design objectives have been implemented in larger systems. These systems are down scaled to a system that will serve the needs of near shore hydrography. Different systems of lines, used to sample the depth, are compared: straight parallel lines, lines of position of electronic positioning systems, circles and radial lines ("star" mode). In order to filter the position data simple gating techniques are compared with Least Squares and Kalman Filters. In order to filter the depth data depth filtering techniques are examined.

The results indicate that the Apple IIe with commercially available peripherals and standard software, offers great promise of replacing larger and more expensive hydrographic data acquisition and navigation controllers. Straight parallel lines give efficient coverage of the survey area only if they can be modified on-line. The "star" mode is the best shoal examination pattern with respect to track keeping ability. The memory and computational speed constraints of personal computers require the use of simple linear filters to filter the position data. Visual comparison of digital depths with analog depths is an efficient depth filtering technique.

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1. INTRODUCTION

The purpose of this thesis is to define the design parameters for an automated data acquisition and processing system and to desribe the development and testing of a specific system that optimizes these parameters for inshore hydrographic survey : a detailed description of the sea bottom including measurements of tides and currents in depths of 40 metres or less *(Umbach, 1976)*. The end product of such a system is a chart or a set of bottom profiles at scales 1:20000 or larger, unless smaller scales are specified in the project instructions.

Activities that require the use of such a system are :

- charting of navigational waters,
- dredging operations for development and conservancy of harbours and waterways,
- examinations of areas to confirm or contradict the existance of seabed obstructions indicated by previous surveys and
- searches for reported seabed features *(Ingham, 1974)*.

This chapter incorporates the data acquisition and processing system with the Hydrographic Survey System, summarizes the contribution of the thesis and gives an outline of the subsequent chapters.

1.1 Elements of a Hydrographic Survey System

As specified in the progress report for Data Acquisition and Processing Systems *(FIG , 1977)* , a Hydrographic Survey System consists of six major inter-related elements: survey planning, data acquisition, data processing, survey management, support functions and survey environment.

Survey planning is the selection of the steps that will lead to an efficient achievement of the client's requirements. For example, if the requirement is "safe passage of ships of some maximum draft", survey planning will delineate the area to be surveyed and the accuracy with which the bottom must be represented. These requirements are translated into the necessary equipment, time, personnel, cost and methodology of the survey. Details on survey planning can be found in *Ingham (1974)* and, *Surveys and Mapping Branch (1982).*

Data acquisition is the recording of information from different sources using calibrated instruments at pre-defined accuracy standards. The survey vessel is navigated along designated tracks, the depth of water is sensed, and tidal heights are measured along with any other information that will assist in representation of sea bottom topography.

Once the data has been acquired, data processing converts and presents it in a manner most appropriate to the client's needs. This includes editing and correction of data, merging data from different sources, selection of representative data and presentation of the data sample in a comprehensive and easy to use format.

Survey management has the responsibility of ensuring that the objectives of the survey project have been met, while optimizing the available resources (personnel, budget, equipment, time etc.).

Survey support consists of various functions including the maintenance and use of hydrographic boats, hiring and housing personnel, and the purchase and/or development of equipment, to name a few.

The survey environment includes sea state, radio and acoustic propagation problems as well as the political and economic environment where the hydrographic survey takes place.

Figure 1.1 illustrates the basic relationship among the survey elements at the level of the Survey System related to data acquisition. For each day of survey work, survey planning specifies the instruments, personnel and methodology that will be used. The launch hydrographer acquires soundings which after being processed, are analyzed by the survey manager (hydrographer-in-charge) who then updates the requirements for the work next day. These tasks are directly influenced by the environment and survey support functions.

1.2 Automated survey systems

This thesis deals with the data acquisition and data processing elements of a hydrographic survey system. Comments are also included where these elements interact with the other elements of the survey system. Both procedures (acquisition and processing) can be manual, automatic, or semi-automatic. Manual methods such as horizontal sextant angle resection, subtense ranging by single vertical angle, intersection from shore stations by theodolites, manual recording of LOPs (Lines Of Position) from radio positioning systems still exist. Semi-automatic methods provide the intermediate steps necessary to complete automation. Automation implies the development of computer assisted techniques for data gathering and processing. Data is converted to digital form to be processed by the computer, which initially was done off-line (e.g. use of digitizing table to convert analog echosounder outputs to digital form). However, many survey instruments are now designed to provide an output that is directly compatible with digital data acquisition systems.

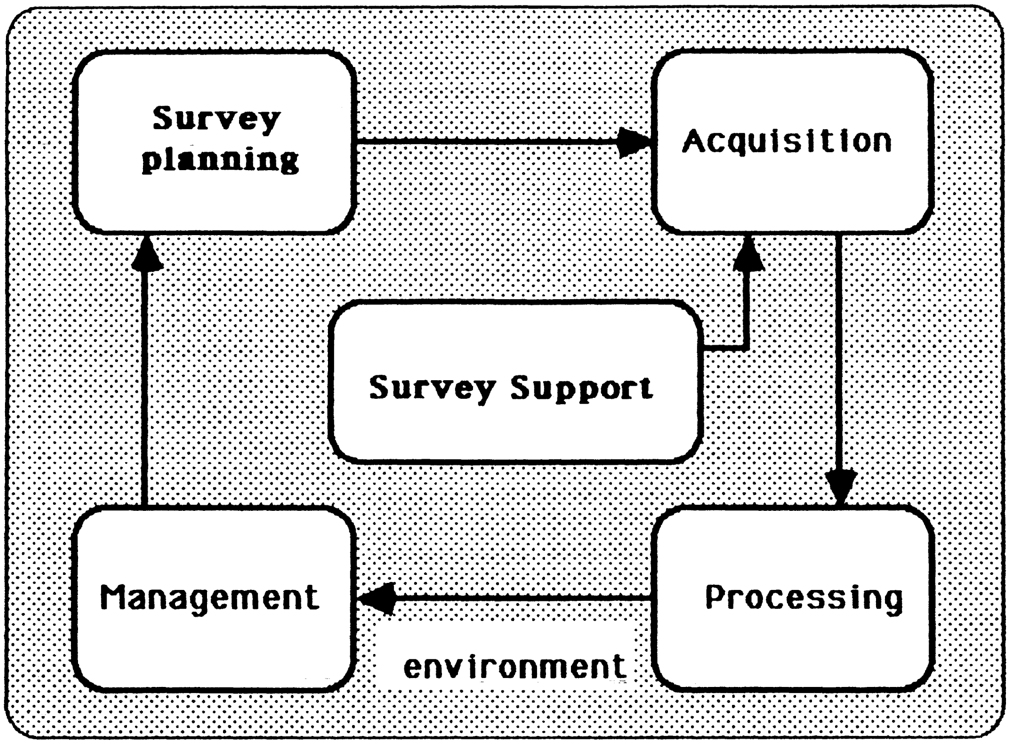

Figure 1.1 : Basic relationship among the survey elements at the level of the Survey System related to data acquisition.

Various authors have addressed the gains which may be achieved by automation in hydrographic surveys *(Mackay, 1972; Macdonald et al., 1975; Janes, 1984).* Computers provide automated error detection techniques and fast automated data acquisition and processing. This results in more accurate and complete field data and in surveys which are more efficient in time, personnel and resources.

A review of the existing data acquisition systems shows that there are two approaches in the design of an automatic data acquisition system. One approach is to use existing hardware (specific microprocessor, I/O hardware) and build a system that is designated to do a specific number of tasks. The other approach is to use "off-the-shelf" computers with a standard operating system allowing the use of "off-the-shelf" compilers.

Many parameters play an important role when one tries to create a data acquisition and processing system according to one approach or the other. The distribution of data processing functions between on-line (on board ship) and off-line (on shore), the amount and quality of gathered data, and the man/machine interaction are some vital parameters that have to be taken into consideration when designing a system. Various organizations and companies have proposed implementations geared towards the optimum solution of design problems. A widespread philosophy is to design systems which are <u>hardware oriented</u>, fast and store great amounts of data. However, these systems are <u>inflexible</u> and <u>incompatible</u> with a variety of peripherals. For example, only straight lines are to be navigated (one line at a time) or the systems may not provide navigational capabilities at all. Special hardware is required to process the data.

1.3 Main contribution of this thesis

The research desribed in this thesis resulted in the development of a complete, working, sea-tested hydrographic data acquisition and processing system, together with a complete user's guide. This system has been given the name **SEAHATS** (**S**urveying **E**ngineering **A**utomatic

Hydrographic data **A**cquisition and **T**rack control **S**ystem). The philosophy inherent to the design is that the system will be:

a) software oriented,

b) easily modified to meet different requirements,

c) compatible with existing hardware,

d) flexible for the user (e.g. different modes of operation) and

e) of low cost.

The backbone of the software structure for **SEAHATS** was created by *Mc Carthy (1983)*, however this first version of **SEAHATS** was lacking in flexibility and efficiency, had not been sea-tested, had no post-processing capabilities and lacked many of the features of the present system.

The following topics were investigated in order to meet the **SEAHATS** design objectives :

1. An automatic hydrographic data acquisition system consists of a central computer, the environmental sensors and peripherals as well as the hydrographer and the coxswain. Information is exchanged among these elements. The speed and the manner (format, digital or analog) of information exchanged is discussed in sections 3.1 and 3.2.

2. The survey vessel is navigated along lines of pre-defined geometric patterns. These patterns may be parallel straight lines, circles etc.. The application, size and configuration of area to be surveyed, sea bottom morphology, and the coxswain's experience in hydrographic surveys are some of the factors that govern the choice of a survey pattern. An evaluation of these patterns is made and the most appropriate techniques have been implemented in **SEAHATS**. These are discussed in section 3.4.

3. Data (positioning and bathymetric) must be filtered in order to be reliable. Many filtering techniques exist (gating, Least Squares, Kalman filtering etc.). These techniques are evaluated for use in inshore hydrographic surveys in section 3.3.

1.4 Outline of the thesis

This thesis is divided into six chapters. The sequence of chapters conforms to the sequence of tasks involved in hydrographic surveys : data acquisition, on-line and off-line data processing. The acquisition and processing algorithms are reviewed and developed or modified to accommodate the needs of inshore hydrography. A brief description of them is as follows.

In chapter 2, the design criteria for a hydrographic data acquisition and processing system are established with emphasis on the accuracy of the output and the flexibility of the system. Detailed description can be found elsewhere *(Boudreau , 1984; IGM report #2 , 1982).* The current status of commercially available systems is reviewed and these systems are evaluated with respect to the established criteria.

For the development of the navigation and hydrographic data acquisition controller, a top-down design concept is adopted. In chapter 3, the system is broken into separate modules including : the interface, quality control of observations, navigation, on-line modification and output modules. This chapter is devoted to the description of the direction and rate of information flow between different modules, as well as to the description of each module itself. The interface module describes the communication between the CPU (Central Processing Unit), operator, positioning system and echosounder. The quality control module investigates the errors inherent in positioning and bathymetric data, and provides the means to eliminate them. The navigation part deals with the algorithms used to steer the vessel and the systems of lines used to sample the depth. Finally, **SEAHATS** is described.

Chapter 4 deals with the off-line data processing procedures to edit, correct, reduce and present the collected data. These procedures are not new and are widely used in the hydrographic community. What has been absent (at least in the systems used by Canadian Hydrographic

Service), is the ability to use them in real time or almost real time to help the "data collector" in judging the results. This chapter describes such a processing package.

Chapter 5 is devoted to a brief description of the tests during the development history of the system and the evaluation and explanation of the obtained results.

Chapter 6 gives the conclusions and recommendations for future work and development.

Appendix I contains the algorithms used to provide steering information to the coxswain to keep the vessel on pre-determined tracks. In order to facilitate the use of the system, a User's Guide is available as the Technical Memorandum: **Operating Manual and Software Listings for SEAHATS** *(Hourdakis, 1985).* The difficulties encountered in testing the acquisition software in real time, gave rise to a simulation package *(Hourdakis, 1985)*, designed to simulate, as realistically as possible, the marine sensor data supplied to the vessel at sea.

2. DESIGN CRITERIA and REVIEW OF EXISTING SYSTEMS

The study of the requirements of an application, the philosophy behind the existing acquisition and processing systems, and the experience gained in hydrographic operations reveals a set of design criteria that has to be satisfied. These are: accuracy of sea bottom representation, reliability, man/machine interaction, modularity and compatibility, cost and future expansion capability *(Baudreau, 1984 ; IGM report #2 , 1982).* A brief review of the existing acquisition and processing systems will show to what extent these systems satisfy the above criteria.

2.1 Accuracy of sea bottom representation

The survey system should be capable of positioning seabed features within specified accuracy standards. These standards, according to the International Hydrographic Bureau Special Publication 44 *(IHB, 1982)*, for chart making purposes are :

- maximum distance between subsequent soundings 1cm (at the scale of survey) unless sea bottom topography or purpose of survey permits wider distance;

- positioning accuracy (referred to shore control) should not exceed ±1 mm (1 σ level at the scale of survey);
- the allowable errors for depth presentation are :

for depth	0-30 metres	0.3 metres
for depth	30-100 metres	1.0 metres
greater than	100 metres	0.01 of depth (metres).

For example, in order to achieve these requirements and produce a chart at a scale of 1:5000 steaming at a speed of 15 knots (~ 7,5 m/sec) the survey system should provide fixes every 6 seconds or less. This is practically manageable. In practice however, more frequent fixes are necessary in order to have valid soundings. A sampling period of 1-2 seconds or less is often necessary and it is discussed in chapter 3. Using the same example, to ensure that the estimated misposition on the chart does not exceed ±1 mm, the positioning system should give accuracies better than ±5 metres. For near shore hydrography and dredging operations the requirement for positioning accuracy is stricter : 0.3 - 3 metres and 2 metres probable error respectively *(Vriesendorp, 1981).*

The survey accuracy depends on the following :

1. X,Y positional accuracy.
2. Accuracy of locating the sounder transducer vertically with respect to the chart datum.
3. Miscorrelation in time between horizontal position and depth observations.
4. The beamwidth of the sounder transducer.
5. The frequency of the sounder.
6. The depth of water.
7. The maximum bottom slopes.

The frequency of sound transmission affects depth resolution. Depth resolution (R_{depth}) is equal to one half of the length of transmitted pulse :

$$R_{depth}=0.5\,n\,V_s/f \qquad (2.1)$$

where f: transmitted frequency, V_s: sound velocity in water and n: number of cycles of frequency f that the transmitted pulse contains. This implies that targets contained within pulse length/2 return a single echo and targets separated by greater distance return individual echoes. Wide beamwidths also degrade resolution in several ways. First, the echo signal is stretched due to the wave front curvature. Second, wide beamwidths result in worse angular or horizontal resolution which varies with depth. Finally, a seabed with great slopes is distorted as discussed in section 3.3.2. *Lewis (1980)* describes in detail the effect of beamwidth in sounder resolution.

When precision surveys are required for engineering or navigational projects, hydrographic conditions, such as tidal currents and storms, should be taken into account. For example, these conditions can alter sandwave crest heights up to 1 metre from Neap to Spring tide *(Langhorne, 1981)*.

The heave problem (vertical displacement of the sounder transducer due to wave action) can also be serious. A heave sensor feeding into an automated system is another role for automated systems. The heave problem is further discussed in section 4.3.5.

Weeks (1981) points out that another source of error lies in the miscorrelation of positioning and bathymetric data. The problem arrives from the way bathymetric and positioning data is transfered to the computer. If the data arrives asynchronously, a time tag of 1 second at a speed of 15 knots produces 7.5 metres miscorrelation . The problem is amplified when large scale surveys are produced with high speed boats. Another source of miscorrelation is the relative location of the antenna of the positioning system and the echosounder transducer on the ship.

The positioning system and echosounder should be capable of providing the specified accuracies. The software/hardware must support arithmetic operations without large round off errors.

The accuracy limits are the most difficult factors to control in the design of an acquisition system. On the other hand, it is difficult to compare the accuracy standards of two systems either due to a lack of information, or due to the many ways to express accuracy. Some of the methods used to evaluate and confirm accuracy are calibration, residual noise levels and bathymetric data correlation.

By calibration we determine the zero error for the survey equipment *(Riemersma, 1979)*. Comparing known seabed features to the same features developed from survey data the overall behaviour of the system is evaluated *(Gilg, 1970)*. In practice, an additional set of survey lines is run. Precision is determined by examining the distribution of differences between soundings at the intersections between principal sounding lines and cross check lines *(Monahan et al. , 1981)*.

Accuracy has the highest priority among the criteria as we approach shore (1-2 km), particularly when the surveys are related to marine construction. There is a limit, however, to the technique implemented in this research (microwave positioning) and we must return to the "old" method using theodolites or seek for other more accurate techniques such as range/azimuth positioning using a laser ranging system. For more details for this type of technique see *IGM report #1 (1982)*.

2.2 Reliability

An acquisition system is reliable when its correct operation is interrupted only by the operator. We consider both hardware and software reliability. Hardware reliability is the resistance of the hardware components to environmental effects. Software reliability implies that the software is capable of handling every situation for which it has been designed, and produces error messages when it is outside the specified limits.

The environment in which the navigation equipment lives is not an ideal one. It is subject to shock, humitidy, dust, vibration and temperature fluctuations. The system must be able to withstand all these factors, maintain control, produce error messages and continue running. The system should have been built with the marine environment in mind and should perform self diagnosis of all subsystems periodically to ensure reliable operation.

Operational reliability may be derived from down time statistics. Other considerations are system recovery time after a power or hardware failure, resistance to external disturbances and the operator's ability to solve both software and hardware problems (Mean Time To Repair, MTTR). An ideal acquisition system should have 100 % redundancy of hardware and software components. By redundant software we mean that software is written for the same task but implemented in a different way. However, this seldom exists in practice. For a software approach to reliability and resilience in hydrographic systems see *Leenaarts et al. (1984)*.

Some features that contribute to the reliability of a system are:

1. When receiving input from a positioning system, the output of range reading should be accompanied by a quality indicator (such as signal strength) and a source indicator which defines how the data was obtained (raw data, predicted etc.).

2. Computations should be done in the computer to ensure that standard algorithms are used.

3. Quality checks of standard deviations of system position measurements, crossing angles of lines of position, error ellipses, histograms and scatter plots are comprehensive tools to measure and monitor system performance. Most of these quality checks have to be provided in real time.

4. Redundant observations from a positioning system strengthen the position fix.

5. Redundancy of positioning aids ensures uninterrupted navigation if some aid fails, or strengthens the weaknesses among them. Integrated navigation is needed for reliable and accurate navigation. The benefits from integrated navigation can be found in *Grant et al. (1983)* and *Swift et al. (1981).*

2.3 Man/machine interaction

There are a variety of ways to organize the information flow between the computer and the users of information (hydrographer and coxswain). The form of communication can be computer initiated (inflexible) or operator initiated (flexible). These ways are:

- Question and answer dialogues. The computer asks the operator a series of questions and the user responds. It is very simple for the operator and can be written with a simple program. It is however, of limited flexibility (computer initiated).

- Command entry using mnemonics. The dialogue is concise and precise, but the operator must be familiar with mnemonics and input formats (operator initiated). Complex software is required.

- Menu - selection dialogues. The communication is simple for the operator but a large number of characters are used (operator initiated). Very complex software is required. The replacement of the conventional keyboard with input devices like mouse, joy stick and trackball provides more efficient menu-selection communication.

- Graphics using chart displays. A very effective method for summarizing information, but it is expensive. Elaborate programming requirements are also needed

The selection of a particular form of interaction depends on the application, the capabilities and attitudes of the potential operators, on the hardware requirements and on the necessary response time. The marine environment demands a communication method that will be simple, quick and inexpensive as the environment is harsh, real time and under the computer memory constraints. However, computer memory will not be a great problem in the near future. The menu-selection method seems to satisfy these requirements. In addition, for this application to minimize failures such as data loss, the communication between the acquisition system and operator should have :

- unambiguous high level language messages;
- help menus in case of misunderstandings;
- well structured documentation;
- most of the navigation parameters to be autoloaded to minimize manual entry;
- limited number of keystrokes or trackball movements required to modify system operation to a minimum;
- auto resumption after power outage;
- audible, printed and electronically displayed messages to attract the user's attention when an error occurs or an operator's interaction is required.

Usually there are two operators involved in the acquisition of hydrographic data : the hydrographer and the helmsman each one requiring a different type of information. *Kayton et al. (1969)* categorizes the displays for these types of information as command and situation displays.

The hydrographer requires LOP coordinates, geographic or grid coordinates with associated statistics, along and cross track distances and the speed of the vessel to evaluate the general performance of the survey (situation display). The helmsman requires steering information to keep the vessel on track (command display). *Ingham (1974)* describes the "visual" and "electronic" ways of track control. The electronic steering information is available in one or more of the following ways:

(a) moving pointer meter or digital (LED: Light Emitted Displays or LCD: Liquid Crystal Displays);

(b) track plotter or graphic display;

(c) video display (CRT) with ripple plot,

and it is called "Left / Right Indicator", (L/R). See also Figure 2.1. We group the L/R indicators by the type of information displayed and not by the medium on which it is displayed.

The important feature of the L/R indicator is that meaningful information can be obtained from the position of a pointer and it is not necessary to read the instrument. Among the different types, the video display and track plotter or graphic display are preferable as they also show survey vessel trends. The helmsman is responsible to compensate for these trends . In addition, the track plotter is suitable for running closely spaced survey lines since the overall picture of the lines is portrayed. Its disadvantage is that the processor needs more time to drive the plotter than a video display and therefore the track update time is increased. *Bertsche et al. (1981)* compares digital (moving pointer meter, LCD and LED displays) with graphic displays using simulated navigation. Graphic displays produce better results in ship's maneuvering and track keeping ability. In addition to the L/R indicator, cross-track velocity and course error (angular difference between course and survey leg) provide helpful steering information.

The rate at which the L/R indicator is updated (cycling time) and its sensitivity to cross-track errors (L/R Indicator resolution and scale) are of vital importance to keep the vessel on track. For this application, the L/R indicator must be more sensitive to off-track errors when

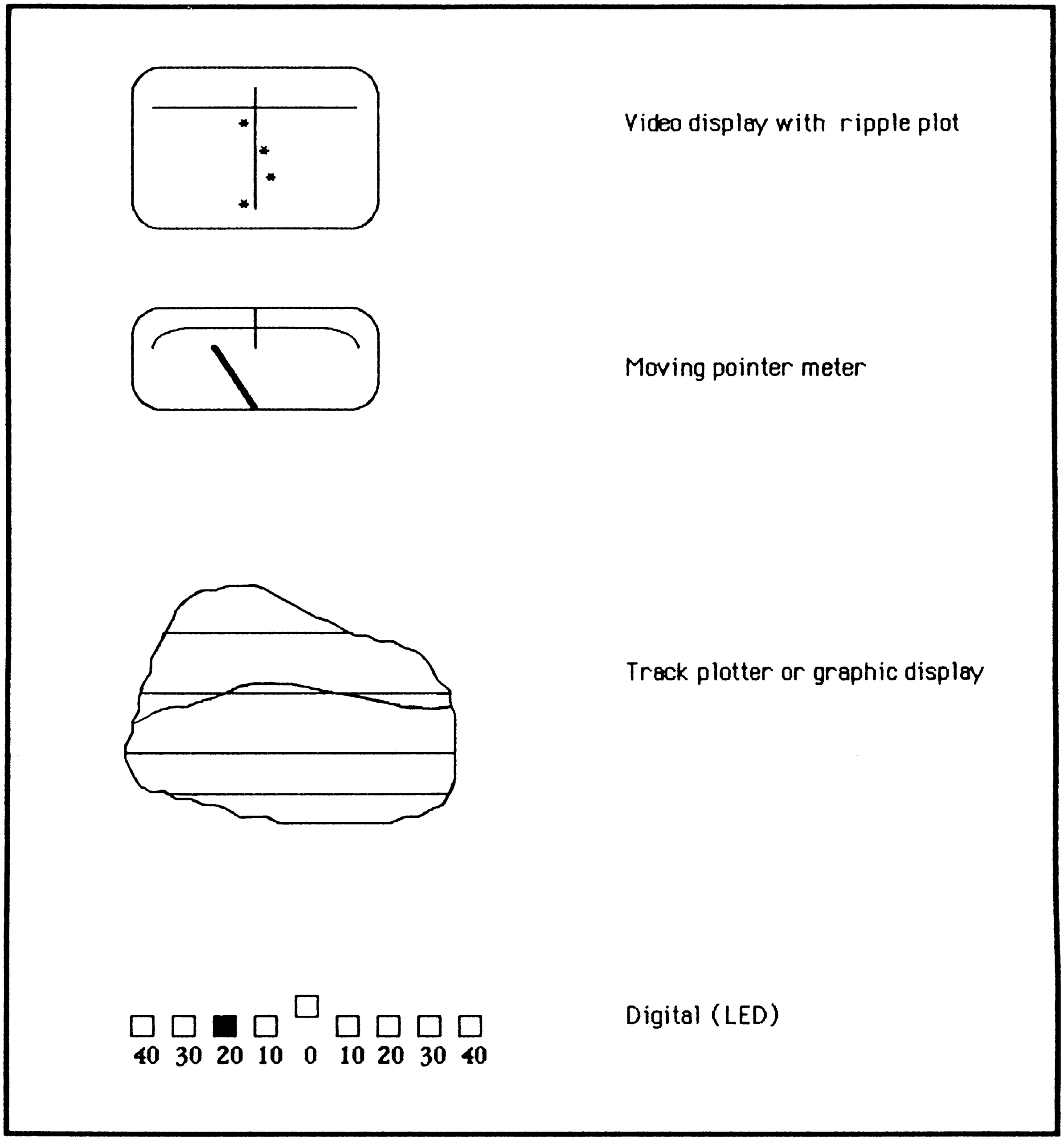

Figure 2.1 : Types of L/R indicators.

the off-track distance is of the order of 5-10 metres than for off-track distances of the order of 100 metres. The difference in sensitivity can be achieved using different scales or a logarithmic scale. The L/R update rate must increase with increasing scale. The exact rate must be verified in the field. Finally, the situation information and the command information should be (if possible) separately displayed. In practice, the helmsman is often confused with information that concerns the hydrographer.

2.4 Modularity and portability.

A method for successfully designing a system is to break the development process into phases and the developed system into modules *(Boudreau, 1984; Leenaarts el al., 1984).*

Phase I is problem definition. It is a study of the survey requirements and the available resources. Problem definition follows functional specification in order to select the algorithm. The algorithm is broken down into sub-sections with specific tasks known as the "modules". Examples of such modules are the navigation algorithms, quality control algorithms for positioning and bathymetric data and interface modules. These modules are implemented in software, firmware or hardware and are independently tested. The final phase is the integration of modules and the system test. The process is more likely to yield a system which is reliable and easily expanded, modified and debugged (errors inherent in one of the modules do not propagate into the others). The development process is illustrated in Figure 2.2 .

Contractors for inshore hydrographic survey projects are not willing to make an expenditure for buying a survey boat. On the other hand, no one vessel is suitable for all the various surveys that are required. This demands that the system used should be very portable.

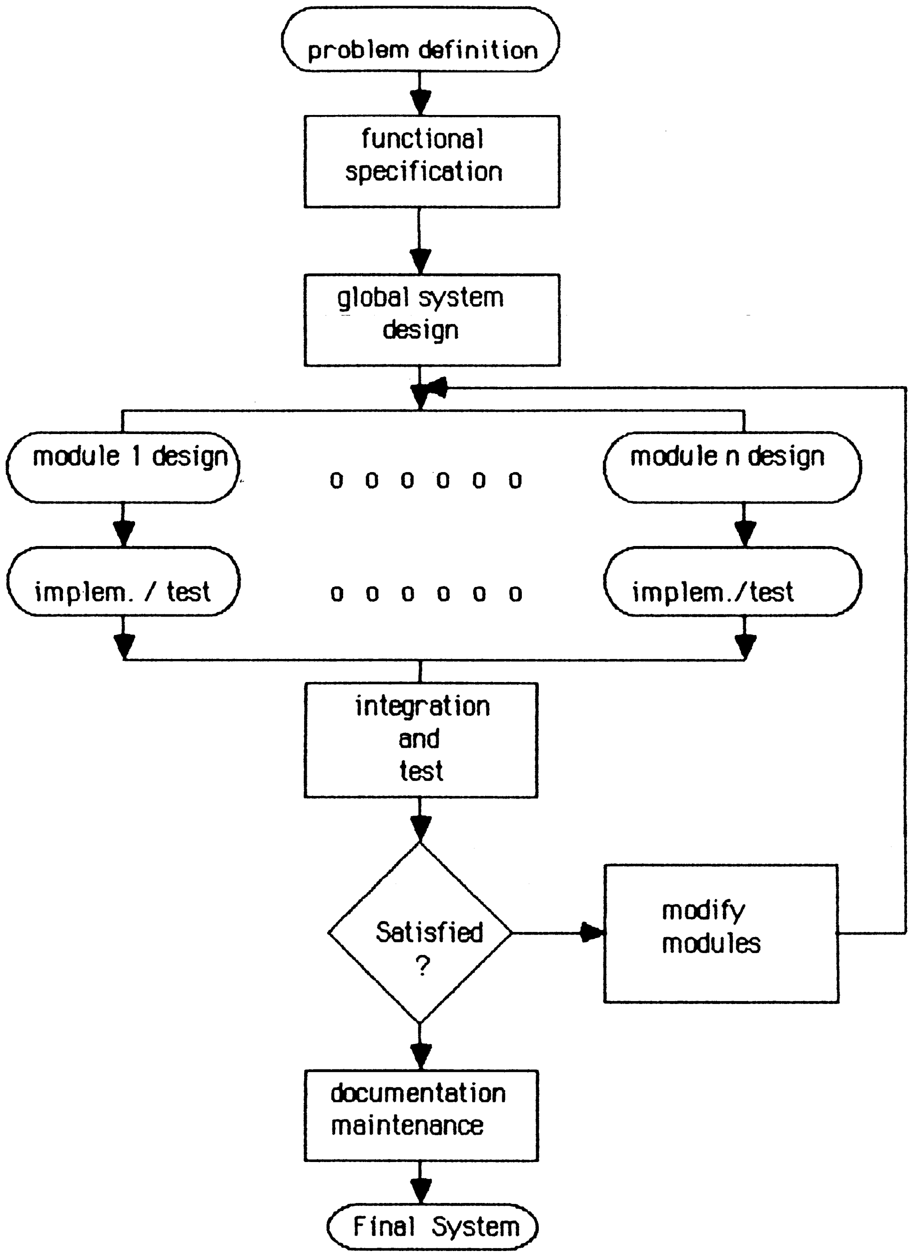

Figure 2 .2 : The development process.

2.5 Compatibility

Compatibility is the ability of the system to communicate with a variety of devices and to work in a variety of computer environments.

The way that data is transferred between the different sub-systems depicts its compatibility. For example, data should be recorded on a standard medium with compatible records and not packed records requiring special assembly language routines to access the data. The use of standard interfaces (RS-232 or IEEE-488 , see *Mc Namara (1977)*) enables the system to work with other standard interface devices.

The system should use standard hardware, and in the case where special hardware has to be built, a bus-system organization can be adopted.

The software should be machine independent. This implies that a standard operating system and language compiler be used from a reputable manufacturer. Structured and modular programming contributes to compatibility. Any necessary software transfer to another computer that requires modifications can be done by changing only specific software modules. Software transfer or modification can be better done in high level language. Hence, assembly routines should be kept to a minimum and only in these parts of the system that are not going to change during the system-life (e.g. sensor communication routines).

2.6 Cost

In order to determine the upper limit cost of the system we have to identify the agencies that require inshore hydrographic surveys and how much they are willing to pay. As stated in *IGM report # 1 (1982)* these agencies mainly belong to the public sector and are satisfied with the conventional methods of surveying (e.g. intersecting directions with theodolites with line keeping controlled by one of the theodolites). When the volume of survey work requires small amount of manpower these methods are cost-effective. The proposed system should be able to compete with these techniques with regards to cost.

Therefore, a reasonable goal for the navigation controller, not including the positioning system and the echosounder is $5000 minimum per unit. This includes:

- computer	$ 1500
- interface unit and echosounder digitizer	$ 2500
- computer peripherals	$ 1000
TOTAL	$ 5000

Maximum cost should be $10000. This does not include the expense of development and prototyping. However, it is a cost-effective alternative to present commercially available data acquisition and processing systems such as the NAVBOX *(Tripe, 1978)* and the ATLAS SUSY 30 *(FIG, 1984)*.

It is difficult to give priorities in the above list of design criteria unless the project requirements and the available resources are exactly known. As previously stated, accuracy has the highest priority in near shore marine constructions. However, for near shore applications reliability is not so important since, in the case of system malfunction, the boat can immediately return to shore for repair.

2.7 Review of existing systems

Some of the concepts addressed in this thesis are not new. The concept of L/R indicator, the algorithms to further process the data have been implemented in larger systems while the emphasis here is the scaling down of these systems to a system that will serve the needs for near shore hydrography and it based on microcomputer technology. Therefore, potential benefits may be gained by reviewing these systems and pointing out their limitations and highlights. Their review and comparative performance evaluation will be done according to the established earlier in this chapter design criteria.

In Canada, the Canadian Hydrographic Service (CHS) is responsible for charting Canadian waters. This responsibility is distributed to the regional offices which have designed their own acquisition and processing systems. Some regions use computer-assisted techinques for data processing only. Data is collected using conventional manual methods during the day and in the evening is processed on board the "mother ship". Even within regions some types of surveys (e.g. wharf surveys) are not automated and others (e.g. offshore surveys) are.

The development of acquisition systems does not follow any standard formats and therefore the information exchange is difficult. The latest developments include the Integrated Data Acquisition and Processing System (INDAPS), the Portable Hydrographic Acquisition System (PHAS) and the NAYBOX or HY-NAV. The INDAPS system is a mini-computer based system suitable for launch or major ship fittings. PHAS is a microprocessor based system which like INDAPS is still in use. NAYBOX is a similar to PHAS system but in addition, has navigation functions. Detailed descriptions of the hardware and software organization of INDAPS can be found in *Brayant et al. (1976)* and of NAVBOX and PHAS in *Tripe (1978)*.

These systems are machine language programmed and therefore are strongly hardware oriented. It is difficult, and sometimes impossible, to modify them to meet different user requirements. This reduces their compatibility with other hardware and software.

In terms of man/machine interaction, data and command entry is done using keyboard or keypad entry of mnemonic commands; an inefficient means of communication especially in the harsh hydrographic environment. This form of communication is found in all the systems (INDAPS, NAVBOX and PHAS). The problem worsens when the user wishes to modify the survey parameters during the survey. The ability of the systems to implement different patterns of survey lines is also reduced. Only straight lines, or lines of position can be surveyed.

At some stage of HY-NAV's development the system was not reliable *(Wells, 1983 personal communication)*. For example, the system had a floating point arithmetic board but with some algorithm bugs. The depth digitizer used required strong bottom echoes to trigger its clock mechanism. Aeration, especially in rough seas, produced false soundings. Some temperature sensitive components resulted in different computed positions at different temperatures.

The data is obtained from the sensors asynchronously . A one second lag exists (~ 3 m at 5 knots) between the position and depth samples and the samples are not correctly correlated with time. Filtering techniques (positioning and bathymetric) are implemented for data validation but they are not always effective. For example, lane jumps are detected in the Minifix phase comparison system by comparing the lane jumps to the distance travelled at maximum speed. The technique does not give the exact cycle ambiguity. There is more success, however, in depth filtering techniques.

The Interact Research and Development Corporation has recently anounced the ISAH acquisition and processing system. Some of the features of ISAH are:

- Man/machine communivation using graphic displays and graphic left/right indicator with selectable scales.
- Hyperbolic, multi-range and range/ bearing algorithms using weighted least squares to derive position fixes.
- Track and sounding plotting.
- Tide and sound velocity corrections to depth data.

The Pacific Region recently announced the development of its own data acquisition system with a real time operating and application system supplied by Interact Research and Development. Low level programming, high data acquisition speed and no applied filtering techniques are some of the characteristics of the new design. The philosophy of the design is to record great amount of data without bothering about quality control as this will delay the acquisition process. The quality control task is left for post-processing.

The National Ocean Survey also announced the replacement of the aging HYDROPLOT acquisition and processing system with Shipboard Data Systems III (SDS III). Details about HYDROPLOT system can be found in *FIG (1977)* and *Wallace (1982)*, and details about SDS III system in *Enabnit (1985)*. Some of the deficiencies that led to the decision to replace HYDROPLOT are :

- Virtually all the instruments interfaced to HYDROPLOT are asynchronous. The probability that two lines of position and a depth will all occur at the same time is almost zero.
- Navigation is provided only for parallel straight lines.
- It is difficult for the hydrographer to "see" the survey data in real time and take appropriate decisions. This difficulty is found in many other acquisition systems.

In addition, SDS III system has the following features:

- Real time display of soundings and ship's tracks using colour graphic displays.
- Implementation of a hydrographic data base.

Some other systems that are used in hydrographic syrveys, navigation and oil exploration are NAVPAK *(Falkenberg, 1981)*, ATLAS SUSY 30, NAVCUBE NC-100 *(FIG , 1977 ; FIG, 1981; FIG, 1984)* etc. . Although some of these systems are not suitable for inshore hydrography and dredging operations, concepts like path guidance and position filtering are common for near shore and off shore applications.

Here is a summary of the different approaches that have been adopted, the unsolved or controversial problems in data acquisition systems :

1. The proper distribution of data processing functions between on-line and off-line computers produces differences in opinion.

2. Computers are now widely used in data acquisition systems to take advantage of their ability to provide a navigation function and data processing capabilities such as error detection and filtering. Systems that employ dedicated microprocessors are not flexible. What is absent (at least in the CHS) is a modular, software oriented design based on the rapidly developing microcomputer technology.

3. The majority of manufacturers have agreed to standardize I/O (Input/Output) operations and create flexible systems. The old practice of providing BCD (Binary Coded Decimal) output has resulted in acquisition systems with many large cables and troublesome connectors. But the area of I/O interfaces is the only one in which standardization has been achieved. Standardization should include all other modules of the survey system such as navigation algorithms and software languages.

4. The correlation of data from various sensors is a real problem. An "intelligent interface" is needed to reduce the data to a common digital format and time instance.

5. The requirement to obtain reliable depth data in digital form remains as one of the biggest problems in automatic hydrography. This is reflected in the different approaches that are now in use and the great activity in this field. The reasons for this will be discussed in chapter 3.

6. Man/machine interaction is not efficient. System operators may normally be people with little training in computer science or in hydrographic operations. The software should be able to reflect possible operator's errors by producing unambiguous error messages.

7. Straight line navigation is not always an efficient way of sampling depth as will also be discussed in chapter 3.

If automatic data acquisition systems are employed, a suitable processing system is required that will handle digital data. Two groups of processing functions are necessary :

- General data processing. This includes computation of grid or geographic coordinates, application of monitor corrections or propagation corrections to improve the quality of position data, adjustment of soundings for speed of sound corrections, adjustment for water level or heave, filtering, smoothing, interpolation or extrapolation of data, detection of shoals and generation of statistics. This is not a complete list.

- Processing for presentation of results. This includes selection of representative samples, plotting, generation of profiles, volume computations etc. .

It is not practical to use the on-line computer to accomplish all these tasks, except perhaps in the case of large shipboard installations such as INTERPLOT 200 survey system manufactured by INTERSITE Co. *(FIG, 1984)*. For inshore hydrography and marine engineering, where a small lightweight system is used for acquisition, a small portion of functions in general data processing is accomplished on-line. The rest of processing is done either on the same computer off-line or on a larger computer which will handle data from several acquisition systems such as in the system INDAPS used by the Canadian Hydrographic Service *(Bryant et al. , 1976)*.

3. DATA ACQUISITION and ON-LINE PROCESSING

3.1 General system configuration

We will now elaborate on the previous two chapters to functionally specify an <u>ideal</u> data acquisition system.

The distribution of data processing functions is such that acquisition, navigation and some of data validation is performed on-line, while the rest of processing is done off-line. By adopting this arrangement we overcome some of the disadvantages of complete on-line processing : tidal heights are not available (unless they are transmitted to the survey boat by a radio link) and a sophisticated and expensive system is required. The launch equipment used with off-line processing is simpler and inexpensive. The disadvantage of this approach lies in the requirement to accurately record large amounts of data for post-processing. However, since all the data is available we can employ any data reduction technique to satisfy users with varying requirements.

The components of such a hydrographic acquisition and navigation controller are shown in Figure 3.1. The selection of the appropriate components for inshore hydrographic surveys must follow the established criteria.

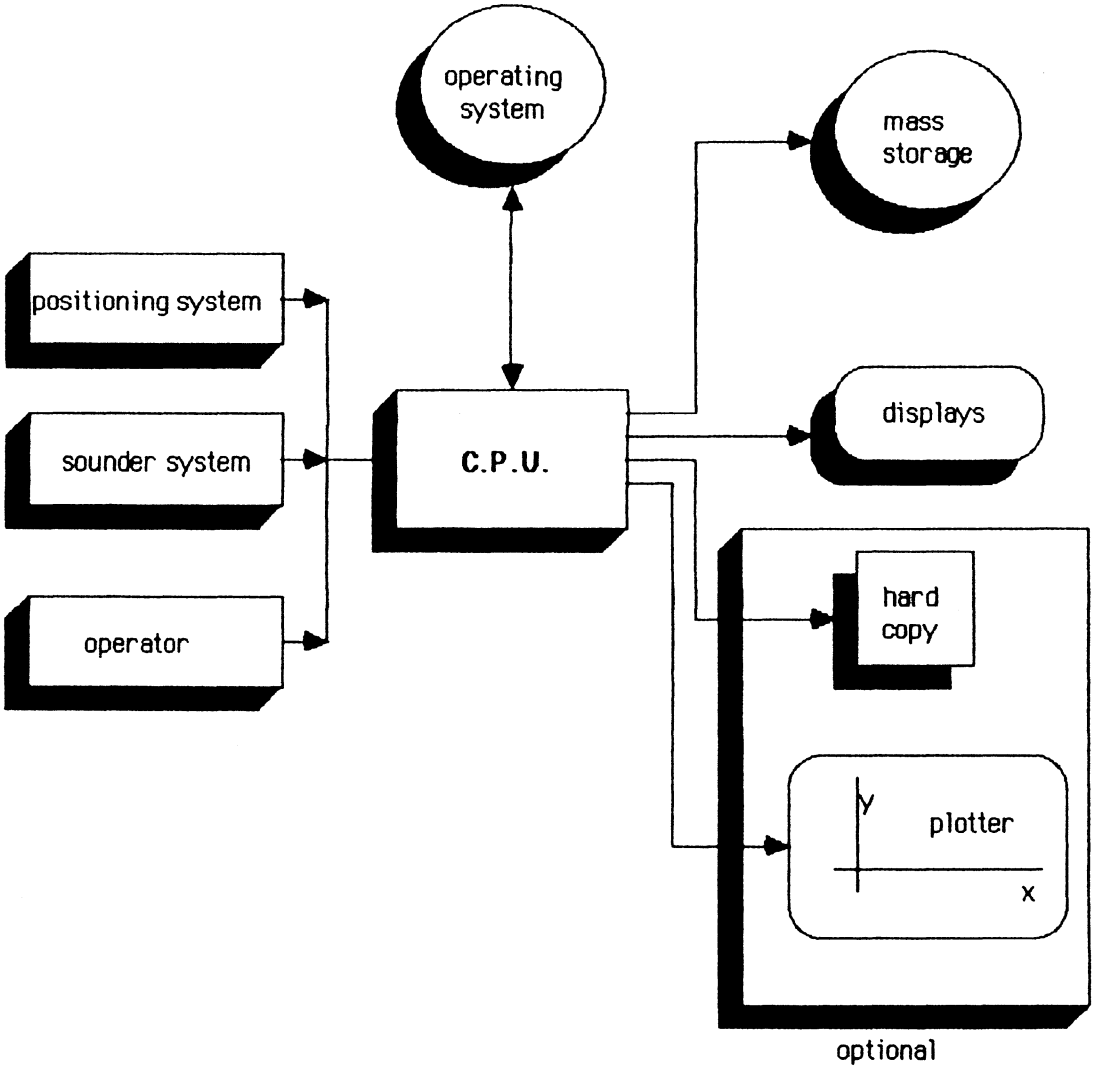

Figure 3.1 : Block diagram of a navigation and hydrographic data acquisition controller.

In the remainder of this section we discuss hardware considerations, and the structure for an idealized software package. Later in the chapter we deal with details of the software.

3.1.1 Position input

Positioning systems that use microwave techniques, such as the pulse matching systems Motorola Mini Ranger and Del Norte Trisponder, satisfy the criterion of accuracy for inshore surveys. These systems provide metre order accuracy. Higher accuracy can be achieved (near shore) by range-bearing position fixing systems such as Atlas Polarfix (30 cm at 1 km far from shore) *(Wentzell, 1985)*. Recently, Racal Positioning Systems Ltd. announced a pulse matching microwave system of submetre accuracy *(Teunon, 1985)*.

The Global Positioning System (GPS) is a new satellite based positioning system that is expected, by the year 1987, to provide continuous two-dimensional navigation which is sufficient for many marine applications (general navigation, off shore surveys etc.). However, at present the system is unable to satisfy the accuracy requirements for inshore surveys. In ship trials conducted by Magnavox *(Eastwood, 1984)*, the Magnavox T-Set GPS receiver, when compared with Trisponder, gave standard deviations of fix differences of the order of 20 metres. Furthermore, the U.S. Department of Defence is planning to deteriorate the accuracy of the system for civil use. One way to recover this accuracy or improve it, is to use Differential GPS. The basic concept is to locate a GPS monitor station at a known benchmark, observe ranges to satellites, compute corrections to the ranges or positions and transmit them to the local users. *Stansell (1984)* says that the method can give position accuracy better than 5 metres. Therefore, with Differential GPS it is possible to meet the accuracy requirements of inshore surveys and at the same time minimize the labor cost required by the present positioning systems. However, hydrographers would have to rely on the decisions of U.S. Department of Defence about the released accuracy.

For **SEAHATS**, we limit ourselves to considering the Mini Ranger system as the positioning system. This implies that the input data will consist of ranges to a number (2-4) of control stations on shore.

3.1.2 Depth input

For inshore applications the echosounder should be chosen to give a high definition echogram of the "first" bottom. The requirements of good depth resolution, small beamwidths and small transducer sizes are satisfied only with high frequency transmissions *(MacPhee, 1979)*. Selection criteria for bathymetric systems can be found in *Raytheon (1984)*. *Watt (1977)* justifies the use of 30-200 kHz echosounder with beamwidths 2.5-10 degrees and pulse duration 0.1-0.5 milliseconds.

For **SEAHATS**, the Simrad Skipper 802 echosounder with 50 kHz transducer is chosen to provide depth input.

3.1.3 Central Processing Unit

The requirements for the central processor include low cost, low power consumption, bus oriented structure for flexible I/O, and the ability to work in a standard operating system environment like CP/M or DOS, allowing the use of "off-the-shelf" compilers like BASIC and PASCAL. Features like DMA (Direct Memory Access) and 16 or 32 bit word lengths are desirable. DMA will permit fast output of collected soundings to the logging device without stopping the navigation functions. Larger word lengths will permit access to larger RAM than 64 kbytes. The mass storage device should be able to store at least 3-4 hours of survey data (150 kbytes typically).

For **SEAHATS**, the Apple IIe microcomputer has be chosen as the CPU. Apple IIe is based around the 6502 microprocessor and it has 8 expansion slots for I/O devices and other peripherals. In general, Apple IIe does not support interrupts from I/O devices although the 6502 microprocessor has an interrupt pin. However, with user written programs the Apple IIe can be modifieed to support one I/O interrupt. The Apple IIe microcomputer has not a DMA feature.

3.1.4 Acquisition software

As mentioned in section 2.4 the development process is broken into modules. For **SEAHATS**, the following modules were implemented:

- INITIALIZATION,
- INTERFACE,
- QUALITY CONTROL,
- NAVIGATION,
- ON-LINE MODIFICATION and
- OUTPUT.

Figure 3.2 illustrates the information flow between modules.

The INITIALIZATION module is responsible for loading the Operating System, application programs, default parameters and navigation constants from the system storage. The default parameters are the latest navigation parameters that were in use. It also accepts operator's inputs and selects the navigation function (shoal examination, primary survey lines and way point navigation)[1].

The purpose of the INTERFACE module is to convert the inputs (LOPs and depth) to digital form and provide data to the navigation module. Between the interface and navigation modules, the

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[1] they will be discussed in section 3.4

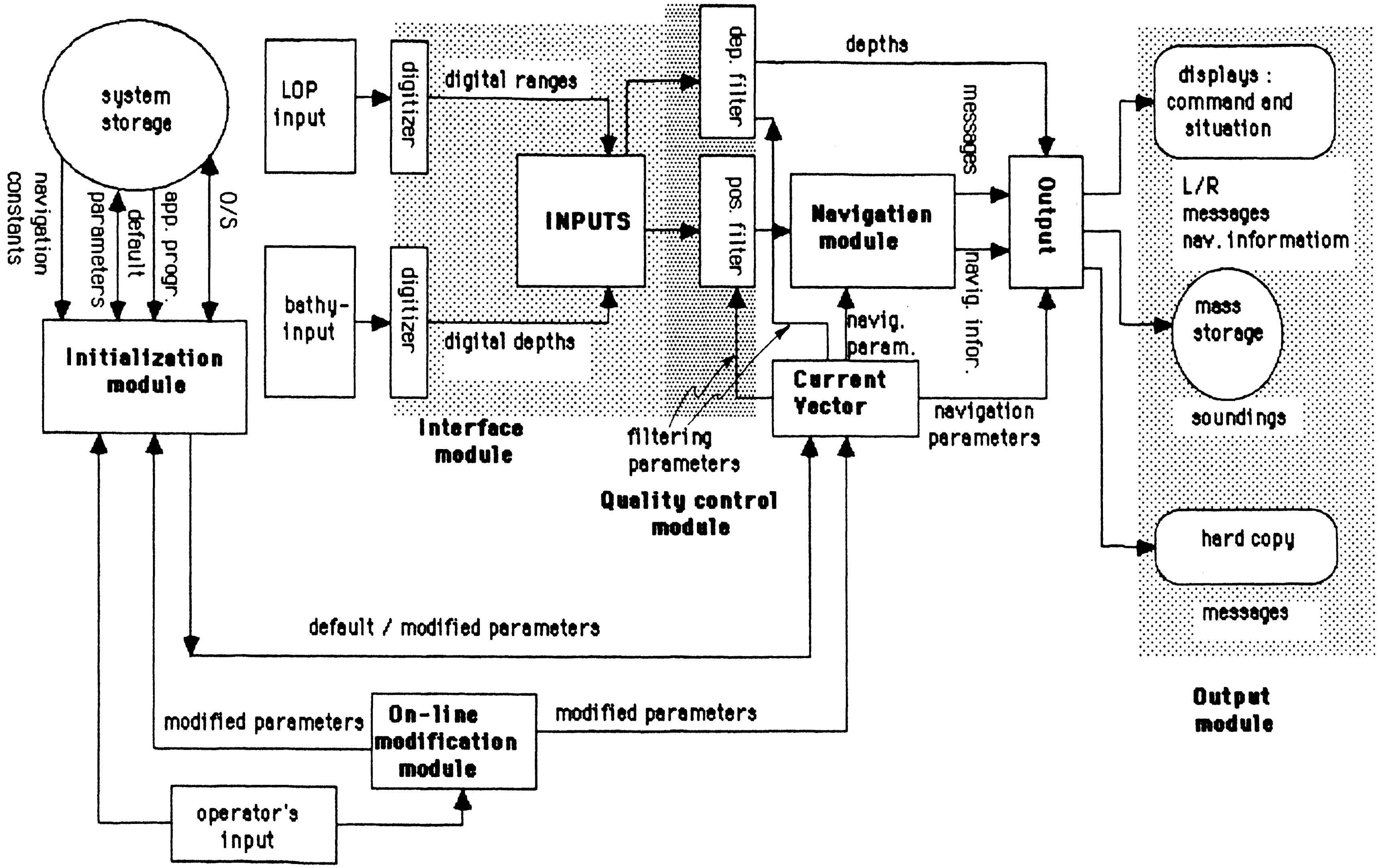


Figure 3.2 : Information flow among the elements of an ideal navigation and hydrographic data acquisition controller.

QUALITY CONTROL module is responsible for filtering position and bathymetric data. The task of the NAVIGATION module is to compute the vessel's position and translate the position information to a form familiar to coxswain and hydrographer. The OUTPUT module will display steering and navigation information, log positions and depths with their statistical characteristics.

The bus with which the above modules communicate is the CURRENT VECTOR *(Boudreau, 1984)*. It contains the survey parameters which are effective during the running of the survey lines. These parameters are :

- the survey function selected (shoal examination, primary survey lines or way point navigation) with the specifications of lines (line spacing, maximum leg length);
- the way points selected to defined the system of lines to be run;
- the control points used;
- rates used
  - sampling data rate (ranges to transponders and depths)
  - position update interval
  - logging rate
  - printing rate
  - display update rate (for skipper)
  - display update rate (for hydrographer);
- flags for
  - logging data
  - printing data
  - minimum depth (to prevent grounding);
- filter parameters for position and depth validation and
- file names used for storing survey data or default parameters.

The content of the current vector is modified either off-line in the initialization procedure or on-line (while running survey lines) through the ON-LINE MODIFICATION module. The elements of current vector can also be specified loading the DEFAULT file. Its structure is similar to the structure of current vector and resides on a non-volatile medium. Upon completion of survey work the DEFAULT file is automatically updated.

The rest of this chapter is devoted to an in depth analysis of INTERFACE, QUALITY CONTROL, NAVIGATION , ON-LINE MODIFICATION and OUTPUT modules. The part of OUTPUT module that deals with man/machine interaction was discussed in section 2.3 .

3.2 The INTERFACE module

We describe the interface environment necessary for inshore hydrography. At least two sensors are involved : the echosounder and the positioning system. Their outputs should be computer compatible. All electronic positioning systems, used in the line-of-sight area, currently provide digital positioning data either in BCD format or through an RS-232 serial interface. Unfortunately, no depth sounder has been designed as a truly digital sounder. A special device, called "the digitizer", is needed to convert analog depth signals to digital form.

The digitizer computes depth using equation :

$$\mathrm{DEPTH} = (1/2)\ n\ T\ V_S \tag{3.1}$$

and counting the number of cycles (n) of a crystal controlled oscillator (period T) during the travel time of acoustic pulses in sea water. The assumed sound velocity is V_S. For shallow water systems, where there is only one pulse in the water at any one time the implementation of this equation is straight forward. For systems used in deep waters however, groups of pulses are transmitted and there must be some programmed logic controlling which pulse will signal the digitizer counter to stop. Details about depth digitization can be found in *Thomson et al. (1981)* and *Raytheon (1984)*.

The rates at which digital LOPs and depth data are provided by the positioning and sounding system are different. A high depth rate is necessary to accurately represent sea bottom topography since sea bottom has an unpredictable behaviour. Also, the filtering techniques described in section 3.3 require high data rates. Echosounders used for shallow waters (depths less than 100 metres) can give soundings at a rate of 10 soundings per second *(see MacPhee, 1979).* This rate is adequate provided that it is available for every second. Hardware constraints, however, may prevent soundings from being read when the computer is busy doing computations or recording data.

On the other hand, the movement of the ship is well predicted for short periods (2-3 seconds). Range sampling rates of 1 per second are adequate to describe ship's kinematics for inshore surveys.

Basically there are two approaches to input bathymetric and positioning data to the computer *(see Short, 1981)*:

1. Program Controlled Input/ Output.
2. Interrupt Controlled Input/ Output.

With the program controlled I/O, the microcomputer initiates the transfer of data by cycling through the sensors as illustrated in Figure 3.3 . A real time clock has been added to the list of sensors to provide the time of day. Sometimes it is necessary to check if the sensor is ready to provide data by "polling". Polling a sensor consumes a significant amount of microprocessor time. Time delays are introduced and therefore position and bathymetric data is no longer correlated. Program controlled I/O does not efficiently handle asynchronous data transmission and large data streams.

Hardware interrupts can be used to overcome these obstacles. The computer responds to the input devices when they have data. Each device has its own interrupt service routine and priority level. Figure 3.4 illustrates an interrupt driven input/output layout.

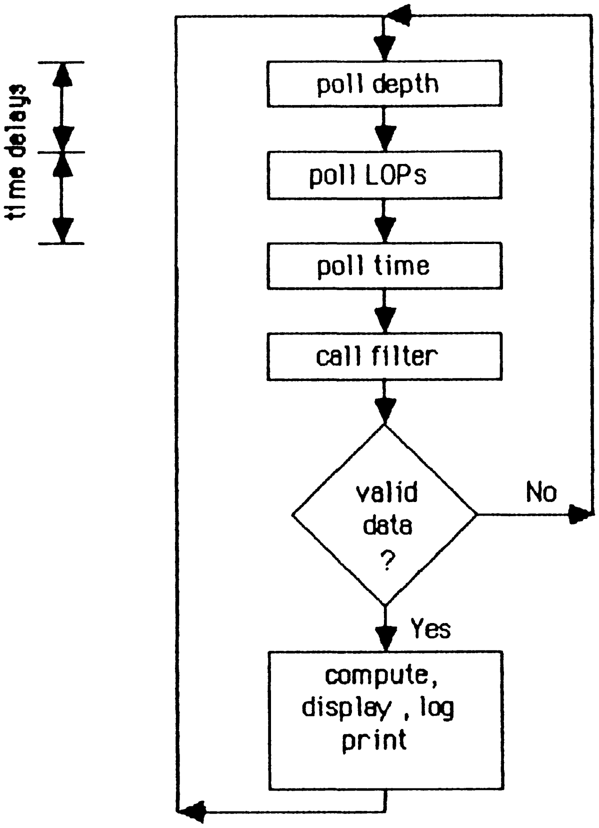


Figure 3.3 : A program Controlled Input/ Output.

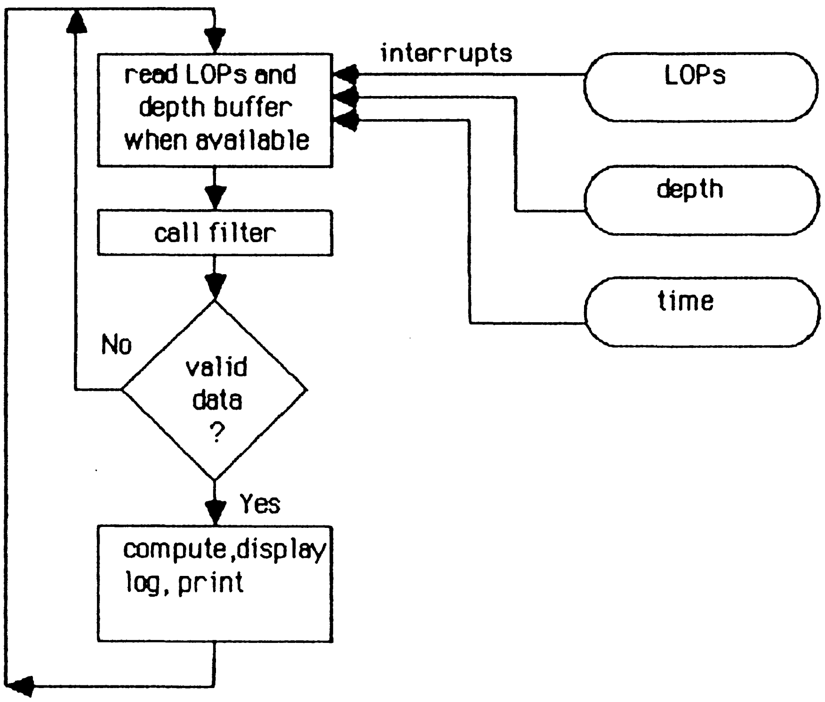


Figure 3.4 : An interrupt Controlled Input/ Output.

The need for interrupts of the central processor may be avoided by using an "intelligent interface" provided that it has sufficient intelligence to chronologically correlate positioning and bathymetric data. The interrupt function is still there, but allocated to a separate processor, in a distributed processor architecture. The central processor can then access only buffers, provided by the peripheral processors. The ultimate extension of this distributed architecture is building the peripheral processors into the sensor packages (the sensors have a buffered output).

The "intelligent interface" may serve other purposes such as the reduction of data to a common format. An example of one such interface is the JMR marine data acquisition and navigation system (SYSTEM 21) *(JMR, 1981)*. The electrical and functional operation of the interface should be standardized. By electrical operation we mean the electrical interface used (e.g. RS-232 or 20 mA current loop). The functional operation is the regulation of the flow of data between the sensors and the central processor. For the particular application, a basic functional operation is described by the following communication protocol :

START : Start receiving ranges and depths at equally spaced time intervals and store them in a local buffer.
REQUEST : Request a data point from the local buffer.
STOP : Stop taking samples.

Figure 3.5 illustrates the use of an "intelligent interface" for hydrographic purposes.

Hydrographic data must be stored in digital form for further processing. Underway recording should be fast and correct in order not to delay the acquisition process. DMA (Direct Memory Access) is an appropriate fast data transfer mechanism, provided that the microprocessor has a DMA feature. The Apple IIe computer for example, does not have direct memory access for its disk controller and must stop everything else while it reads or writes information on the disk. During this time information from keyboard or other I/O device is lost.

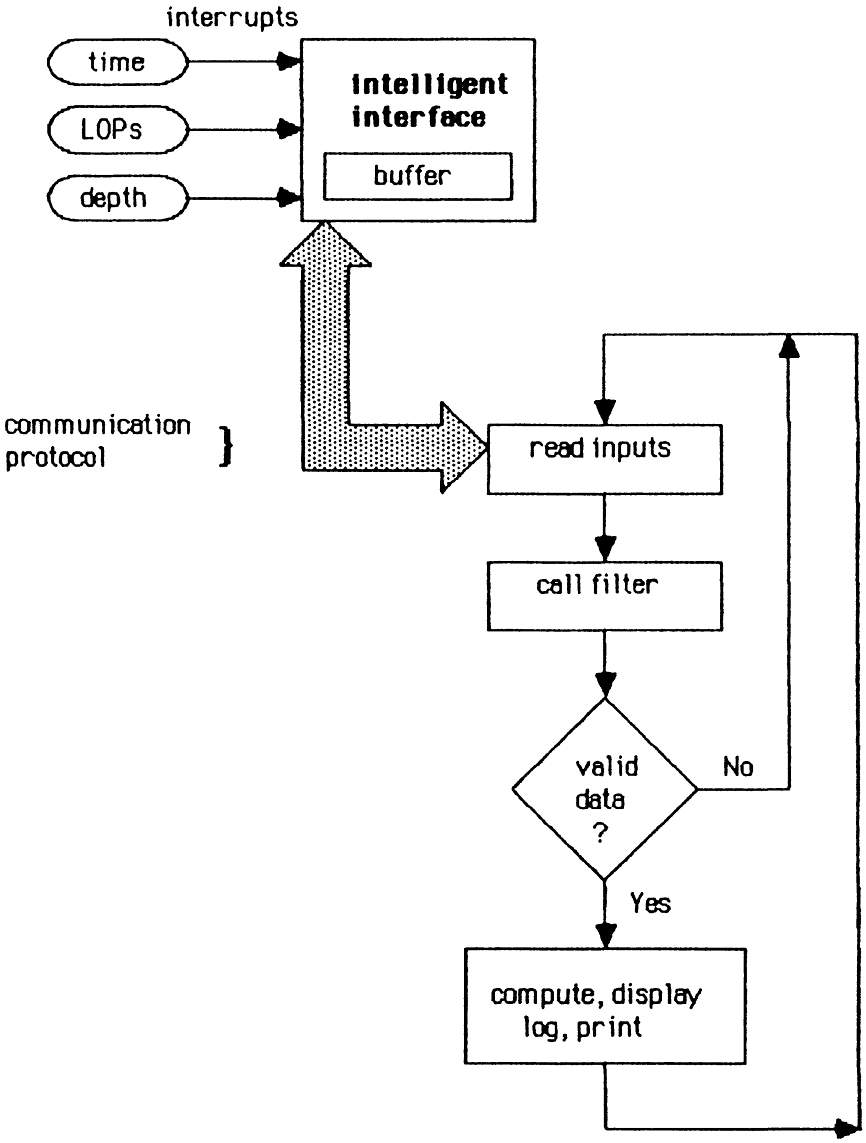


Figure 3.5 : An "intelligent" interface.

The need for valid recording of acquired data is vital in order not to lose data due to "electrical noise" that exists in hydrographic vessels. It is not sufficient to only detect an error, it must also be corrected. Procedures used in automatic hydrographic data acquisition systems to validate recorded data are *(from FIG, 1981)* :

(a) methods to validate data before the writehead :

- Parity check;
- Cyclic Redundancy Check (CRC) and
- Redundant storage (same data written two or more times);

(b) methods to detect errors that occur while performing a read or write operation :

- Read after write with error flag and
- Read after write with re-write.

Cyclic Redundancy Check is an error detection method that provides multiple bit error detection in serial data transfer while parity check cannot. Details on error detection techniques can be found in *Mc Namara (1977)*. The majority of the systems use either parity check or CRC to detect an error before the writehead and re-write the data when an error occurs. Cyclic Redundancy Check is a common method of error detection for serial data transfer in systems using floppy disks such as the Apple IIe microcomputer. It seems to perform well in the electrically noisy environment of hydrographic launches.

For **SEAHATS**, the intelligent interface approach was taken. The specific interface used was specially developed for **SEAHATS**, and is called the **PS-01** (for Parallel to Serial converter). Details are given in *Nickerson (1983)*.

3.3 The QUALITY CONTROL module

3.3.1 Nature of positioning errors

Before we try to monitor the errors inherent in microwave systems we have to examine the nature of these errors, particularly for pulse matching systems such as Del Norte Trisponder and Motorola Mini Ranger. This error budget is done according to the well known classification in random, systematic and gross errors, although it is difficult to draw distinct boundaries between the classes.

These sytems measure the travel time of pulses, from remote transponders to the Receiver/Transmitter antenna mounted on the ship, without phase comparison techniques. Figure 3.6 shows the typical forms of transmitted and received pulses. The factors that affect the accuracy of time measurement are : the noise that deforms the leading edge of transmitted pulse, the threshold level variation and the instability of Mini Ranger clock oscillator.

Random Errors: Tests made *(Tripe et al., 1974; Casey , 1981)* demonstrate that random errors in Mini Ranger system are normally distributed as a sum of two normal distributions with zero means but different variances. One has a standard deviation of 2 to 5 metres containing the majority of the readings and a second with standard deviation 5 to 15 metres containing the remaining values (Figure 3.7). The random process responsible for the first originates from the slight variations occurring naturally within the system such as clock instability and variations on threshold level. Signal to noise ratio accounts for the second distribution. In microwave systems ($300MHz<f<300GHz$), the detailed structure of the atmosphere becomes important and therefore, the signal to noise ratio decreases as the beam is scatterred by rain or hail particles *(Hall, 1979).* For the frequency used in Mini Ranger (5480 MHz), the attenuation due to the energy absorption by rain drops is approximately 0.2 dB per km. The instantaneous signal level is also a function of distance, pointing of the antenna, as well as roll and pitch of the vessel that alter the effective gain of the antenna.

Systematic Errors: When the signal level is above the threshold the relationship between range error (due to reduced signal to noise ratio) and distance is predictable. This relationship is described by the radar equation *(Laurila, 1976)* which says that, if we isotropically transmit a power P_t with an antenna of gain G, the power we receive at a distance R is : $G\ P_t\ /\ R^2$. The signal to noise ratio is therefore inversly proportional to the square of distance. With reduced signal to noise ratio the Mini Ranger system has difficulties in discriminating the leading edge of the pulse in Figure 3.6, and this results in a positive range error proportional to the square of distance. *Casey (1981)* shows these results experimentally. This error can to some extent be eliminated.

Zero error, caused by signal delays inside the electronics (e.g. Receiver/Transmitter cable induced delay) can be removed by proper calibration. For microwave systems, atmospheric refractivity varies with the velocity of radio wave propagation. Deviations from the assumed speed of light (refractivity N_S=320) are given by Smith-Weintraub or Essen-Froome formulae *(Laurila, 1976)*. The range errors are relatively small e.g. 0.20 metres at 10 km .

Gross Errors: Multipath propagation causes serious problems to microwave positioning systems. Reflections from rock faces or ship hulls can cause range errors up to hundred of metres *(Tripe et al., 1974)*. The Mini Ranger system has a feature to detect these reflections and sets the readings to zeros. Unfortunately these zero readings can appear as gross errors to automatic systems which do not have a zero range software detection technique. When geometry permits, the direct signal arriving at the receiver and the signal reflected from the water's surface interfere with each other resulting in signal cancellation and no range reading. This phenomenon is called a "range hole" and is very common in hydrographic surveys using microwave techniques. *Gilb et al. (1976)* describes this phenomenon and gives methods to avoid its occurrance. Mainly, these methods are practical and are not suitable for an automatic data acquisition system. The following two methods can be use in an automatic system:

(a) To use two Receiver/Transmitter antennas at different elevations. The automatic system will

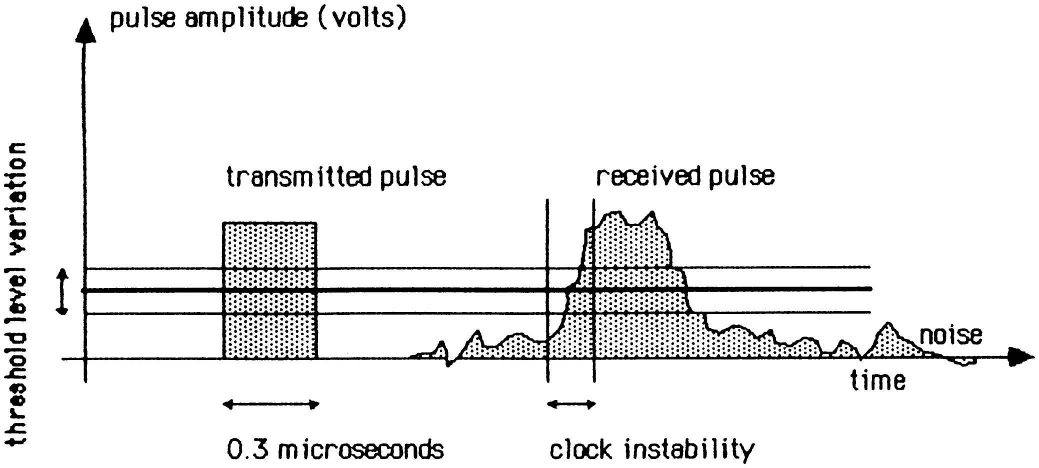
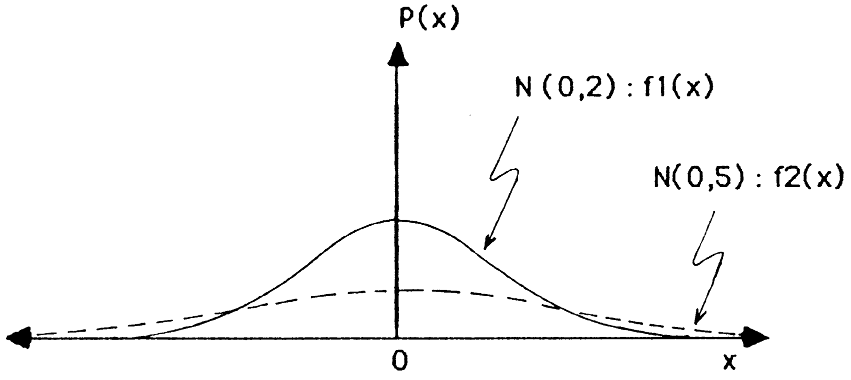


Figure 3.6 : The forms of transmitted and received pulses in Mini Ranger.



$P(x) = a\,f1(x) + b\,f2(x)$ with $a \gg b$ and $a+b=1$

Figure 3.7 : Random errors in Mini Ranger.

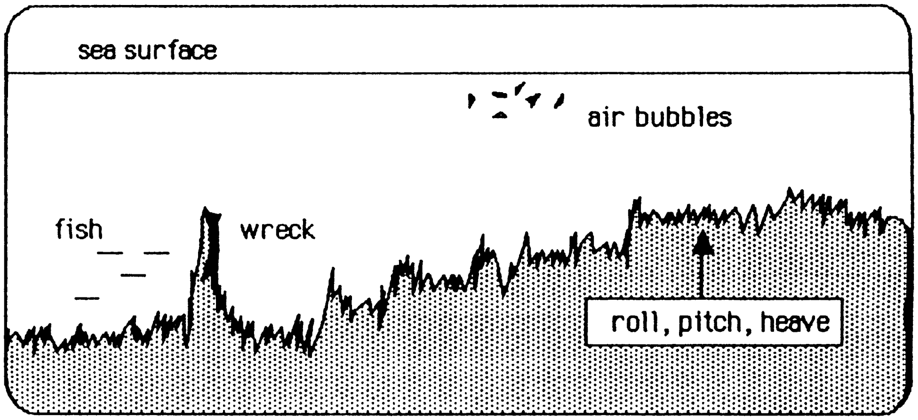


Figure 3.8 : A typical echogram.

switch between the two antennas depending upon the strenght of the signal from each antenna.

(b) To model the Mini Ranger range time series as discussed in section 3.3.3.

Mini Ranger does not suffer from cycle ambiguities, as it does not use phase comparison techniques.

3.3.2 Nature of bathymetric errors

The nature of bathymetric errors is slightly different from that of positioning errors. Figure 3.8 is a typical analog trace of echosounder. Interpreting the echogram we notice the following :

The sawtooth effect is normally caused by the rolling, pitching and vertical motion of the vessel (heave), or it is a picture of sea bottom that has undulations of similar order. Roll, pitch, heave effects can to some extent be modelled, sensed and corrected *(Hopkins , 1980)*. In addition to the seabed, the echosounder also receives reflections from fish, wrecks, seaweed and air bubbles in the water which are called false echoes. The human eye is a perfect filter and can easily distinguish between seabed and false echoes on the trace. But the use of on-line depth digitizers invariably digitizes a percentage of false echoes along with the valid soundings. As a result, procedures are required to detect these errors and it is usually necessary to compare the digital soundings directly with the echogram. Hence an important feature of the digital system is the capability of producing a plot from the digital data that can be adjusted in time and depth scales to exactly match the analog trace on the echogram.

Differences in the speed of sound in sea water can cause systematic depth errors of the order of decimetres. These errors and others associated with echosounder instrumentation (stylus

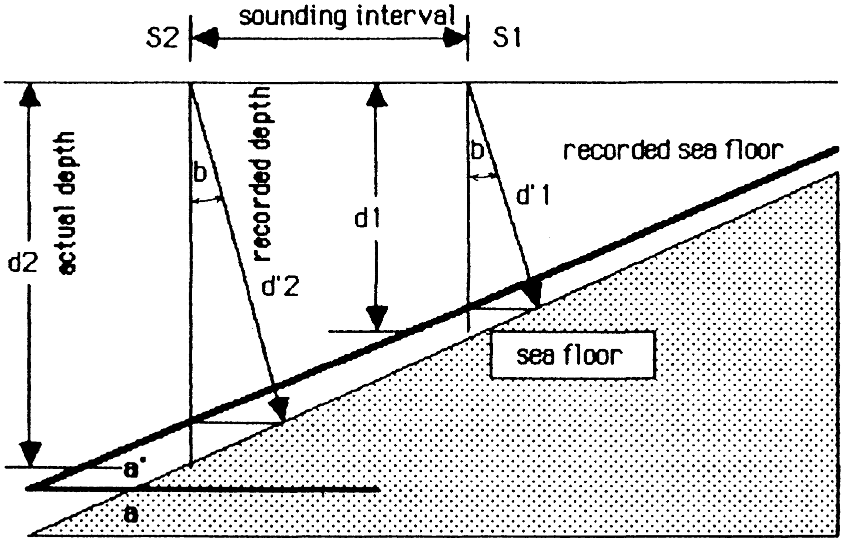


Figure 3.9 : Distortion of seabed due to beamwidth.

Table 3.1: Error sources and error magnitudes in depth determination (from Eaton 1968).

	expected magnitude of stand. dev.	
error sources	**min**	**max**
stylus speed	—	0.015 d
stylus arm length	—	0.010 d
zero setting	10 cm	30 cm
sounding velocity	0.005 d	0.015 d
waves	—	30 cm
tide prediction	10 cm	50 cm
sea level variations	10 cm	30 cm
scaling errors	15 cm	50 cm
sound velocity correction	—	10 cm
tidal correction	—	10 cm
where d : depth		

speed, stylus-arm length, zero setting etc.) can be removed by proper calibration *(Umbach, 1976; Thomson et al., 1981).*

Other sources of errors in the determination of depth are errors in tide prediction and abnormal variations in water level (due to atmospheric pressure differences or wind effects). Also, sampling a seabed with steep slopes results in distortion of the actual depths and slopes due to the beamwidth. It can easily be shown that the recorded depth and slope are :

$$d' = (\cos(a) / \cos(a-b))\ d, \quad a' = \arctan (\sin(a) / \sin(a-b)) \tag{3.2}$$

where : a, d actual slope and depth; a', d' recorded slope and depth and b=1/2*beamwidth (see also Figure 3.9). A direct consequence of this is the hyperbolic presentation of peaks on the sea floor.

If we exclude false echoes and the effects of beamwidth, Table 3.1 gives an indication of the magnitude of the above errors *(Eaton, 1968).*

3.3.3 Quality control of positioning data

The filters that are widely used in hydrographic surveys to derive accurate positions from noisy range observations are the time domain filters :

- Gating (or screening);
- Least Squares (multiranging);
- Least Squares curve approximation (with fixed or expanding or fading memory); and
- Kalman filter.

These techniques can be applied either on-line or off-line. In this section we will deal with their on-line use.

Before we try to evaluate them, we will describe the real-time environment for inshore automatic hydrography. The positioning system can provide ranges at high rates (Mini Ranger III system can be configured to give up to 18 ranges per second). The coxswain needs navigational information, if possible, at the rate of once per second. Data transfer and data manipulation are time-consuming processes for a microcomputer. So, the computational burden is one evaluation criterion. The nature of range errors in microwave systems specify two other criteria: smoothing ability to remove random errors and gross error detection e.g. to remove reflections. When running survey lines, it is possible for the boat to make sudden turns or stops. The dynamic response of the filter is another criterion. Finally, the implementation cost and ease of understanding are necessary to privide the overall performance of a filter. *Casey (1982 b)* describes the evaluation criteria in detail.

Gating: This technique is the most commonly used error detection technique in the hydrographic community as it is simple to implement, comprehensive and inexpensive in the sense of implementation cost. It works on the observation space to block out wild ranges. A technique used in the NAVBOX acquisition system *(see Macdonald, 1981)* stores ranges in a temporary buffer every one second. The technique establishes a gate (permitted variation) around the average of the good ranges acquired during the previous second. The gate width is based on the maximum distance the survey vessel can travel in one second. If none of the observed distances are within the gate, the gate is expanded by an amount proportional to the rate of change of the range. If the range is not reacquired within a user defined maximum time, known as gate length, the operator is informed. The length and width of the gate must be well tuned to the survey conditions. If these values are too narrow good ranges will be rejected and if the values are too wide wild ranges will be accepted. Figure 3.10 illustrates this technique.

Multiranging: The use of multiranging is restricted to ranges from one positioning system. It is difficult to estimate the relative weighting to be given, especially in real time, to different systems *(Weeks , 1982)*, particularly if these systems use different measuring techniques (e.g. phase comparison or pulse matching techniques). Therefore, the use of Least Squares is limited to 3 or 4 LOPs from one type of sensor. The redundant ranges, increase expenditures, time and labor cost. However, redundant ranges permit real time error detection and prevent the need for having to resurvey or detailed checking of data. Various authors have addressed the disadvantages of multiranging as the filtering technique to detect wild ranges *(Bergen, 1979; Casey, 1982a; Eaton, 1982)*. It may have a zero response time and inform the user for a poor fix, but it does not have any spike detection ability (at least for 3 LOPs). These are limitations to the main advantage of multiranging that no alternative to multiranging provides error detection without any assumpions.

Least Squares curve approximation : Another way of deriving accurate positions is to approximate the range time series by a polynomial. We may implement an expanding or fixed or fading memory filter. However, expanding filters (recursive or not) may give systematic errors that grow very rapidly. For details concerning fixed, expanding, and fading memory filters see *Morrison (1969)*.

Suppose we want to approximate the Mini Ranger range time series (shown in Figure 3.11) using a fixed memory filter. The observations are equally spaced in time. The number of observations that will be used (memory length : L) the degree of polynomial (m) must be carefully chosen in order to balance systematic and random errors. Systematic errors arise from the fact that the chosen polynomial may not match the true range time series and random errors have their origin to random errors in the observations. The following should be kept in mind. Details can also be found in *Morrison (1969)*:

- By increasing the degree of the filter the systematic errors are reduced. However, as we increase the degree, the variances of the random errors increase.

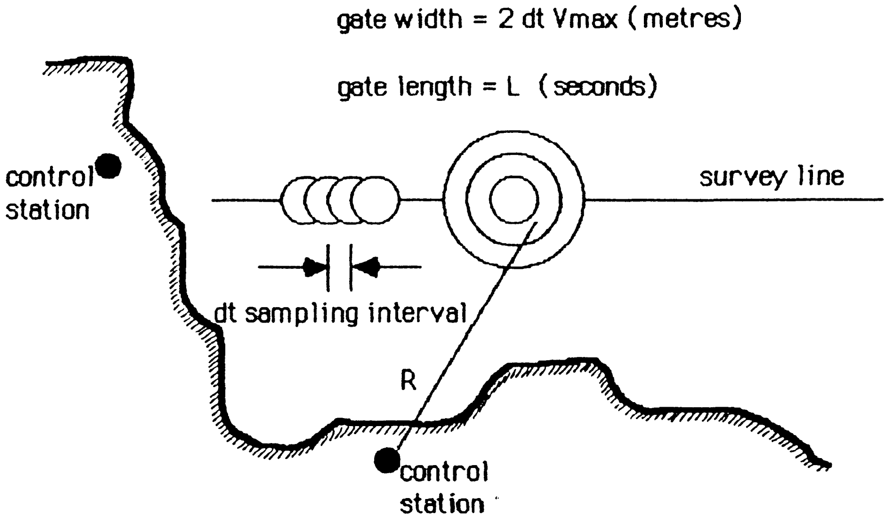


Figure 3.10 : Gating technique to detect range spikes.

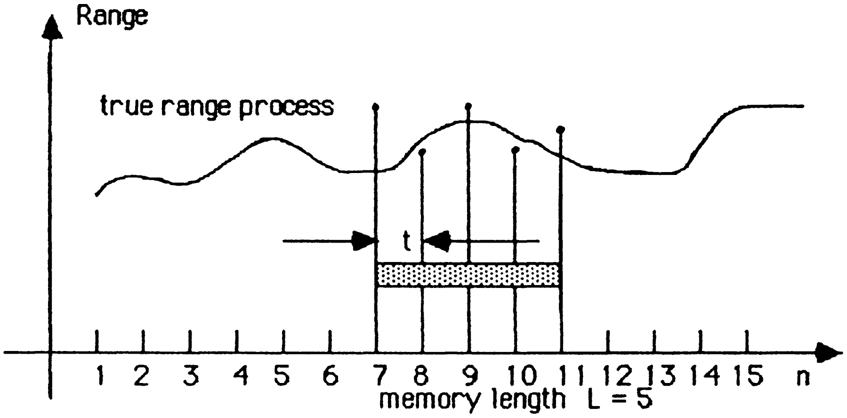


Figure 3.11 : The fixed memory range filter.

- When the length of memory increases the systematic errors increase but the variances decrease.

Casey (1982b) shows that Mini Ranger ranges are locally linear for short time intervals (2-3 seconds). This is probably due to the design of the range tracking filter built into the receiver. Also, it depends on how the vessel is being used; running straight lines is likely to result in linear behaviour of the ranges. So, the range process can be approximated by the linear filter (see Figure 3.11):

$$R = b_0 + b_1(nt) \tag{3.3}$$

For memory length L=5 ($R_n, R_{n-1}, R_{n-2}, R_{n-3}, R_{n-4}$) the n+1 predicted range is given:

$$R_{n+1} = 1/10\,(8R_n + 5R_{n-1} + 2R_{n-2} - R_{n-3} - 4R_{n-4}) \tag{3.4}$$

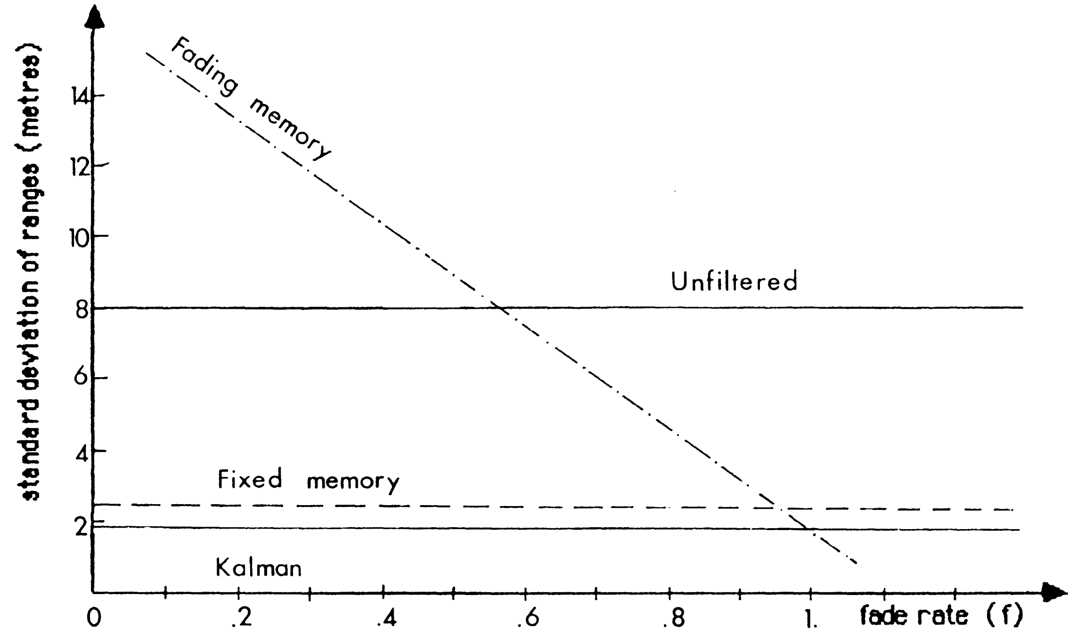
and the rate of change:

$$b_1 = 1/10t\,(2R_n + R_{n-1} - R_{n-3} - 2R_{n-4}) \tag{3.5}$$

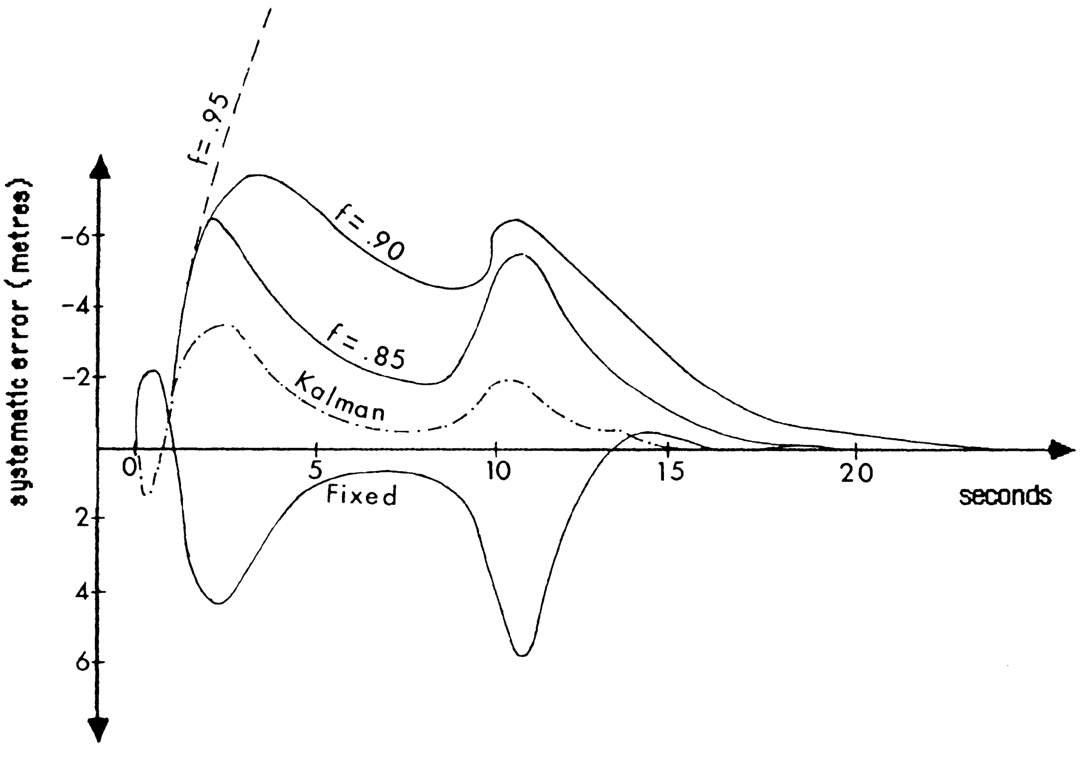
where: t is the sampling interval (e.g. 0.5 seconds). *Morrison (1969)* gives the general forms for degree (m) and memory length (L).

Casey (1982b) also shows (using simulation techniques) that this type of filter has good statistical efficiency and dynamic response equivalent to that of the Kalman filter (see Figure 3.12). The form is easily programmed and can be used to predict the next range reading. If we specify a maximum difference between predicted and observed range (gate width), the filter is similar to the gating technique described earlier. However, the computational burden is increased if the observations are not equally spaced in time.

Kalman filtering: If we know the dynamic behaviour of the ship with its statistical characteristics, we can incorporate this knowledge with range observations and their associated statistics to improve our fix. This technique, known as Kalman filtering, implies the use of a "dynamic" model to describe the ship dynamics and an "observation" model to relate the "state vector" with the observations. The formulation of these models and the derivation of normal equations can be found in *Grant (1976)*, *Schwarz (1983)* and *Gelb (1974)*.



(a) statistical efficiency



(b) filter response in high speed turn (180 degrees)

Figure 3.12 : Statistical efficiency and dynamic response of range filters (from Casey, 1982).

However, there are a number of draw-backs in Kalman filtering that do not permit its implementation in the acquisition system studied here. These include:

1. It carries a heavy computational burden.

2. The filter is very sensitive to the existance of outliers in the system noise statistics. As mentioned erlier, in microwave systems, the occurrence of outliers in range observations (reflections from rocks, range holes etc.) is very common. The Kalman filter will only control the random errors of the Mini Ranger system. *Janes (1983)* gives a qualitative performance of filter robustness against model and observation noise statistical characteristics.

3. It is extremely sensitive to variations from the true dynamic model.

We must always keep the raw data and not alter it with a filter which might have not been the appropriate filter for the particular application.

From Figure 3.12a we see that the fading memory filter has a good statistical efficiency for fading rate f > 0.98. We also see that, for this fading rate, it has a very poor dynamic response (Figure 3.12b). For such values the induced systematic errors are large.

For **SEAHATS**, range spikes are detected in real time by using a gating technique. The gate width is based on the maximum distance the survey vessel can travel between range observations. In addition, provision for multiranging has been made in the software. After eliminating range spikes in real time, a simple Kalman filter is used to post-process the ranges. The filter can be tuned to reflect the actual survey conditions (range stability, vessel's accelerations etc.). This filter is discussed in section 4.3.1.

3.3.4 Quality control of bathymetric data

The only way to control errors caused by beamwidth is to use narrow beamwidth echosounders. In this section we focus on procedures to eliminate digital false echoes. Each digitized depth in order to be reliable, has to successfully pass the following tests:

1. test for valid format and
2. to be inside a tracking gate (gating technique).

Test 1 is performed easily. The gating technique is difficult to use. It has to be well tuned to the survey conditions (sounding speed, bottom type, sampling rate) to be effective. If the majority of false echoes are caused by aeration or surface reverberation, these echoes can be eliminated by testing them against a minimum defined depth. The minimum depth should be carefully chosen not to conflict with the shallow water alarm used to prevent grounding. If the echosounder does not track the bottom and produces deep depths (that equal the deeper limit of the echosounder range selector switch) these depths can be eliminated by testing them against a maximum defined depth.

The gating technique used in NAYBOX system *(Macdonald, 1981)* establishes a <u>permanent gate</u> around an accepted depth that has a user defined <u>gate width</u>. If the next depth falls inside this gate, the gate is re-established around the new depth. If a depth is outside, a <u>temporary gate</u> is established around it. If a number of subsequent depths (the number is specified by the user and it is known as the <u>gate length</u>) falls within the temporary gate, this gate becomes permanent and all the depths are accepted.

The gate length and width have to be selected carefully. If the gate length or width are too small, echo returns from steep slopes or wrecks will be excluded; when it is too large the error rate will inevitably increase. The selection of gate length and width is based on the type of bottom, boat speed, weather conditions and sounding rate. If the maximum seabed slope to be recorded is i (degrees) the sounding rate is r (soundings/sec) and the ship's speed V(m/sec), the gate width (g) should be:

$$g >= (2V/r) \tan i \quad \text{(metres)} \tag{3.6}$$

The minimum gate length (L) that will record echoes from seabed features similar to those shown in Figure 3.13 will be

$$L = a_{max} r/V >= 1 \tag{3.7}$$

where a_{max} = maximum length of feature to be recorded.

Another way to check digital depths is to visually compare them with the echogram. Some means of correlating digital and analog depths must be devised. One way is to transmit time marks to the analog trace. A better way is to convert digital depths back to analog and display them simultaneously with the original analog depth record.

The above filtering techniques can be implemented either in software or hardware. For **SEAHATS**, the quality control of depth observations is done in software while post-processing the acquired data. False echoes are detected by displaying depth versus time at the same scale as the echogram and visually comparing digital and analog plots (see section 4.5).

3.4 The NAVIGATION module

The vessel's position is usually found by measuring ranges to a number of known points. The procedure required to compute the ship's coordinates and provide steering information is :

(i) to project the measured distances onto the chosen coordinate system,

(ii) to compute the position and

(iii) to compute the navigation information (e.g. off-track distances).

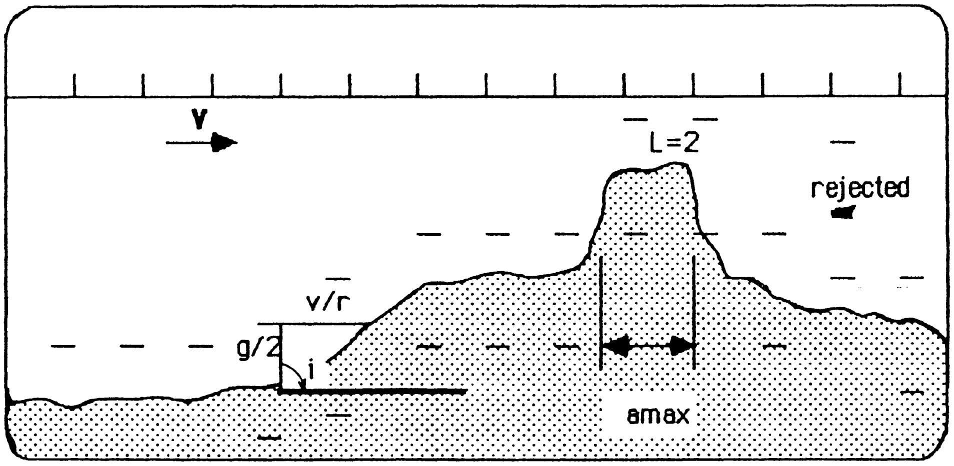


Figure 3.13 : The sea bottom tracking gate.

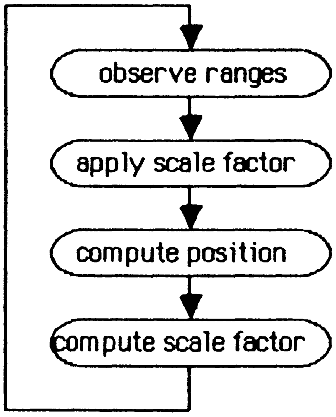


Figure 3.14 : The sequence of tasks needed to apply a scale factor.

There are two routes to follow in order to do steps (i) and (ii). The first route is to reduce the observed ranges onto the reference ellipsoid, use ellipsoidal computations to find geodetic coordinates and project these coordinates onto the mapping plane. The second route is to reduce the observed ranges onto the reference ellipsoid, multiply them with a scale factor and use plane trigonometry to compute grid coordinates. In practice, the second route is preferable because it saves large amount of computer execution time. Finally, the navigation information (step iii) is computed using plane trigonometry, provided that the way point coordinates are referred to the same coordinate system as ship's coordinates.

For inshore surveys the above procedure can be simplified. *Laurila (1976)* gives the formulae to reduce observed ranges to the reference ellipsoid. The estimated correction, for short ranges near the sea surface, is negligible. For example, if we measure a distance of 30 km between two points with elevations 10 and 100 metres and assume a coefficient of refraction k=0.16, the correction is only -0.602 metres. However, we cannot ignore the scale factor computations. For example, if we are working in the vicinity of central meridian of a U.T.M. grid, where the scale factor is $k_0=0.9996$, and fail to apply the scale factor to observed ranges, our ranges will be 30000 X 0.9996 = 12 metres in error.

Cross (1981) gives the approximate formula to compute the scale factor on a given point P, developed by Redfearn in 1948:

$$M/M_0 = 1 + 0.5(E/R)^2 + (1/24)(E/R)^4(1 + 4\,e\cos^2\varphi) \qquad (3.8)$$

where:

M_0 : scale factor on central meridian

M : scale factor on point P

E : Easting of point P

N : Northing of point P

e : square of second eccentricity of reference ellipsoide

φ : latitude at which the (N/M_0) equals the meridional distance

$R^2 = M_o^2 \rho \nu$ at latitude φ and

ρ, ν: meridional and prime vertical radii of curvature.

Given the points 1 and 2, to compute the scale factor applicable to the line joining them we compute the scale factor at the mid point of the line :

$$M_{12} = M_{mid} \qquad (3.9)$$

or integrate numerically by Simpson's rule :

$$M_{12} = 1/6(M_1 + 4M_{mid} + M_2) \qquad (3.10)$$

Bomford (1962) shows that by using equations (3.8) and (3.10) the error in the line length can not exceed 0.1 ppm. Formulae (3.8) and (3.10) are therefore satisfactory with regard to accuracy. In practice, the algorithm showed in Figure 3.14 is used to correct for scale. However, if we are working in a limited area it is acceptable to compute the scale factor once and then use it to convert all the distances.

SEAHATS software computes vessel's position using the second route described above. The ranges are not reduced to the reference ellipsoid, as the reduction quantity is negligible. In addition, due to the increased computational cost associated with scale factor computations, **SEAHATS** does not apply any scale factor. Therefore, vessel's position may be in error if we use a U.T.M. grid. However, when working in small localized areas such as inshore waters, river estuaries and harbours, it may be convenient to define a local coordinate system instead of using one of the standard national systems.

The hydrographer's aim is one or more of the general processes *(Wells , 1976)*:

a. station keeping: (remain on or close to a target);

b. homing: (proceed to a target);

c. route following: (remain on or parallel to a pre-defined track);

d. track following: (remain on a pre-determined track).

In hydrographic surveys the track following process is mainly used. However, homing is used to find the survey area and station keeping to measure, for example, depths at specific points. Route following is used for general navigation.

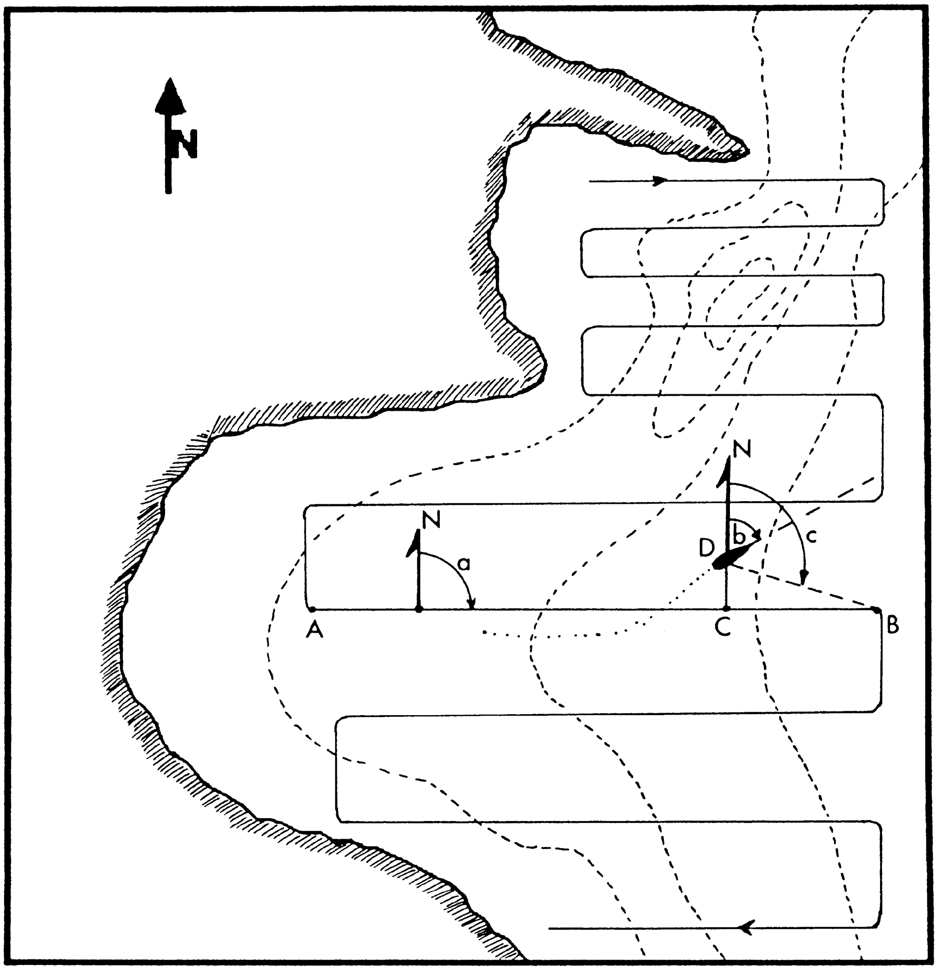
The type of track (lines, arcs etc.) depends on the survey function performed. These functions are *(Umbach, 1976; Boudreau, 1984; Ingham, 1974)*:

- to run primary survey lines;
- to investigate seabed features;
- to run cross lines; and
- to run lines at junctions between surveys.

3.4.1 Primary survey lines

The purpose of primary survey lines is to efficiently sample the depth of the whole area. Usually this is best accomplished by running a system of parallel staight lines (Figure 3.15). The advantage of this system of lines is that the best delineation of depth contours is obtained with a minimum of sounding lines. A disadvantage is that variations in speed at the inshore ends often causes erroneous plotting of soundings.

If navigation routines are not available the vessel can be navigated along LOP arcs (hyperbolic or circles depending upon the positioning system used or the mode adopted for the particular survey). *Boudreau (1984)* suggests that, even in modern hydrographic systems, the ship should be navigated along LOPs. The advantage of such system of lines is that the off-track error is evaluated without concern for strength of fix or accurate positioning of the control station. However, LOP arcs do not have the flexibility of straight parallel lines.



AC : along track distance
CB : distance to go (to reach the end of leg)
CD : off-track distance (left)
a : desired bearing of survey line
b : actual course
c : bearing to the end of line

Figure 3.15 : The sounding system of parallel straight lines.

The length of each leg and the line spacing should be variable (on-line). In this way close water areas can be surveyed simultanously with the outer waters, and the density of soundings can be increased with increasing seabed slopes (see also Figure 3.15).

The information that will feed the command DISPLAY consists of the following:

- distance to start of leg,
- distance to end of leg,
- distance off leg (L/R indicator),
- desired bearing of line (corrected for magnetic declination),
- actual course (corrected for magnetic declination) and
- bearing to end of line (corrected for magnetic declination).

Generally it is easier for the coxswain to navigate along lines of constant bearing. In addition to the L/R indicator he compares the magnetic bearing to the desired bearing.

With regards to the general direction of survey lines, the tracks should preferably be run at right angles with the isobath, as this will minimize the degree of uncertainty in charting of such an isobath. The right angle intersection is clear but not always sufficient and not always easy to carry out, as the actual directions of contours will only emerge during the survey. Another restriction is that in many applications that require resurveys (e.g. monitor the movement of sand waves) it is desirable to follow permanent survey lines. Also, when surveying waterways, it is desirable to run lines perpendicularly to the banks, because these lines will serve as bottom profiles for volume computations.

Usually survey lines are specified by a set of way points. A different approach useful for channel surveying, is to specify as survey lines the lines that are normal or parallel to the central line at equal distances. The table of way points contains:

- way point identification number,
- Northing and

- Easting.

The table of lines contains :

- line identification number,
- Northing of start of line,
- Easting of start of line,
- Northing of end of line and
- Easting of end of line.

SEAHATS provides navigation along parallel straight survey lines that are specified by a set of way points. The following navigation information is displayed to the helmsman and launch hydrographer:

- distance to start of leg,
- distance to end of leg,
- distance off leg (L/R indicator with ripple plot),
- desired bearing of line (not corrected for magnetic declination) and
- bearing to end of line (not corrected for magnetic declination).

3.4.2 Investigation of seabed features

The general system of lines reveals a set of points, the shoals, which must be given special attention since these points may be hazards to navigation. This is called shoal examination . This procedure is also used to locate obstructions reported to exist in a given area (searches). Usually the least depth has to be determined. The table of shoal points contains:

- shoal identification number,
- Northing of shoal,
- Easting of shoal and

- least depth (if known).

Mainly there are three line systems to delineate shoal areas or do searches : parallel straight lines, "circles" and "star" modes *(Umbach , 1976; Ingham , 1974)* , see Figure 3.16 (a,c and e). The system used depends on the location and shape of shoal. A basic requirement is that the system lines should cut at right angles the contours of shoals. Each system should be adjusted (on-line) to the current shoal configuration as illustrated in Figure 3.16 (b,d,and f).

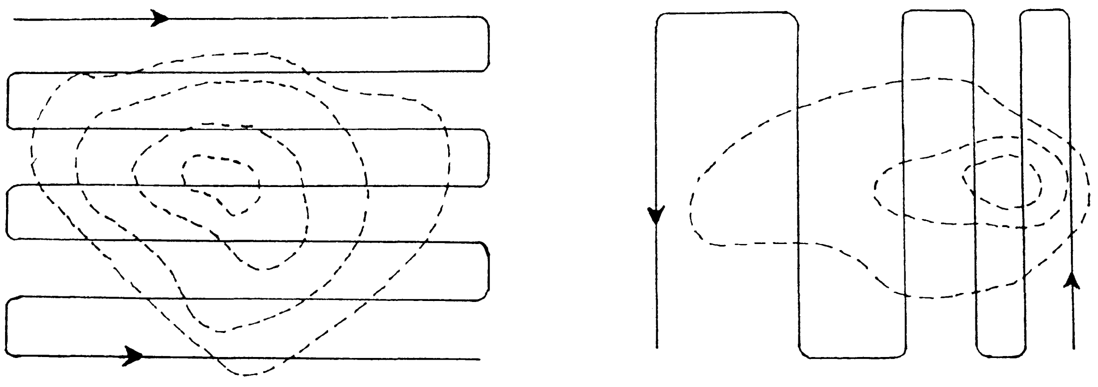
Parallel straight lines give an even coverage of shoal areas. Their use is demanded when the soundings collected during shoal examination have to be plotted. In the "star" mode the density of soundings decreases as we go far from the shoal point. The "star" mode gives closest coverage over the shoal and is best when the location is known accurately (lines cut contours at right angles). The current position of the vessel must be included in the table of way points. This will help to define the first leg of "star" mode. The "star" mode can waste both time and effort if the location is vaguley known. *Boudreau (1984)* suggests that the shoal coordinates should be on-line re-established each time a shallower depth is measured.

For shoal examinations the following information is provided to the skipper:

for <u>straight lines</u> : - distance to start of leg
- distance to end of leg
- distance off leg (L/R indicator)
- desired bearing of line (corrected for magnetic declination)
- actual course (corrected for magnetic declination)
- bearing to the end of line (corrected for magnetic declination)

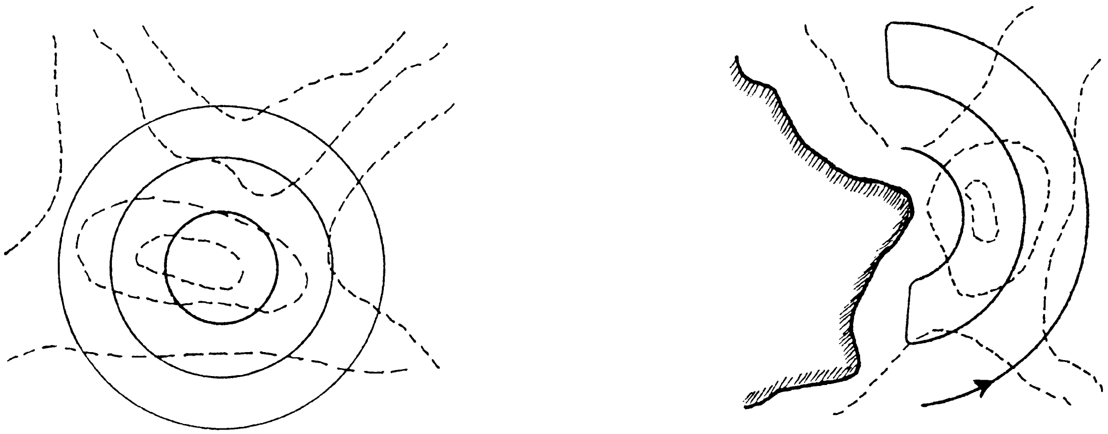
for "<u>circles</u>" mode: - distance to start of leg
- distance to end of leg
- distance off leg (L/R indicator)
- actual bearing

for "<u>star</u>" mode: - distance to start of leg



(a) parallel straight lines

(b) parallel straight lines
unequally spaced



(c) "circles" mode

(d) modified circles to follow
the coast line

(e) "star" mode

(f) modified "star" mode to follow
the coast line

Figure 3.16 : Shoal examination patterns.

- distance to end of leg
- distance off leg (L/R indicator)
- desired bearing of line (corrected for magnetic declination)
- actual course (corrected for magnetic declination)
- bearing to the end of line (corrected for magnetic declination).

Appendix I gives the mathematical models used to derive the above quantities.

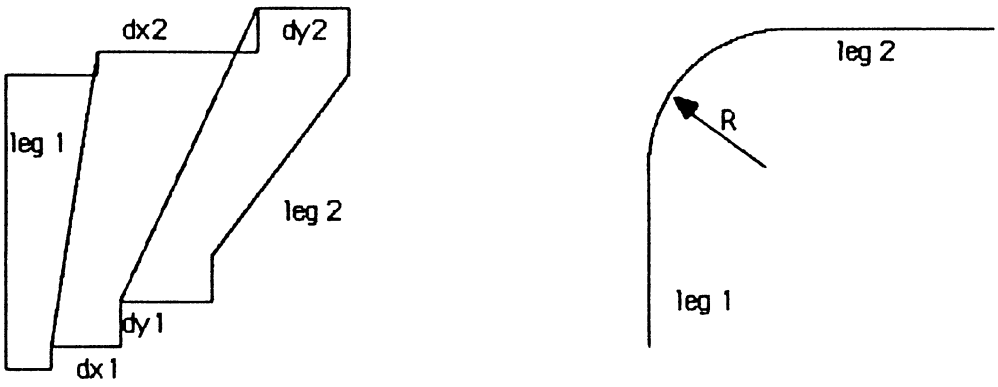
SEAHATS provides shoal examination with straight parallel lines or the "circles" mode or the "star" mode. All of these sounding systems can be on-line adjusted to the current configuration of the shoal area.

3.4.3 Cross and junction lines

The purpose of cross lines is to check the primary survey lines. The system of lines used here is similar to the system used in primary lines. Details concerning their necessity, orientation and density can be found in *Umbach (1976).*

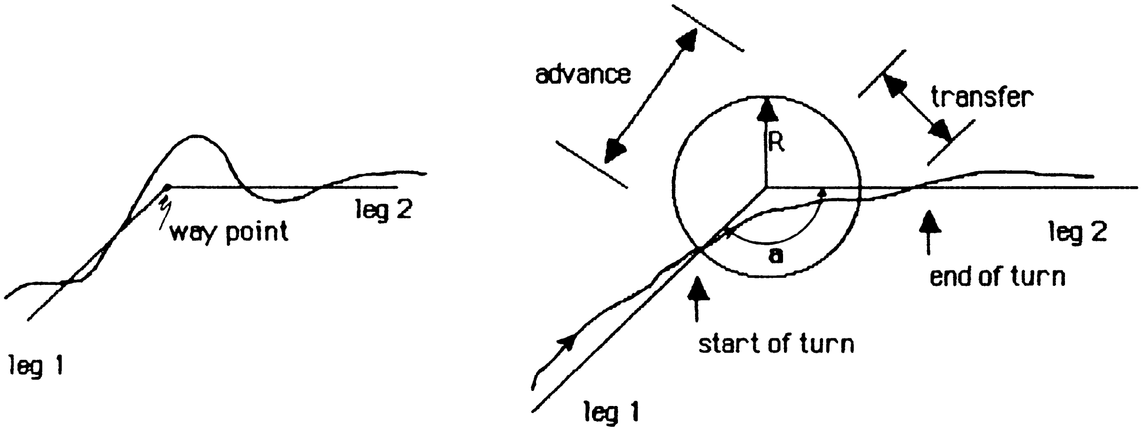
Junction lines connect the soundings of two adjacent surveys. Junction lines may be of the form of Figure 3.17a and 3.17b . In practice however, it is preferred to have overlaps between surveys.

It is obvious that the functions involved in hydrographic surveys (primary lines, inestigation of seabed features, cross and junction lines) can share two navigation sub-modules named "circles" and "straight lines". The functions are differentiated by the method that the way points are specified (shoal points, start and end of legs).



(a) Step type junction lines (b) Arc type junction line

Figure 3.17 : Types of junction lines.



(a) without anticipation (b) with anticipation

Figure 3.18 : Way point navigation.

Channel navigation or steaming to the survey area requires that "route following" be added to the navigation module. The route is specified by a set of way points. But since it is not necessary to reach the points, or the navigation clearance around the way points is not adequate, some means of anticipation must be devised. The next course must be triggered early enough to avoid the vessel's overshooting (see Figure 3.18a). The user can preset the range of circle of proximity where the automatic sequence of the next way point will occur and mark the time the rudder has to be put over. This range (R) depends on the turning characteristics of the ship (advance and transfer), that depend on the amount of rudder used and the angle (a) through which the ship is to be turned. The vessel's speed has little effect *(see Attwood et al. , 1967).*

Figure 3.19 incorporates the NAVIGATION module with the data acquisition system.

For **SEAHATS**, cross lines are run using the mode for primary survey lines. The system also provides way point navigation.

3.5 The ON-LINE MODIFICATION module

The ON-LINE MODIFICATION module is the key to the flexibility of **SEAHATS** (see Figure 3.19). While running survey lines there is often a need to view or modify survey parameters and continue to navigate without passing through the initialization procedure. A routine that will interrupt the navigation function is needed. Here are some examples of where this routine is used:

- If the network of shore transponders gives high GDOP (Geometric Dilution Of Precision) in the working area, the geometric configuration of control stations may be changed on-line to give low GDOP (provided that there are enough transponders).

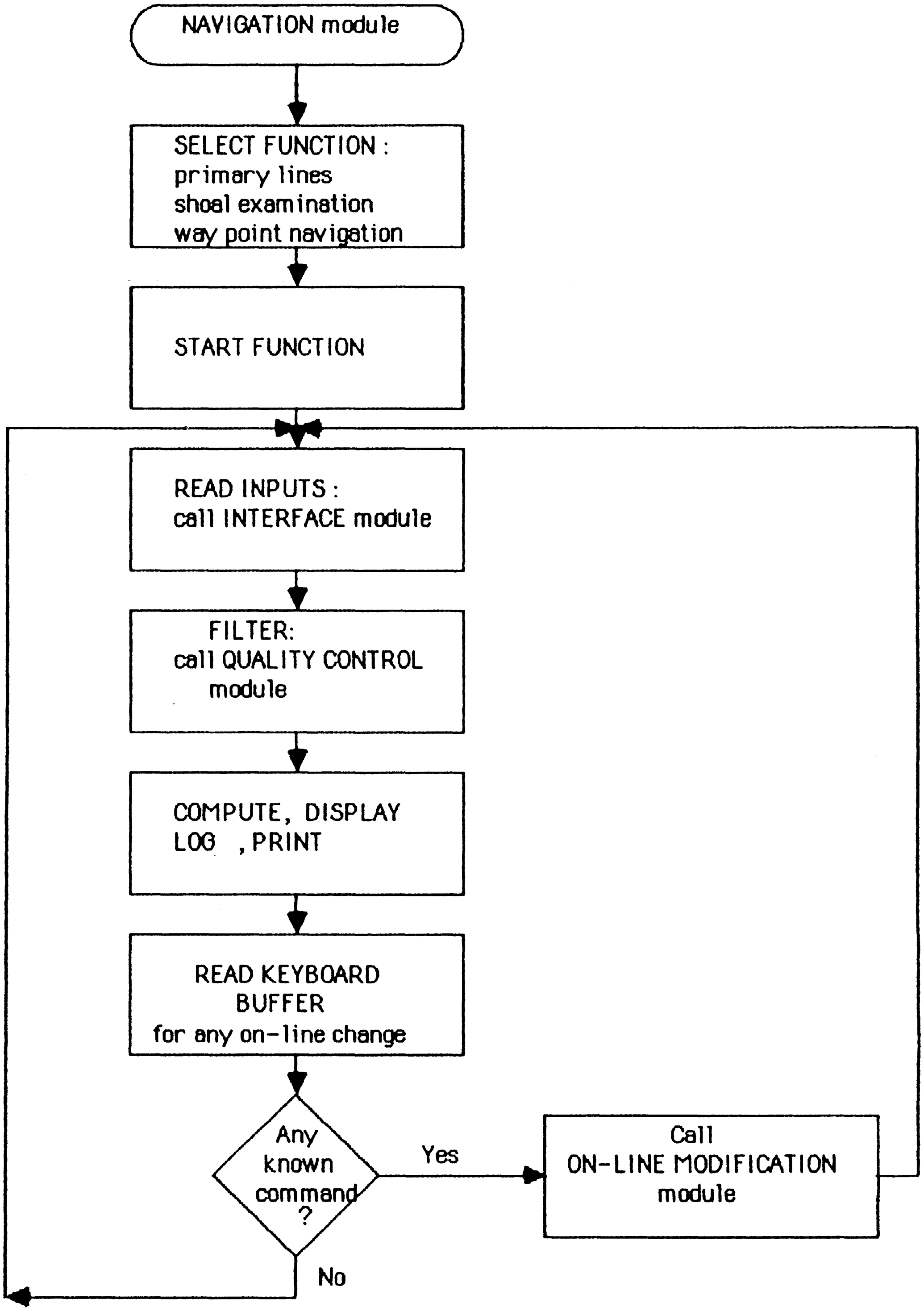


Figure 3.19 : Flow chart of the NAVIGATION module.

- If sea bottom slopes become steeper then more dense coverage is necessary. The hydrographer would reduce spacing between survey lines to achieve the desired coverage.

After the change is made, control is passed to the navigation function. This interrupt, when it occurs must not destroy computational integrity or disrupt any I/O operation. It has the lowest priority among these procedures.

Since the C.P.U. of **SEAHATS** (Apple IIe) cannot support multitasking, the navigation is suspended. The modification therefore should not take more than 10 seconds as otherwise the skipper is left without steering information.

3.6 Description of current version of data acquisition system (SEAHATS)

The present data acquisition and navigation controller consists of the following components :

1. Central Processor: Apple IIe microcomputer.
2. Storage Device: 140 kbytes floppy disks.
3. Positioning System: Motorola Mini Ranger System III (MRS III).
4. Interface Unit and Echosounder Digitizer: CADMI PS01.
5. Echosounder: Simrad Skipper 802 (with 50 kHz transducer).

The Mini Ranger System *(Motorola, 1980)* provides positioning information to the interface unit PS01 *(Nickerson , 1983)* via two parallel BCD connectors. At the same time the echosounder digitizer *(Harris, 1984)* provides depth determination via another parallel interface. The collected information with the associated time tag is sent to the Apple computer as an input to the navigation and logging functions. The interface module provides position and depth correlation of the order of milliseconds. The structure of system is that of Figure 3.2 .

Navigation functions include primary survey lines (parallel straight lines), shoal examination ("circles" and "star" modes) and route navigation (up to 10 way points). Logging functions include the logging of data according to time or distance travelled. Navigation software is written in UCSD Apple Pascal version 1.1 that runs under the Apple DOS environment. Software is menu-driven with the exception of the ON-LINE MODIFICATION module which is partially command driven in order to speed up the process of modification.

Position validation is performed using a gating technique. Depth verification is left for post-processing for the following reasons :

(a) Depths reach the INTERFACE module at high rates (10 per second, see *Harris 1984*) but the CPU at lower rates (1 per second). It can be shown from equation (3.6) that if we want to implement a gating technique and want to record sea bottom slopes of 45^0 steaming at 10 knots the estimated gate width is 10 metres. This value is not acceptable for shallow waters.

(b) A depth filtering algorithm will increase computational time, a critical factor for microcomputers.

(c) Tests showed that the percentage of false echoes is small in the digitizer implemented here. False echoes are mainly produced when the echosounder does not track sea bottom. These depths are usually very deep and can be eliminated by checking against a maximum depth.

As stated before, computation speed is a limiting factor. In a real time application, such as this, the skipper should have instantaneous display of the off-track distance. This is not possible. However, a certain amount of time can be tolerated without disastrous consequences. This amount depends on the operator's experience and the vessel's speed and turning characteristics. Experience shows that for small hydrographic boats, steaming at less than 10 knots this amount is about 2-3 seconds. The current version updates the helmsman display every 3 seconds and displays position history (ripple plot) for the past 12 seconds.

There are basically two types of computer speed limitations (a) data transfer time (~0.70 sec at 1200 baud rate) and (b) data manipulation time (~2.30sec). Data manipulation time is the sum of execution time (~1.80 sec) and time for display updating (~0.50 sec).

Errors detected in all phases of data acquisition can be classified into two types: <u>warning</u> and <u>fatal</u>. The first type tells the hydrographer that inputs are unreliable but the execution of navigation is not halted. Fatal errors indicate that the system is not performing well and navigation stops. Warning errors are bad data sample format, bad disk I/O operation, etc. . Incorrect inputs from the keyboard do not cause fatal errors. The inputs are read as character strings, examined, converted to real or integer numbers and then stored. *Mc Carthy (1983)* describes these error detection techniques.

The system RAM available for the Apple IIe microcomputer is 64 kbytes. It is required to store the Pascal Operating System, the executable code and data buffers. The O/S occupies 12 kbytes, leaving 52 kbytes available to the user. This memory is not enough to store the whole code so, a portion of it resides on the disk. It is important that only non real time software resides on a mass storage device as otherwise, cycling time will be increased by the time required to perform a disk I/O operation (benchmarking results showed ~ 0.3 seconds). The mass storage device for storing acquired data has a capacity of 140 kbytes, which is enough for approximately 1000 soundings.

4. OFF-LINE DATA PROCESSING

4.1 General processing considerations

The introduction of computers to hydrographic surveys has changed the type and amount of tasks of the hydrographic team as pointed out by *Macdonald et al. (1975)*. This processing package is mainly dedicated to the use of "Data Collector" the third level of the hydrographic team, the others being the "Hydrographer in Charge" and the "Data Processor".

The traditional role of the "Data Collector" or launch hydrographer is to conn the survey vessel along pre-determined tracks, collect position, depth, time and any other relevant information useful for post-processing. The hydrographer in the field wants to know how his survey is progressing in a very short period of time. Therefore, during or just after data collection, he portrays the data to identify shoal areas or gaps in his surveys. This implies that a certain amount of data processing has to be carried out in the field (e.g. reduction to the datum of reference, removal of blunders) before data is fed to the "Data Processor" for final presentation.

This amount of data processing, called "field data processing", is done manually. The tide is interpolated from tide tables and soundings are plotted manually. This requires an additional 3 to 4 hours of work for each day of data collection. The software package discussed here tries to minimize this extra work.

It must be emphasized that the computer resources necessary to speed up this process must be available any time during the survey work. The computer facilities of the hydrographic office or the "mother ship" are not suitable. The best way to further process the data off-line is to use the acquisition computer system. The final product will be rough field sheets accompanied with the associated corrections.

This processing package does not replace the task of the "Data Processor" but rather helps it. For example, if the purpose of survey is chart production, the "Data Processor" is responsible for merging data from different sources, contouring and performing quality control on the data. These tasks require stronger computer capabilities than the acquisition computer system can provide and a great amount of judgement and knowledge. For the sake of completeness, however, methods for off-line quality control of data and ways for final presentation are discussed.

Data processing consists of five elements :

(a) EDITING,
(b) REDUCTION and CORRECTION,
(c) SMOOTHING,
(d) SELECTION and
(e) PRESENTATION.

We cannot draw distinct boundaries between the amount of correction, reduction, smoothing, selection and data presentation that is done on-line and off-line. For example, correction for roll, pitch and heave effects can be done either on-line (by integrating to the system roll, pitch, heave sensors) or off-line (by merging separately collected heave and depth data).

The field data processing is an iterative process. It is repeated until the launch hydrographer (with the assistance of hydrographer-in-charge) has strong evidence to choose to :

-resurvey the whole area or part of it,

-fill survey gaps,

-examine shoal areas or

-provide the collected data to the "Data Processor".

4.2 Interactive editing of hydrographic data

The objectives of an interactive editor for hydrography are:

(a). To correct identified errors in the location and value of a sounding.

(b). To delete soundings collected during a shoal examination and used to reveal the shallowest depth.

(c). To fill gaps between soundings (merge soundings from different sources).

(d). To identify the shallowest point in a given area.

In order to meet these objectives the editor must have the ability to add, delete, move, change, suppress, unsuppress or search soundings or survey lines. To do this, the operator must have the capability to identify where the soundings or lines come from and treate them as inputs.

The changes in soundings must be registered on the survey data files. In order to implement the features of the editor, it is necessary to design a data base successfully. *Varma (1984)* describes the editor and *Malone (1984)* describes the data base used in the Canadian Hydrographic Service. The design of such an editor and data base is beyond the scope of this research. We will restrict ourselves in the implementation of simple editor commands like add, delete and change.

A major reason for using a commercially available system like the Apple IIe microcomputer and not a specialized system like the HY-NAV, is that editor features are provided. **SEAHATS** makes use of the Pascal Operating System editor to add, delete or change soundings.

4.3 Smoothing, correction and reduction of hydrographic data

The next phase of processing the recorded data (positioning and bathymetric) is to smooth them by applying our knowledge about the behaviour of depths and position. Then, the observed soundings are corrected from departures from true depths and are reduced to the reference datum. These corrections include *(Thomson et al., 1981; Umbach, 1976)*:

(a) Transducer correction (static draft, settlement and squat).

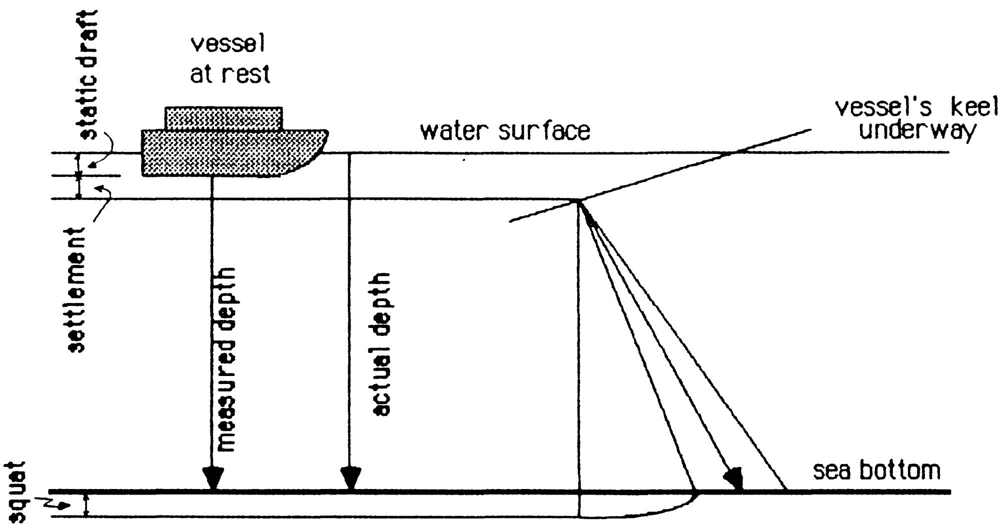
(b) Correction of different sound velocities in the water column.

(c) Reduction to datums of reference.

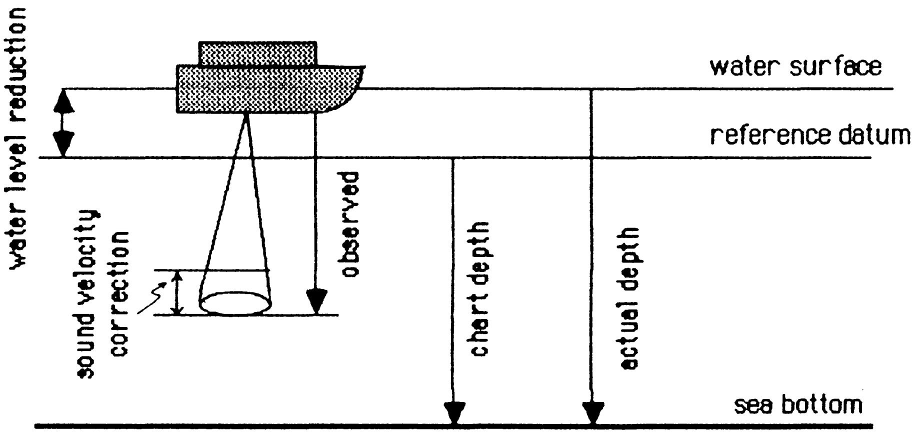
(d) Roll, Pitch, Heave corrections.

Figure 4.1 illustrates corrections (a), (b) and reduction (c). Usually these corrections are applied off-line. Correction (d) is shown in Figure 4.6 and it is an underway correction.

Static draft is the depth of transducer when the vessel is at rest. Settlement is the difference in depths of transducer when at rest and underway. Squat is the change in vessel's trim, while underway, that changes the verticality of the transducer.



(a) transducer correction



(b) datum reduction and sound velocity correction

Figure 4.1 : Corrections and reductions to observed soundings.

The two main factors that cause an increase in squat, are increasing speed and decreasing under keel clearance. Decreasing under keel clearance is important only when the ratio of depth/static draft is less than 2.5 *(Bowditch, 1977).* For launch hydrography with static draft of the order of 1 metre, the effect is negligible. The increase in speed results in a "down by stern" squat which is also negligible for speeds less than 10 knots. Transducer correction is therefore constant and equals the static draft.

With **SEAHATS** processing software, depths are corrected from static draft and different sound velocity in the water column. Soundings are reduced to the datum of reference. Roll, pitch and heave corrections are not provided. The effect of ignoring these corrections (roll, pitch and heave) is investigated in section 4.3.5.

4.3.1 Smoothing of positioning data

In section 3.5 it is mentioned that in **SEAHATS** a gating technique is used to block out wild ranges. Now we will further smooth the ranges to Mini Ranger transponders using a simple linear model with driving noise. An off-line filter is developed that uses fixes before the fix under consideration. The factors which prevent on-line implemenatation were discussed in section 3.3.3.

The dynamic model that describes the behaviour of each range to control station for short time periods is:

$$R_k = R_{k-1} + V_{k-1}\ t + 1/2\ a_{k-1}\ t^2 \qquad (4.1)$$

$$V_k = V_{k-1} + a_{k-1} t \qquad (4.2)$$

where:

R_k : range at fix k

V_{k-1} : range rate from fix k-1 to k

a_{k-1} : range acceleration from fix k-1 to k

t : time interval between fixes.

The philosophy behind the model is that, for a short period of time (2 to 3 seconds), the Mini Ranger ranges change linearly and experience accelerations which are not only small but, for this time period, average around zero. As a result , the range accelarations in both channels A and B are modelled as stochastically independent variables with zero means and variances σ_a^{A2} and σ_a^{B2} respectively:

$$E\{a^A\} = E\{a^B\} = 0 \qquad (4.3)$$

$$Var\{a^A\} = \sigma_a^{A\,2} \qquad (4.4)$$

$$Var\{a^B\} = \sigma_a^{B\,2} \qquad (4.5)$$

The <u>dynamic model</u> in matrix form for each range of channel A and B is :

$$X_k = F_{k/k-1} X_{k-1} + W_k \qquad (4.6)$$

where :

$X_k = \begin{bmatrix} R_k \\ V_k \end{bmatrix}$: the state vector,

$F_{k,k-1} = \begin{bmatrix} 1 & t \\ 0 & 1 \end{bmatrix}$: transition matrix,

$W_k = \begin{bmatrix} (1/2)\, a_{k-1}\, t \\ a_{k-1}\, t \end{bmatrix}$: system noise with $E\{W_k\} = 0$ and $Q_k = cov\{W_k\}$.

The <u>observation model</u> has the form :

$$Z_k = H_k X_k + U_k \qquad (4.7)$$

where: $H_k = [\ 1\ 0\ ]$ the matrix that relates the observations with the state vector, U_k the observation noise with $E\{U_k\} = 0$ and $P_k = Var\{U_k\} = \sigma_R^2$ and σ_R the range variance. The derivation of normal equations can be found in *Grant (1976).*

The presence of driving noise W_k allows the hydrographer to tune the filter in the actual survey conditions. This is because the main function of the driving noise is an indicator of the accuracy of dynamic model. This implies that , in rough sea, where rolling and pitching of the vessel's antenna introduces high range accelerations and the positioning system is stable, range observations are stronger than the estimates derived from dead reckoning. This knowledge is reflected in the selection of the filter gain factor.

As mentioned in *Janes (1983)* , the gain of the filter is fixed for any constant ratio Q_k/P_k (Q_k is the model noise covariance and P_k is the observation noise covariance) , regardless of their sizes. In the present filter we have $Q_k = E\{\ W_k\ W_k^T\ \}$ which results in :

$$Q_k = \sigma_a^2 \begin{bmatrix} (1/4)\,t^4 & (1/2)\,t^3 \\ (1/2)\,t^3 & t^2 \end{bmatrix} \tag{4.8}$$

We also have :

$$P_k = \sigma_R^2 \tag{4.9}$$

The gain is equally sensitive to Q_k and P_k, which means that the ratio $k=Q_k/P_k$ uniquely defines the behaviour of the filter.

Figure 4.2, curve (a) depicts an actual range rate time series from channel A of the Mini Ranger System, obtained by differencing consecutive measured ranges. The survey boat was running parallel straight lines at Campobello Island. Curves (b), (c) and (d) are estimates of the range rate (V_A) with tuning factors $k = 0.01$, 0.1 and 1 respectively. For large measurement noise and small system noise, the gain of the filter is small and only small adjustments will be

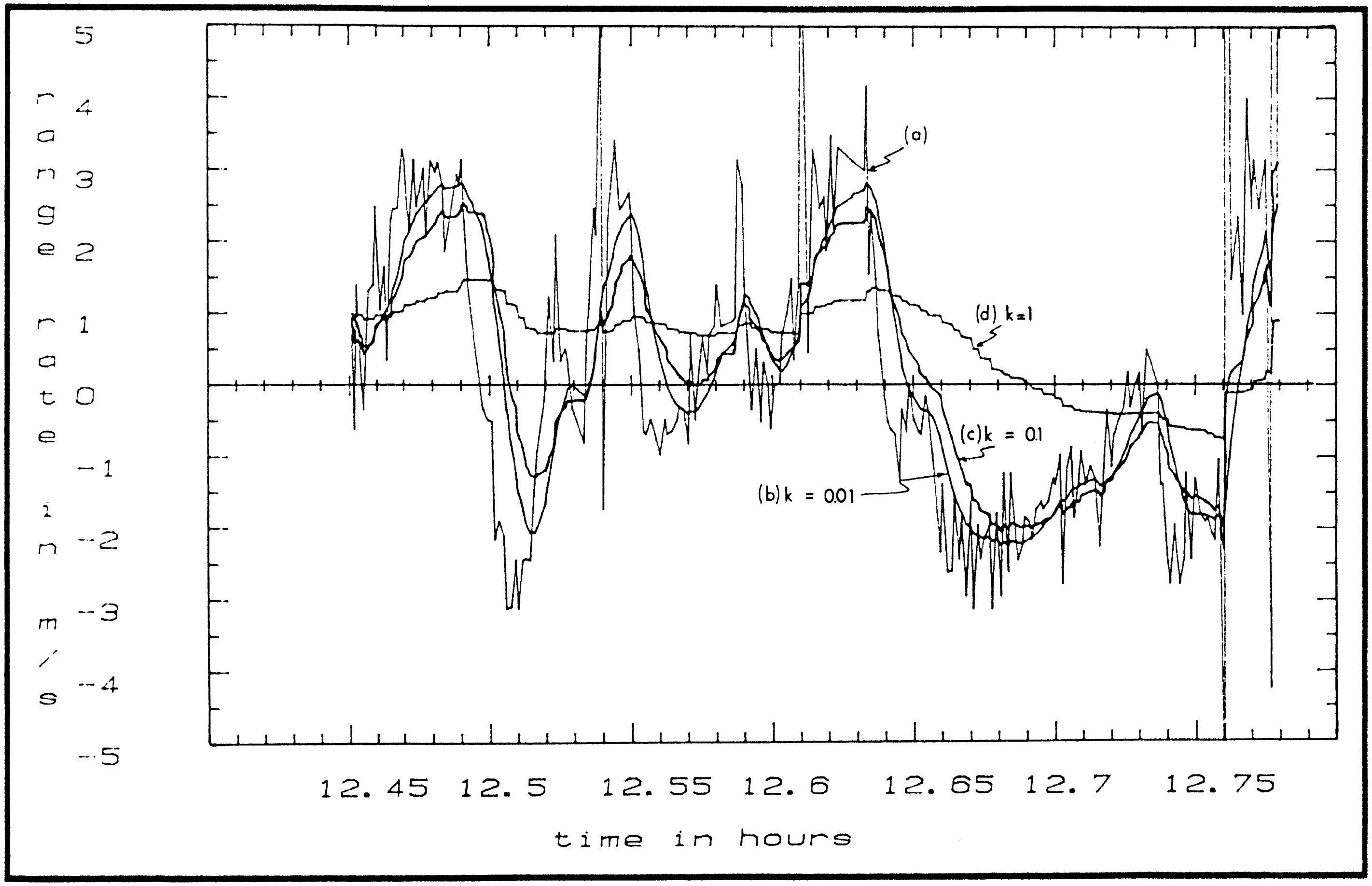


Figure 4.2 : Estimation of Mini Ranger range rate time series with Kalman filtering for various gain factors.

made to the predicted estimate. Conversely, good observations and the large uncertainty in the dynamic model results in a large gain, and the difference between the observed ranges and predicted ranges has a stronger influence on the estimation of the state vector. In the above example, the filter dynamic model with gain factors k=0.1 or k=1 do not match the true range process and therefore the induced systematic errors are large. The Kalman filter with gain factor k=0.01 is well tuned to the actual survey conditions.

4.3.2 Correction of speed of sound in water

While determining depth, sound pulses travel from the transducer vertically towards sea bottom and return through a column of water in which the velocity of sound varies at different depths. If the actual sound velocity cannot be estimated, the standard velocity (1500 m/s) given by the International Hydrographic Bureau can be used. Table 3.1 gives the errors in determining depth based on this assumption.

Velocity of sound in water varies with density, which is a function of temperature, pressure, and concentration of dissolved constituents (salt being the most important in sea water). Temperature has the largest influence. For shallow waters, sound velocity is succeptible to daily and local changes of heating and cooling.

The actual value of sound velocity in the area and time of survey may be estimated using one of the following procedures *(Thomson et al., 1981)*:

(a) By " bar check ". The depth to a reflector lowered beneath the ship at a known depth is measured. When the sea is calm and there is little differential current and wind effect that cause the reflector to be displaced from a position vertically bellow the transducer, bar checks can be obtained in depths less than 20 metres *(Umbach, 1976)*.

(b) By directly measuring sound velocity as a function of depth using an accurately calibrated velocimeter.

(c) By measuring temperature, salinity and pressure (depth) along the water column and using Wilson's approximate formula.

(d) By referring to tables of sound velocity corrections for the same area at a similar time of the year.

Matthews' tables *(Matthews, 1939)* are the reference tables for the last case. Oceans are divided into oceanographically similar areas and sounder corrections are tabulated for these areas. Their use is not recommended for shallow waters because of their very general nature. Such procedures are recommended for ships engaged in hydrographic surveys on the deeper parts of continental shelf. Matthews' velocities do not include variation with pressure and it was found that the surface estimates are 3-4 m/s too low.

Wilson 1960 *(Wilson, 1960)* includes variation with pressure in the determination of sound velocity. The dependence of sound velocity on temperature, salinity and pressure within 1000 metres of the surface is found approximately:

$$C = 1449.2 + 4.6\,T - 0.055T^2 + 0.00029T^3 + (1.34 - 0.010T)(S - 35) + 1.58\ 10^{-6}\,P_a \qquad (4.10)$$

where:

C : sound velocity (m/s)

T : temperature (C^0)

S : salinity (ppt)

P_a : gauge pressure due to water column (N/m^2).

If we ignore compressibility $P_a = \rho_a g z$ (ρ_a : water density) and using $\rho_a = (1+S10^{-3})10^3$ Kgr/m^3, $g=9.8m/sec^2$, $S=35ppt$ and z=depth the variation due to pressure is $0.016z$.

Because the observations used by Wilson in developing his equation included combinations of temperature, salinity and pressure not found in nature, Del Grosso *(Del Grosso et al., 1972)* developed a new equation that is found to differ only by 0.5 to 0.6 m/sec less than Wilson's formula. Since Wilson's equation had already been adopted in the hydrographic community and since this difference is not significant for shallow waters, it is used to estimate the actual speed of sound in water. *Maunsell (1977)* gives the history of sound velocity estimation.

No matter how the sound velocity is estimated at various depths, a mean sound velocity over the effective water column is needed for sounding reduction. A velocity profile such as that illustrated in Figure 4.3 is constructed. The mean sound velocity along the sea water column (propagation area) is computed by :

$$C_m = 1/(Z-Z_0)\int_{Z_0}^{Z} C(z)\,dz. \qquad (4.11)$$

4.3.3 Datum reduction

Datum reduction is applied to the observed soundings after all other corrections have been made. Its purpose is to reduce each measured depth to the datum of reference (chart or sounding datum) for the particular survey area. The difference in elevation of the water surface (tide or water level stage) and the reference datum at the time the depth was observed is the reduction quantity.

The reduction quantity can be predicted or measured and is tidal or non tidal in its origin. Tidal fluctuations of water level are mainly the result of gravitational interactions between the sun, moon and the earth. Non tidal variations can be caused by the wind, atmospheric pressure, storm surges, precipitation and evaporation and seasonal balance between supply and discharge in

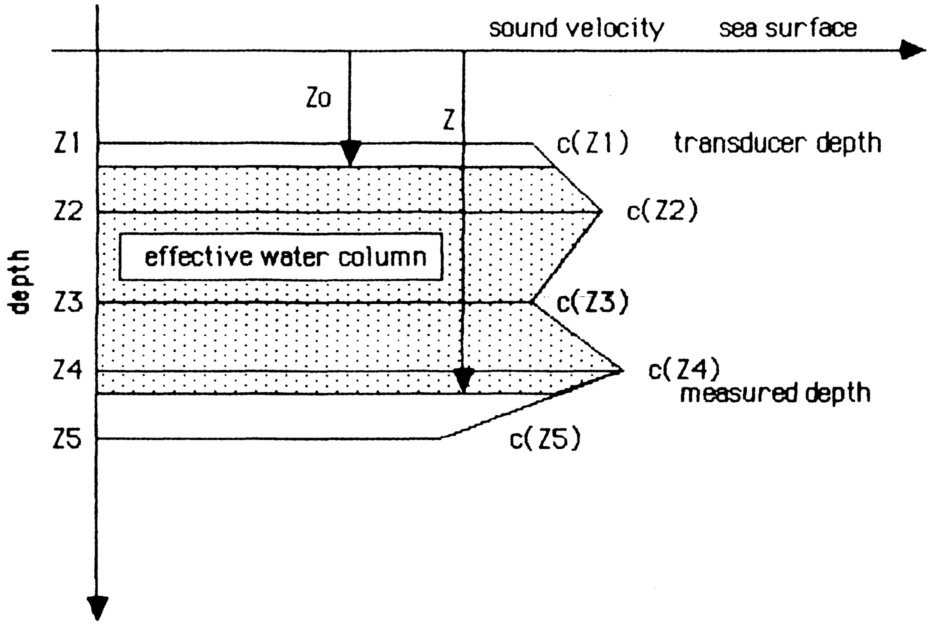


Figure 4.3 : Sound velocity profile in the area of survey.

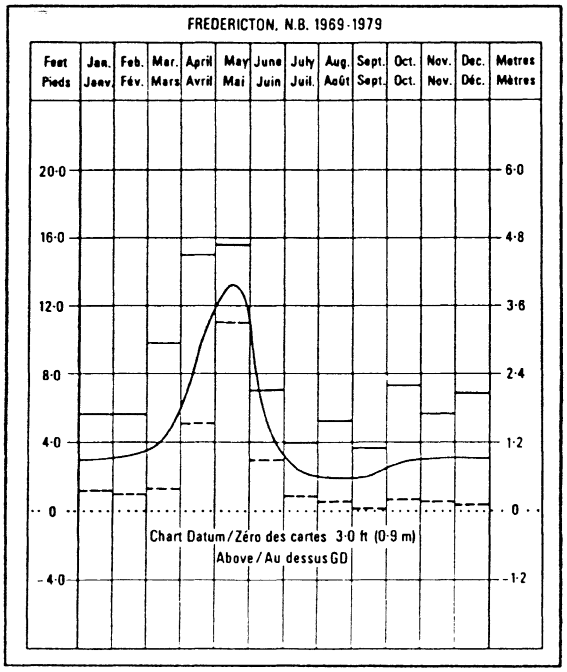


Figure 4.4 : Seasonal variation of water level in Saint John river.

rivers. The tide usually dominates the spectrum of variations of water level fluctuations but in some cases, as in rivers, the tidal range is very small compared to larger variations in water level due to the seasonal disturbances (see Figure 4.4 for Saint John river in Canada).

Prediction of the astronomical tides for inshore waters is based on the description of the tide by means of constants which can be determined by harmonic analysis applied to an observed time series of tide heights in deeper waters *(Dronkers, 1964)*. In hydrographic surveys in shallow sea waters and rivers, the description of the tide using only the astronomical constants is inadequate and "shallow water constituents" must be considered as well *(Dronkers, 1964)*. The prediction model is complex and not practical. Complexity is increased when models for wind set up or atmospheric pressure effects are added.

Prediction models are used for off shore surveys where it is difficult to set up a tide monitoring station, and the tide motion is well predicted by cotidal charts. For automatic reduction of soundings that use predicted models see *Okenwa (1978)*.

It is therefore required that a tide gauge be set up in the vicinity of survey area, and the rise and fall of tides observed while soundings are taken. Often the onsite tidal data differs from the data of the monitoring station in the range and time of arrival of a particular phase. In that case, the survey site is surrounded by a number of tide gauges and appropriate interpolations can provide accurate tide height estimates. For more details on the selection of these sites see *Umbach (1976)*.

Mainly there are three methods of interpolating tidal data in the tide record, depending upon the accuracy requirements and the sampling interval *(Umbach, 1976)*. These are : (a) linear interpolation between readings, (b) scaling of values in a plotted curve, and (c) construction of a reduction table.

A version of the second method requires the observation of only two successive high and low values. Intermediate values are computed by approximating the tidal curve with a sine curve.

If (T_1, H_1) and (T_2, H_2) are two successive high and low points in the tidal record the tide (H) at time (T) is:

$$H = H_1 + 0.5\,(H_2 - H_1)\,\{1 + \sin\{(\pi/2)\ (2T - T_2 - T_1)/(T_2 - T_1)\}\} \qquad (4.12)$$

The application of the method is straight forward when the character of the tide is diurnal or semi-diurnal. When the tide is of a mixed type, it is sometimes difficult to distinguish between successive low and high values. Figure 4.5 represents an actual tide record and its approximation at Campobello Island N.B., where the tide is semi-diurnal. The actual tide record has been constructed with readings every 5 minutes (the height spikes are recording errors). It can be seen that the sine curve agrees with the tide record within 10 cm. **SEAHATS** processing software includes this technique for tide reduction.

4.3.4 Establishment of the sounding datum

There is often a need to refer the local sounding datum to the chart datum. If the chart datum cannot be determined from existing benchmarks close to the survey site, it can be obtained by water level transfer from a near site where a chart datum exists. Thus, processing software should include a utility for water level transfer.

Water transfer implies simultaneous observations of short period (3 to 4 days) of the water level at the site of the survey and at one or more reference stations in the vicinity of the area (e.g. 50 km). The method used for transferring water level depends on the main generating force of water level fluctuations (tide, wind, seasonal balance between supply and discharge in rivers, atmospheric pressure etc.). *Forrester (1983)* gives a description of these forces.

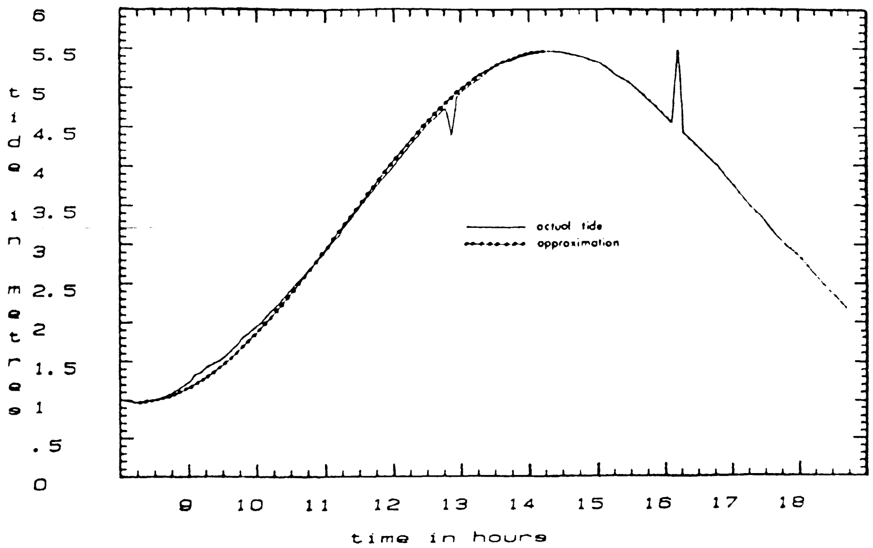


Figure 4.5 : Semi-diurnal tide at Campobello Island and its sine curve approximation.

Table 4.1 : Accuracy (RMS errors) of determination of water level using a 3-day period of observations (from Aboh 1983).

METHOD	SOUNDING DATUM	area of changing range	area of changing character	area affected by river and estuarine effects
Range Ratio	MLW	40 cm	20 cm	4 cm
Height Difference	MLW	37 cm	15 cm	3 cm
Ext. Water Elevation	MLW	50 cm	47 cm	14 cm

In cases where tide is the main contributor to variations in water level, three methods are chiefly used for transferring water levels and establishing a sounding datum. *Aboh (1983)* describes these methods. These are : Range Ratio, Height Difference, and Extrapolated Water Elevation methods. Selection of the best method for a particular area and time depends on how closely the assumptions on which the methods are base are met. The Range Ratio method has been used for years. *Forrester (1983)* says that this method performs well when the tide is semi-diurnal or mixed semi-diurnal (as in the Bay of Fundy).

Aboh (1983) also compares the three methods in areas of different tide character, different range, and areas that are affected by river and estuarine effects. The Height Difference method performs well in all these areas with an accuracy in deriving Mean High Water (MHW) level of 27 cm and Mean Low Water level of 37 cm RMS (see Table 4.1). Therefore, the **SEAHATS** software processing package includes the Height Difference and Range Ratio methods to estimate MLW which will be the sounding datum closest to the chart datum.

Water level transfer in non-tidal waters (as in lakes and rivers) should not be carried out when wind set up or seiche activity is suspected. Without these activities, the mean surface in lakes is the same everywhere and in rivers is only affected by surface slope. *Forrester (1983)* gives the procedures for performing level transfers in these cases.

4.3.5 Roll, pitch, heave corrections

In this section we will identify the need to correct the observed depths and estimated ship's position from ship motions caused by the wave action. The hydrographic vessel, underway, is subject to six motions that can be attributed to the motion of waves. These are three displacements (heave, surge and sway) and three oscillations about the principal axes of the ship (roll, pitch and yaw, see also Figure 4.6). Only roll, pitch and heave affect the observed depths. Roll, pitch and heave corrections are dynamic, periodic corrections and are usually applied underway.

Figure 4.6 illustrates how a vessel's roll and pitch affect the verticality of the transducer and thus the measured depth. Heave is the vertical displacement of the transducer from mean water surface due to sea conditions. Estimation of these corrections requires sensing of angles a (pitch), b (roll) and vertical acceleration (c). The corrected depth is:

$$D_{true} = D_{observed} + C_{roll,pitch} + C_{heave} \qquad (4.13)$$

$$C_{roll,pitch} = D_{observed} \{ (1/(\surd(\tan^2 a + \tan^2 b + 1))-1 \} \qquad (4.14)$$

$$C_{heave} = - \iint_{\Delta t} c\, dt \qquad (4.15)$$

The pitch angle of vessels is normally in the range of 5 to 10 degrees and much smaller than the roll angle, which can be up to 25 degrees. Figure 4.7 gives the error due to roll and pitch of a vessel for depths of 100 metres deep. In shallow waters and in good sea conditions, the errors due to roll and pitch are negligible. More important is the heave effect which can be 2 metres at a period of 5 - 10 seconds *(Hopkins, 1980).* Roll and pitch always give measured depths that are deeper than true depths.

Heave is determined by measuring vertical acceleration and integrating twice to obtain vertical displacement. The heave sensor is designed for a specific bandwidth of heave periods (e.g. 1 to 30 seconds). Outside this frequency envelope, the heave estimates are false. The wider the bandwidth the better the sensor. But such a sensor also senses lower frequency components caused, for example, by horizontal accelarations due to maneuvering. For example, a 90^0 change in the ship's course at a speed of 8 knots, introduces a false heave output of 30 cm. This output is proportional to the square of the ship's speed *(Hopkins, 1980)*. These frequencies have to be blocked out. A high pass filter is needed which requires 1-2 minutes processing time. Two methods are proposed by *Hopkins (1980)* to compensate for heave:

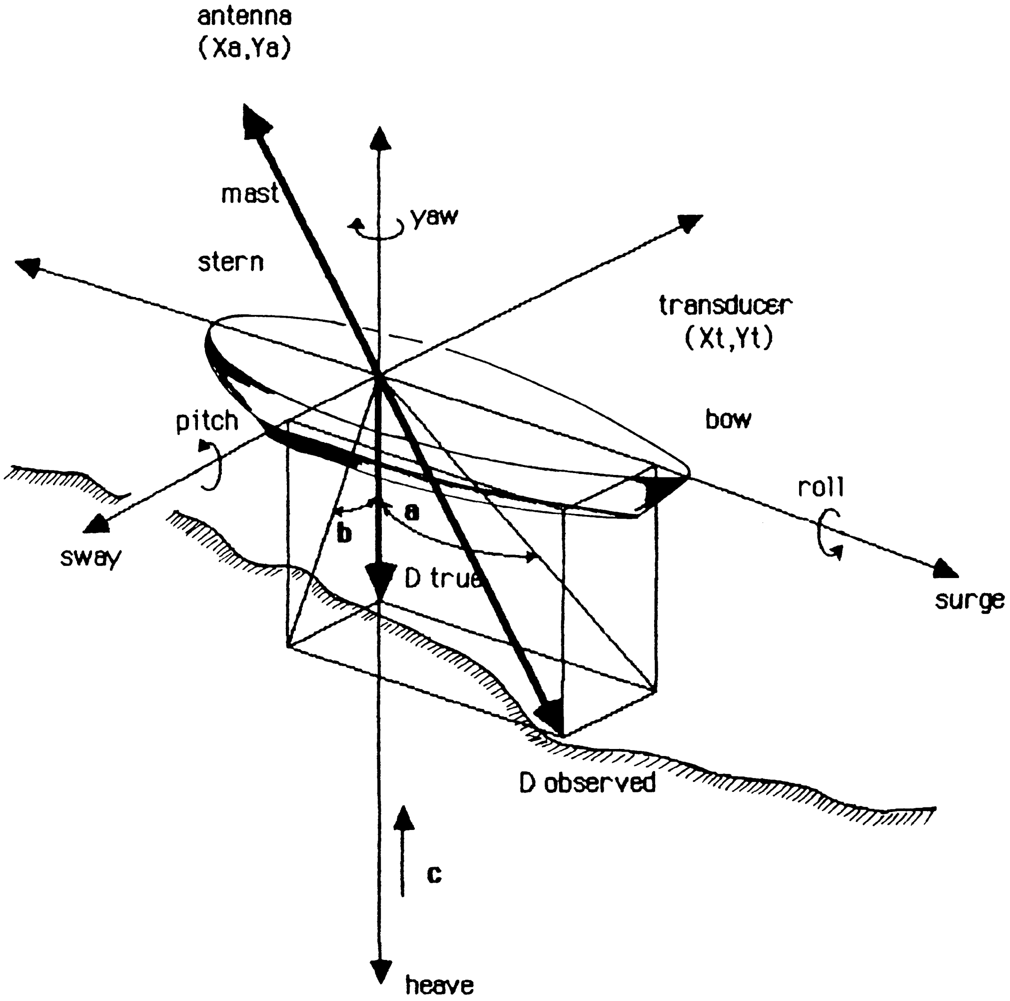


Figure 4.6 : Ship motion due to wave action and its effect on depth detemination and position of the antenna of positioning system.

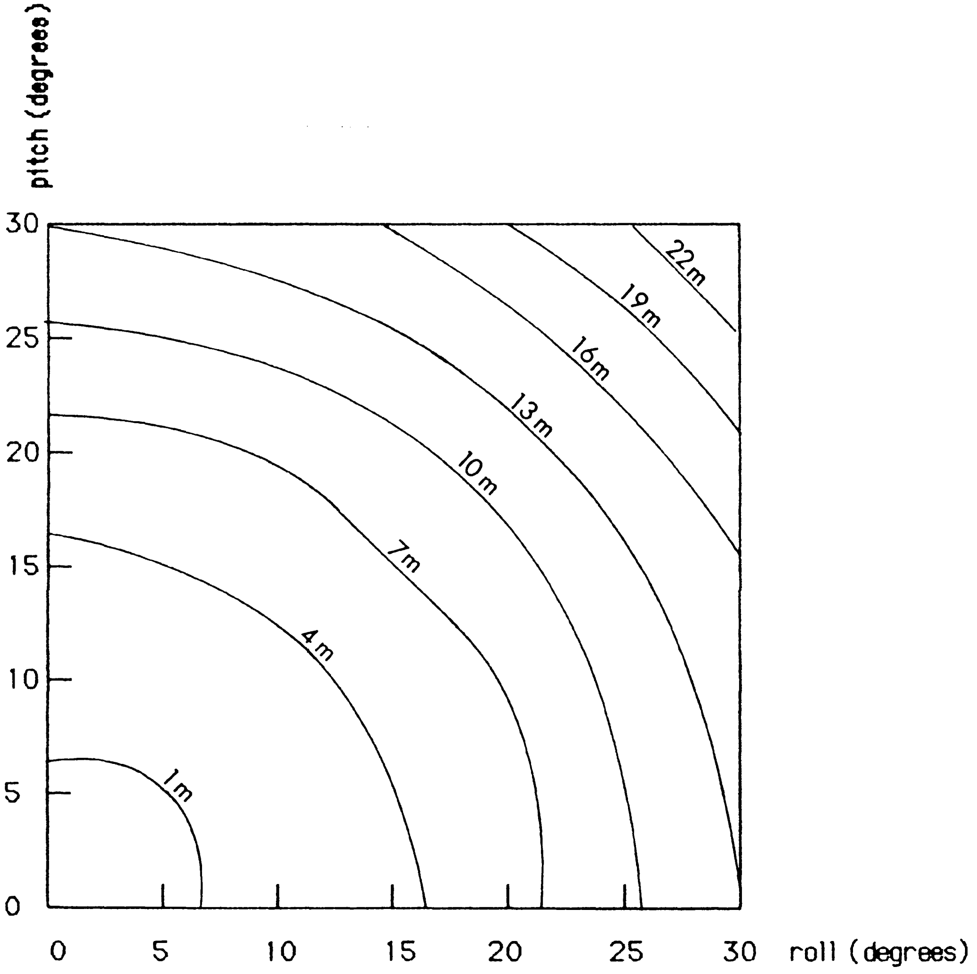


Figure 4.7 : Depth error due to roll and pitch of the vessel
over a flat, horizontal, 100 metres deep seabed.

(a) to approximate heave in real time with reduced bandwidth or

(b) to estimate error free heave with wider bandwidth but delayed by more than 1 minute.

For the present real time application it is suggested that method (a) be adopted. This requires surveying within the frequency range of the heave sensor and avoiding depth observations while maneuvering.

Hopkins (1980) also gives the equation needed to calculate the so-called translation correction. This correction, which will not be further investigated here, is needed when the heave sensor cannot be installed in the same location as the sonar transducer and therefore experiences different accelerations.

We can manually smooth the effect of roll, pitch and heave on the echogram and therefore we do not need any special hardware. But if the bottom has irregularities of similar magnitude to the wave length of heave, manual smoothing will result in an incorrect picture of the sea bottom.

Due to the roll and pitch of the vessel, the coordinates of the antenna of the positioning system (X_a,Y_a) do not coincide with the coordinates of echosounder transducer (X_e,Y_e) (see Figure 4.6). For small hydrographic launches with a 10 metres mast, and roll and pitch angles less than 5 degrees, the offset in coordinates is in the order of 1 metre. For larger values of roll and pitch it is necessary to use roll and pitch sensors.

4.4 Selection and presentation of results

4.4.1 Selection of soundings

Soundings from their "generation" to their presentation on the final field sheet go through three stages: filtering, selection for storing and selection for presentation that alter their quality and quantity.

Filtering accepts soundings on a time base as discussed in chapter 3. Selection procedures select soundings on a time base, or on a distance base, or on a distance and depth difference base.

The selection method that will be used depends on the application. Selection on a time base is simple to implement but variations in the vessel's speed result in gaps or overplots of soundings. For example, running lines normal to the shore lines accumulates soundings near the shore line. Logging data on a fixed along track distance interval portrays sea bottom evenly independent of variations in vessel's speed. Both the above methods may fail to reveal critical depths. To overcome this we may choose the shallowest (for navigation purposes), the average (for dredging operations), or the deepest depth over the travelled distance or time. Averaging over time has the advantage that, if the time interval over which we average equals the period of heave, the depths are compensated for heave.

A more sophisticated approach is to log data based on two criteria: the maximum distance between two adjacent soundings and their minimum depth difference. This technique is widely used in CHS *(Macdonald, 1984)*. The above two parameters are variable and depend on the sea state, bottom roughness and the intended use of the data.

In addition to the above automatic depth selection methods, in some applications it is useful to select depths manually. Selection of depths at the start or end of survey legs or at specific points along the track must be also under the hydrographer's control.

The main purpose of selection procedures is to accurately depict sea bottom topography. In addition, when the survey product is a navigation chart, selection for presentation is responsible for selecting portable depths. The procedure, taking into consideration survey scale and size of depth digits, must show as many depths as possible without overplotting, and if some depths can not be plotted, it ensures that the shallowest is retained.

In **SEAHATS**, soundings are selected in real time. The user has the option to select soundings on a time base or on a distance base. All the acquired soundings are plotted.

4.4.2 Shoal detection

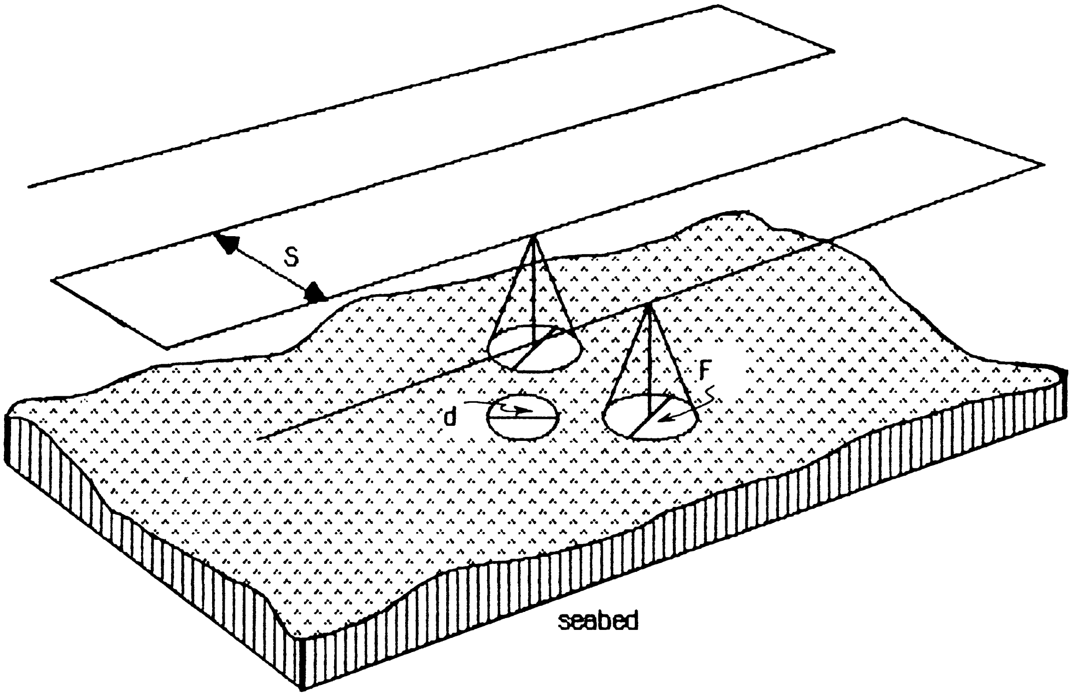
In section 3.4.2 we dealt with procedures to determine the least depth in a shoal area. In this section we will show what to look for in the general system of lines that indicates these areas.

The first step is to determine how closely we have surveyed the area, or in other words, to find the probability of finding an underwater obstacle. If this is high, almost nothing lies undetected between the lines and there is no need to proceed further. *Stenborg (1984)* develops a probability model that is based entirely on the geometry of the survey (see also Figure 4.8) :

$$\begin{aligned} m &= m_0 \quad \text{when} \quad m_0 <= 1 \quad \text{and} \\ m &= 1 \quad \text{when} \quad m_0 > 1 \end{aligned} \qquad (4.16)$$

where:

m : probability of finding an underwater obstacle,
$m_0 = (d + 2(D-e)\tan(b/2)) \;/\; S$,
S : theoretical spacing between survey lines,
D : depth of water,
e : echosounder draft,
b : echosounder beamwidth and
d : diameter of a circular underwater feature.



F=2(D-e)tan(b/2) : echosounder footprint diameter
d : diameter of a circular undrerwater obstacle
S : spacing between survey lines

$$m_o = \frac{d + F}{S}$$

Figure 4.8 : Geometric probability of finding an underwater obstacle.

This model assumes that the offset of the survey line from its theoretical position is negligible. Of course, this model can be applied before surveying to estimate an optimum sounding interval.

If the estimated probability is two low, *Umbach (1976)* suggests that we scan the sounding profiles for protrusions that indicate shoals, or examine aerial photographs, or look for kelp indications and reports of dangers from reliable sources.

Monahan (1975) suggests a morphometric approach to the problem of shoal detection. He claims that, for specific morphologic types (e.g. sea mountains), a relationship can be established between the number of profile protrusions in the survey area and the number of these protrusions that belong to the morphologic type. If this relationship is known the morphologic type can be extracted by examining the distribution of protrusions in the general system of lines. Field shoal examination starts from this point.

It must be emphasized that the effectiveness of this method depends on how well one has understood its limitations. For example, the method is unable to detect a wreck, if the wreck lies entirely between sounding lines, although its morphologic type may be known.

4.4.3 Presentation of results

The collected data is dedicated to the charting of navigational waters or to the needs of engineering constructions in waterways and harbours. These applications have different requirements associated with the depths. To fulfill these requirements, information is manipulated in different ways.

Since navigation safety is a prime requirement when producing charts, the presentation module should portray all extremes, the deepest and especially the peaks. In addition, hydrographic data has a set of characteristics that affect the choice of an appropriate technique. Such characteristics include the: clustering of data in co-linear fashion (ship's tracks) and the existance of discontinuities (cliffs, pinnacles). *Robson (1974)* describes the nature of hydrographic data.

Usually, contouring techniques are used to portray the data. These are gridded or non-gridded. Non-gridded techniques honor the original data more than gridded and therefore preserve dangerous peak values. But, the uncertainty in the formation of triangles does not justify its use for hydrography *(Sallaway, 1981)*. Gridded methods are suitable for navigation purposes only if the interpolation method used is shoal biased. This means that the shallower points contribute more in the determination of depths in the grid nodes.

The inability of the present contouring techniques (used for hydrographic purposes) to incorporate any surface trends is pointed out by many authors. *Cloet (1984)* claims that when the seabed has strongly linearized features, such as sandwaves, the contouring representation may give misleading results. These features, for the sake of legibility, are sacrified. He also suggests an intermediate stage in processing the data involving a pseudo 3D plot of the data. The survey lines run are plotted, after scale and tidal datum reduction, by stacking them sequentially. The bathymetric surface developed in this way may have some irregularities due to the fact that the survey lines are not perfectly run. However, these can be corrected by interpolating from adjacent profiles. This representation is also an effective shoal detection technique.

If the post-processing module is primarily geared towards dredging surveys, volume computations must be included. Bathymetric chart representation displays the overall picture of the seabed, but for dredge volume computations, the inherent approximation errors from these methods cause considerable inaccuracies in volume computations. In practice, volume computations are performed using profiles. It is preferable to use as profile lines those generated in the acquisition process.

4.4.4 Data base management

In this section we assume that the gathered data is used for charting coastal waters. The data should be included in a Hydrographic Data Base. We will identify what quantities the system has to provide to the Data Base suggested by *Malone (1984)*.

According to Malone the Hydrographic Data Base consists of five data bases :

(a) Reference Data Base,
(b) Raw Data Base,
(c) Cleaned Data Base,
(d) Field Sheet Data Base and
(e) Chart Data Base.

The Reference Data Base controls information flow among the other Data Bases. It requires the chart number, establishment, scale, year of survey, location and status of survey.

The Raw Data Base has as entity the " sounding " and as attributes :

- identifier (establishment, vessel, day, time ,location)
- control station file
- way points file
- tidal data file
- parameter file (sound velocity, line spacing,filtering parameters etc.).

The Clean Data Base requires the corrected sounding file with the list of corrections applied:

- identifier (establishment, vessel, day, time, location)
- corrected and reduced sounding file
- tide corrections, sound velocity corrections, datum transformations
- number of field sheet the sounding lies in.

The corrected sounding file (X,Y and Depth) of the Clean Data Base, without the listing of applied corrections, forms the data required by the fourth data base: the Field Sheet Data Base.

The Chart Data Base requires the soundings that have been chosen from the Field Sheet Data Base to represent bottom topography through the "sounding selection" procedure.

4.5 Description of SEAHATS data processing package

The processing package uses the same C.P.U. as the acquisition system. An Epson printer and the Hewlett Packard HP 7470A plotter are added to the system.

Raw data consists of the following files. Sounding file: contains, in digital form, date and time of survey, leg and fix number, code numbers of control stations, ranges to control stations and range signal strengths (optional), position, depth and covariance matrix of position. At present the covariance matrix does not convey any statistical information since there are no redundant observations. Control file : contains the coordinates of reference stations for the particular sounding file. Way file : is the set of way points used to form the survey lines and the shoal points that need investigation. Tide file: is the table of observed tide heights consisting of location, year, day, time and tide height. Sound velocity file': is also a table of either sound velocity observations and depths, or observations of salinity, temperature and depth.

The editing system is based on the ability to point at material currently displayed and treat it as an input. Apple IIe supports (X,Y) display capture devices (such as the mouse, joy sticks and light pen) but these devices do not make any provision for interfacing to the user's program (at least for Apple Pascal 1.1). Therefore, another way was found to manipulate the displayed data. Sounding files are transferred into a number of text files that fit the capacity of the editor buffer of the Pascal Operating System. Then, using the text editor commands, the survey file is edited as a text file. Therefore, the first program executed, called "PREPARE", creates text files. At this point the operator inserts textual information concerning the location of the survey, vessel used, hydrographer, survey condition, corresponding tide and sound velocity files.

To help in making decisions for inserting, deleting, changing or moving soundings, survey points are displayed on the graphics terminal labelled by their fix number. Since the Apple IIe is not a multitasking C.P.U., text editing and display routines can not run simultanously. As a result the editing process is semi-interactive according to the following task sequence :

DISPLAY
EDIT
DISPLAY

Editing is performed at any time during processing. It is used to remove format errors at the beginning, and then and after the execution of error detection programs to correct the detected false echoes and ranges.

The next phase is to pass the sounding file through the "error detection" program. This program consists of two programs; one to detect false echoes and one to detect false ranges. False echoes are effectively detected by displaying depth versus time at the same scale as the echogram and visually comparing digital and analog plots. The program is customized for use with the Simrad Skipper 802 echosounder and requires the "Range", the "Phase" and the "Chart speed" at which the depths were recorded *(see Simrad, 1979)*. The range time series feeds the

Kalman filter described in section 4.3.1 using a certain value of the tuning factor k that reflects the survey conditions. The ranges that fall outside a user's input gate width are listed with their Kalman estimates. The user can either reject these ranges or substitute them with the Kalman estimates.

The smoothed sounding file, as well as the sound velocity and tide file, are inputs to the program for tide reduction, sound velocity and transducer correction called "REDUCE". The tide is interpolated linearly or using a sine curve approximation as described in section 4.3.3. Depths are corrected from sound velocity using Wilson's equation. A mean sound velocity over the effective water column is computed by approximating the integral in equation 4.11 using trapezoids. The same program performs a datum transformation on the sounding datum. Finally,the soundings are plotted on the HP7470A plotter. Figure 4.9 illustrates the hydrographic data processing phases.

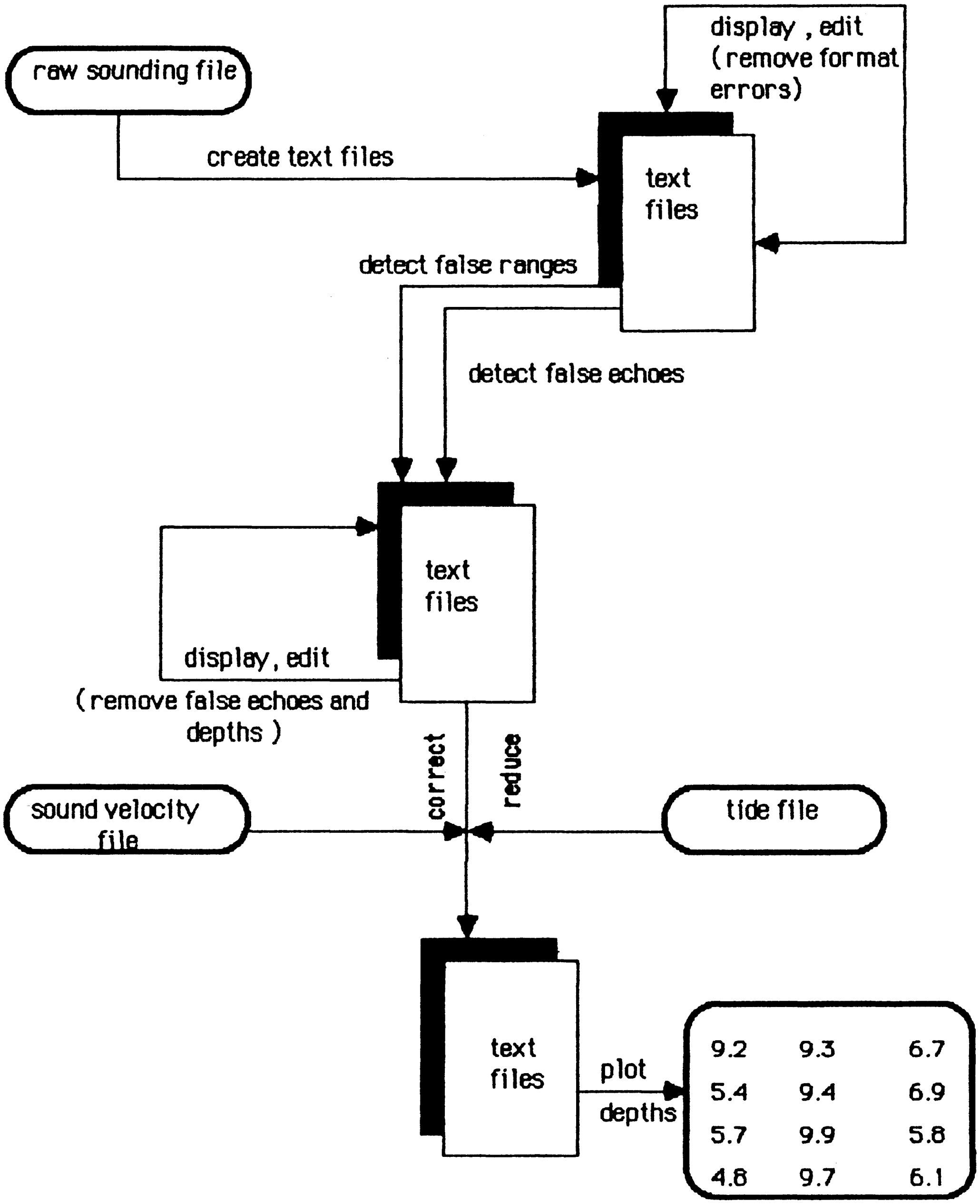


Figure 4.9 : The processing phases.

5. TESTS and RESULTS

5.1 Tests description and objectives

The purpose behind these tests was to determine the feasibility of using personal computers to perform marine survey and piloting functions. Each module of **SEAHATS** was separately tested and the final test was devoted to the behaviour of the complete system. The tests conducted were :

1. Fredericton, January 1984. Land trials were done to check the communication between subsystems, the ability to track rapidly changing Mini Ranger ranges and to give an estimate of dynamic and static accuracy of the system. *Peters (1984)* describes this test.

2. Back Bay, March 1984. The system was tested aboard the vessel Mary O (a13 metres general purpose hydrographic launch owned by the University of New Brunswick) in rough sea conditions to evaluate its reliability and to check the effectiveness of the acquisition software and the man/machine interaction.

3. Yarmouth, May 1984. An attempt was made to use the system for charting the Yarmouth harbour waterway.

4. Fredericton, July 1984. The purpose of this test was to test the depth digitizing unit and check if, under actual conditions, the digitized depths were in fact the true depths. *Harris (1984)* describes this test.

5. Campobello Island, June 1985. A sea trial was conducted during an actual survey by the Canadian Hydrographic Service (Atlantic Region) in the Lubec Channel between the state of Maine and Campobello Island (sea attached Figure 5.1). A network of six control points was established and systems of survey lines were run as illustrated on the chart. Shoal examinations were performed using ficticious shoal points using the "circles" and "star" modes. The sea was calm (0-1 Beaufort, Sea State 0), but there were strong tidal currents that introduced strong biases on the off-track errors. In addition, the ranges from West Quoddy Head station were heavily contaminated with spikes, probably caused by reflections from adjacent rocks. The vessel's speed was 8-10 knots, while the maximum speed for the range filter was set at 20 knots for reasons that will be explained later. The resolution of the echosounder was set to ~22 cm (minimum pulse duration 0.3 milliseconds) and the receiver gain was adjusted to suppress heavy shallow water background noise. When travelling at over 10 knots the echosounder lost the bottom tracking, and the receiver gain needed readjustments. To monitor the tide, a tide station was established at West Quoddy Head and readings were taken every 5 minutes. The objectives of the tests were to compare different navigation algorithms for shoal examinations, to test the on-line modification module and to acquire data for testing the post-processing package.

SEAHATS was also tested using an additional Apple IIe computer that simulated the position and depth data supplied to the vessel at sea. The simulation package was designed to simulate shoal examination using the "circles" mode and the primary survey lines using parallel straight lines.

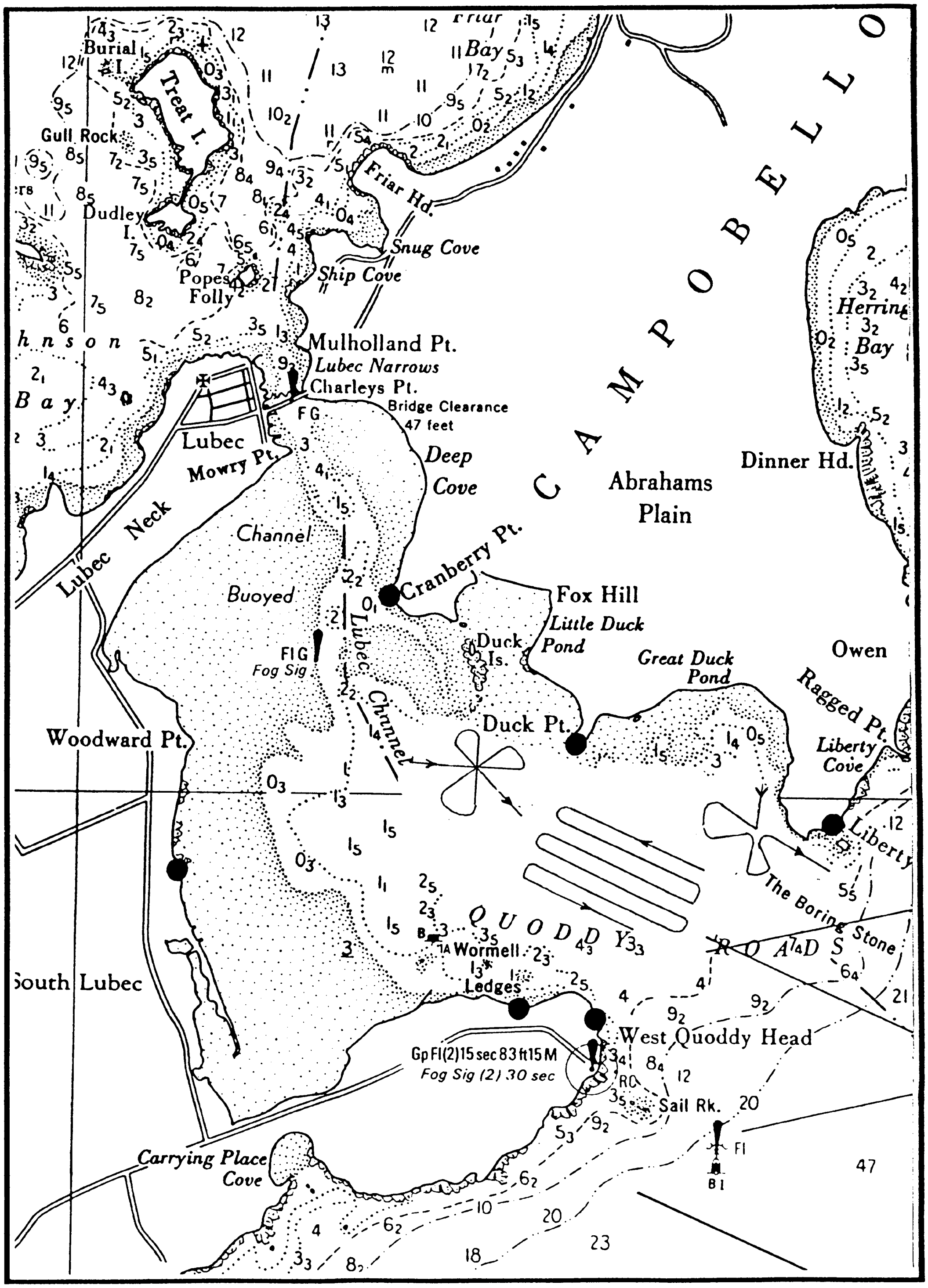


Figure 5.1 : The test site (from CHS chart 4373).

5.2 Accuracy

The accuracy of the system was tested for accuracy of X,Y and Depth measurements and for its ability to keep constant time and distance intervals while logging soundings.

Test No. 1 *(Peters, 1984)* showed that the system can track effectively Mini Ranger ranges at the speed of 50 km/h, much more than the speed of a survey vessel (~ 15 km /h). The uncertainty in the results is almost fully due to the Mini Ranger observation errors. The uncertainty in position, for good geometry (90° intersection of LOPs), is ±4.5m which can be up to ±15m for bad geometry (150°) (semi-diagonal axis of error diamond). As expected the observations were contaminated with spikes as shown in Figure 5.2. The position filter kept track of these range spikes but it lost tracking when it was not initialized with a good set of ranges. For example, if the navigation function stopped and the boat drifted, the filter had to be reset.

The depth digitizing unit was tested in test No. 4. *Harris (1984)* concluded that depths derived from this digitizer agree with the internal echosounder digitizer within ±50 cm. The depth readings were stable.

Figures 5.3 and 5.4 show two echograms and their digital representation. The sea conditions of test No. 5 allowed safe interpretation of the echograms, since the factors (such as roll, pitch and heave) that affect depth accuracy and not considered in the system design, were not present. The analog profile was constructed with a sampling rate of 600 soundings/minute and the digital profile with 20 soundings/minute. We notice the following:

1. The direct effect of reduced sampling rate is that the system cannot track sea bottom undulations of the order of 3 seconds (see echo return 2 on Figure 5.3). Here lies a disadvantage of the on-line range rejection technique. If the position filter rejects range observations (e.g. for 6

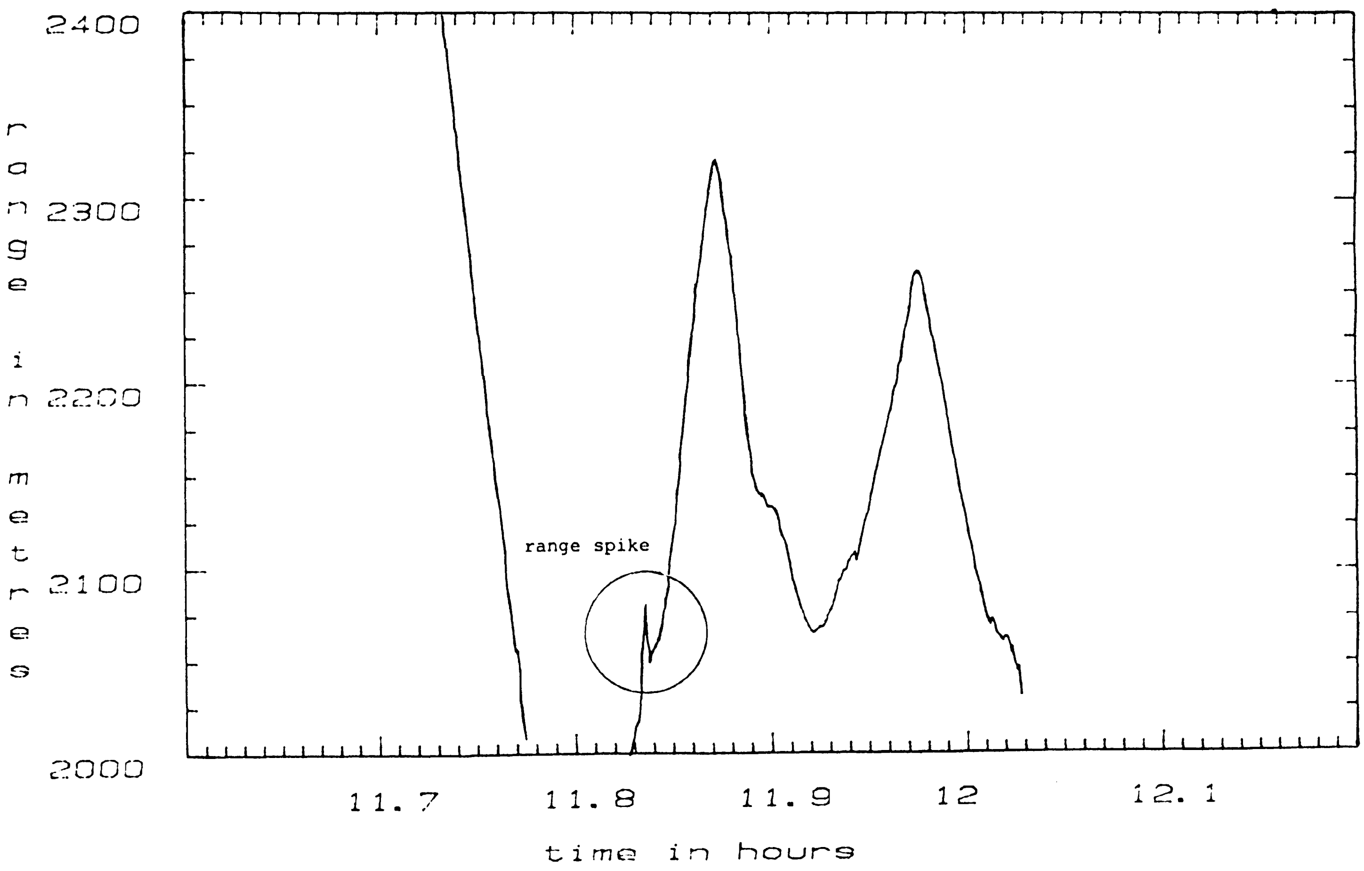


Figure 5.2 : Time series of range from channel B of Mini Ranger.

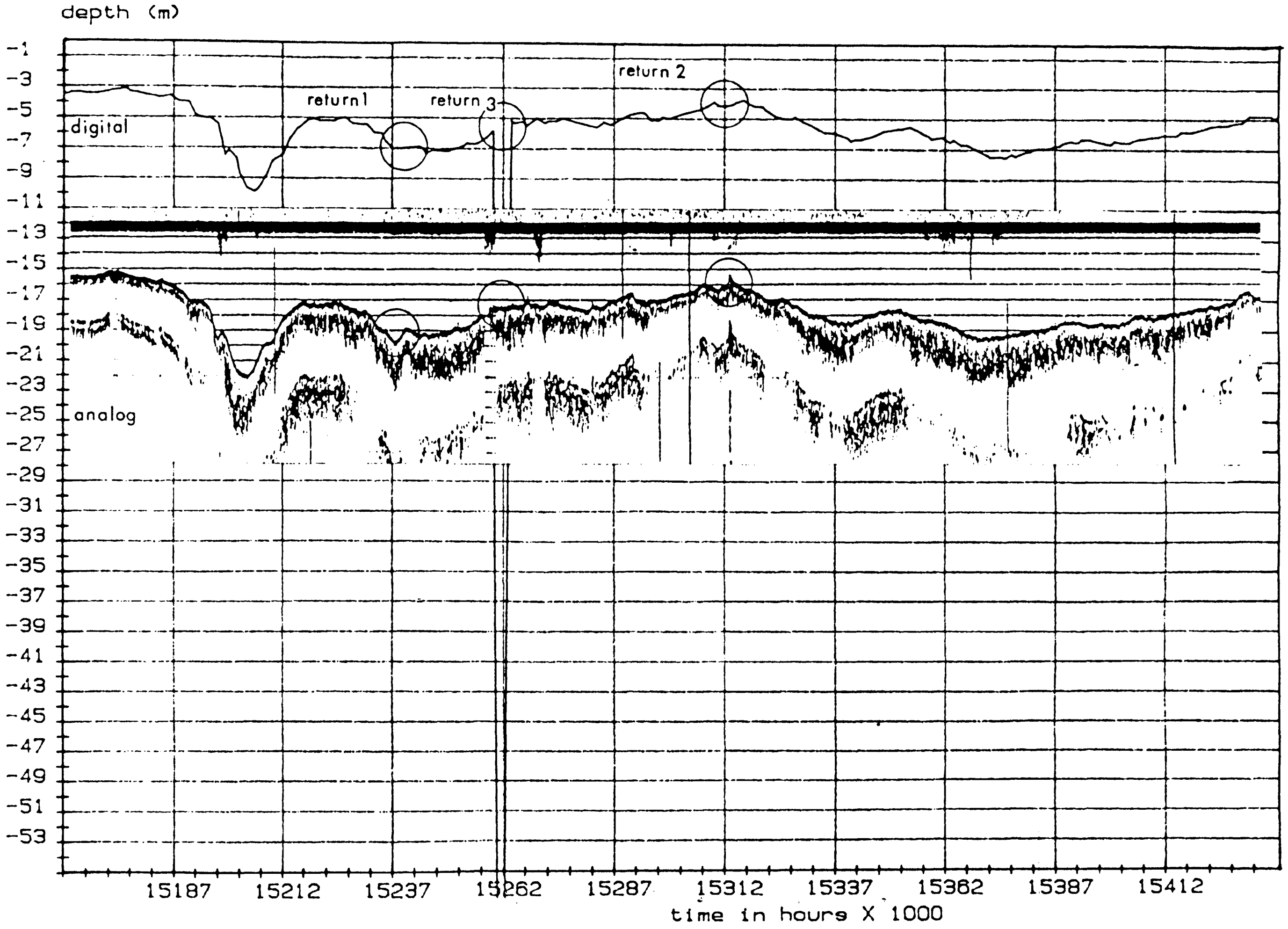


Figure 5.3 : Analog and digital depths over an irregular seabed.

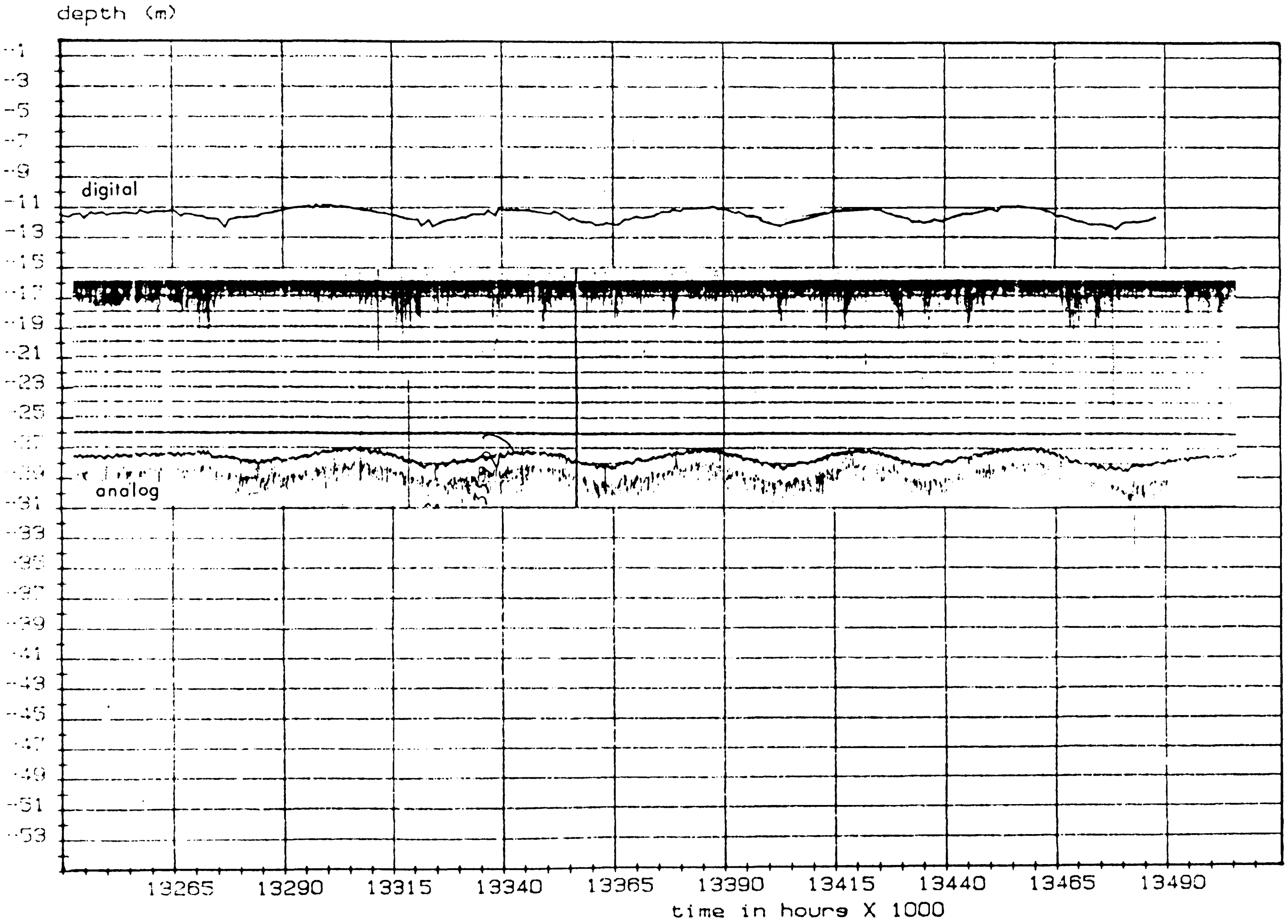


Figure 5.4: Analog and digital depths over a relatively flat seabed.

seconds), no depths are recorded during this period, although depths are good (see echo return 1 on Figure 5.3). This is why it is preferred to set wide range rejection tolerances and use an off-line filter to further smooth ranges.

2. The percentage of false echoes is extremely small. In echogram of 4 hours length, only once did the digitizer pick up an echo other than the sea bottom. On the other hand, echoes such as shown in Figure 5.3 (echo return 3), are common. These, as mentioned earlier, are caused by the echosounder tranceiver not receiving any return from the sea bottom.

3. The rest of the digital output agrees very well with the analog trace. The mean agreement is in the order of 30 cm.

4. It is difficult to attribute the sawtooth effect appearing on the echogram of Figure 5.4 to the effect of ship motion (roll,pitch and heave), even when the seabed is relatively flat. The reason is that the magnitude of this effect is in the order of vertical resolution of the echosounder (22 cm).

It must be emphasized that the above echograms are easily interpreted. The echo returns from the first bottom are strong enough to stop the digitizer clock. However, the behaviour of the digitizing unit in deeper waters, or in muddy seabeds, or in a seabed covered by weed is not guaranteed. More tests under these conditions are required.

<u>Selection error</u>. Hydrographic survey operations require precise and consistent data logging of navigational and bathymetric parameters at specific distance or time intervals. The desired accuracy in time and distance intervals is an unbiased mean error of nearly zero and a sample standard deviation of one second or less. Two factors govern this precision : the <u>computational speed</u> (cycling time) and the observation <u>sampling interval</u>.

For **SEAHATS**, cycling time increases proportionally with the number of data points that remain in the PS01 interface buffer (see also Figure 3.5). This is done as the interface software continuously transfers data points until it receives a recent one. This amount is n X dt, where n represents the number of remaining data points in the buffer and dt the time required to transfer a point (~0.70sec at 1200 baud rate). For example, if the sampling interval is 1 second, after six cycles 6 points remain in the buffer, and the total computation time is 2.3 + 6 X0.70 = 6.5 seconds. But during this time, more points enter the buffer. Figure 5.5 gives a comparison of the computation times for sampling intervals i=1,2,3,4,... . The minimum computation time exists for a sampling interval of 3 seconds (approximately equal to data manipulation time). This ensures that the rate of incoming data in the buffer, equals to the rate of exiting data.

Another alternative for requesting data from the buffer would be to erase all the data points and then request. But if the request is done at the beginning of the sampling interval, the computation time is increased by the sampling interval. In this case, the cycling time is 4 seconds (assuming minimum sampling interval 1 second).

The cycling time of 3 seconds therefore restricts the minimum time selection interval to 3 seconds or distance interval of 12 metres at 8 knots. It is also expected that the error in time intervals will be in the order of 3 seconds. Attemps to reduce execution time include :

(a) reduce the time required to write on the screen,
(b) produce more efficient code,
(c) switch to a different faster operationg sytem, and
(e) use an additional processor to partially off-load the 6502 microprocessor.

The Apple IIe has a memory mapped screen. Writing directly on the screen is faster. Benchmark tests showed a reduction factor of 3. However, this approach destroys the flexibility and machine independence of the system and therefore it was not adopted. For the same reason, coding of Least Squares adjustment (the most time consuming routine) in assembly language was not adopted.

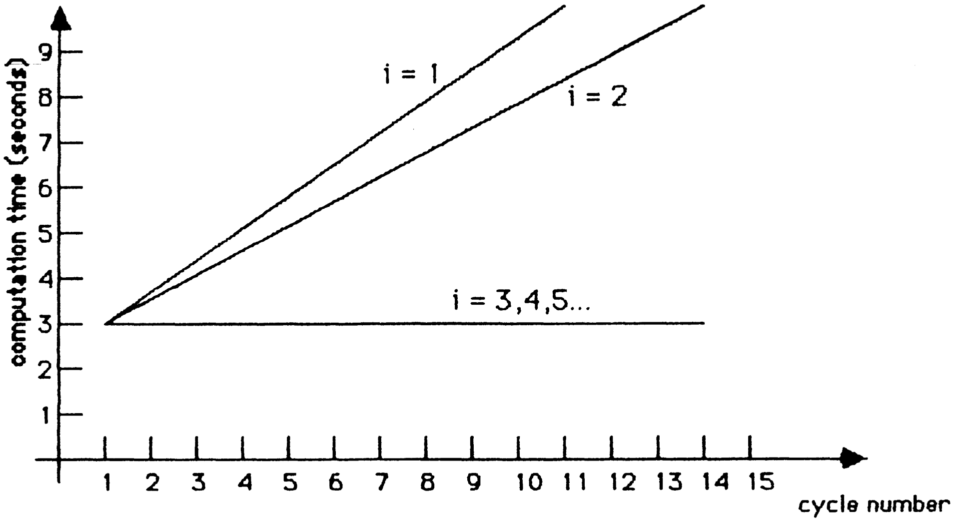


Figure 5.5 : Computation time versus cycle number for various sampling intervals.

Table 5.1 : Size order of the average off-track error in a sample of 7 survey legs.

leg number	1	2	3	4	5	6	7
off-track dist. (m)	17	19	10	7	13	11	10

To each successful range measurement the closest in time depth measurement is attached. The depth digitizer interrupts the interface central processor and provides depth information approximately every 100 milliseconds, leading to a position and depth correlation in the order of 100 milliseconds (or 50 cm at 10 knots).

5.3 Man/machine interaction

A second monitor was required to display information to the helmsman. Unfortunately the command and situation displays could not be separated and the screen contained too much information. This caused some problems to the helmsman. These were overcome following some familiarization with the display.

The track keeping ability of the system lies in its ability to keep small offsets from the survey leg. As mentioned before, the cycling rate of the L/R indicator, its resolution, the vessel's speed and turning characteristics, and the helmsman's experience in conning survey vessels affect this ability. The L/R indicator has a resolution of 5m. There is no need to keep finer resolution when the position accuracy is in the order of 5 metres. Figure 5.6 shows ship's tracks steaming at 8 knots and with line spacing S=50 metres. The survey boat was navigated by an experienced operator.

In order to measure this ability, the area E bounded by the ship's track and the desired track is calculated (see also Figure 5.6). The segment of survey leg, which is used for ship's turns, must not be included in the calculations. If the length of the survey leg is D, an average deviation from the desired track can be computed by :

$$m = E / D \tag{5.1}$$

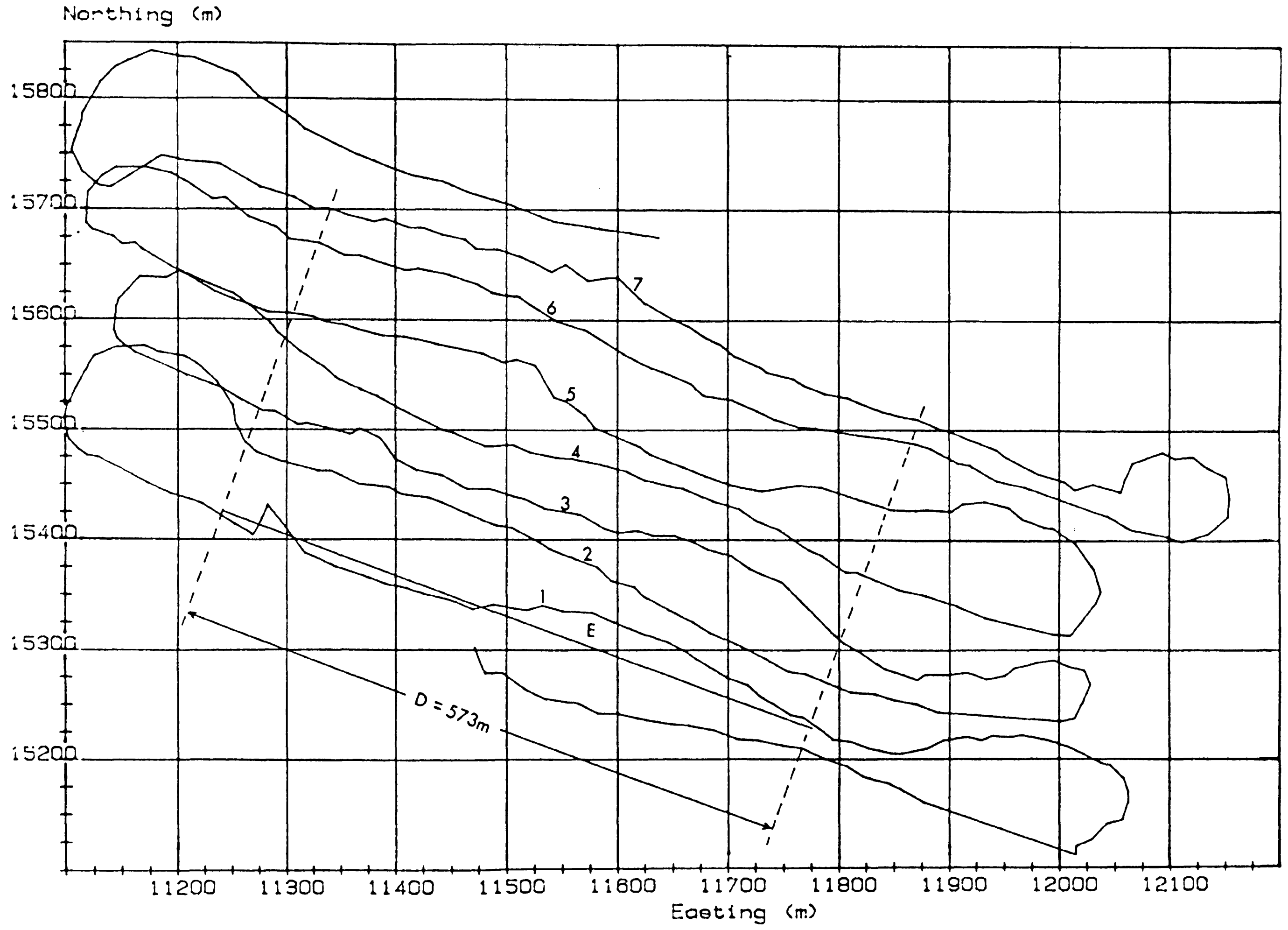


Figure 5.6 : Ship's tracks while running parallel straight lines.

Table 5.1 gives the size order of this deviation. In hydrographic surveys the offset from the survey line must never exceed the line spacing. Therefore, the system is suitable for line spacing of 20 metres or more.

5.4 SEAHATS software evaluation

In test No. 5 the navigation algorithms for running primary survey lines and investigating shoals were tested. The ability to configure the survey lines in real time to the current survey conditions (sea bottom morphology and coastline) proved very useful (see Figure 5.7). This feature considerably decreases the number of way points used to describe the survey lines. The "change transponders" command of the ON-LINE MODIFICATION module proved useful especially in the case of crossing the control stations baseline. In this case the geometry is too weak and the estimated position error is hundreds of metres.

Three geometric patterns for shoal examination were tested: the "circles", the "star" mode and the widely used "radial" system of lines. "Star" and "circles" modes have been described in section 3.4. In the "radial" system of lines, lines are run that cross in the vicinity of the shoal in one direction only (to or from the shoal). The reason why a "radial" system of lines is preferred in the hydrographic community is that their direction is easily established when an automatic survey system is not available. For examinations of large areas (larger than 100 X 100 metres) it is a waste of time to run lines in one direction only. The "star" mode is then preferable. In smaller areas, however, the vessel may not have enough space to turn and the "radial" system of lines is more effective.

Concerning the line keeping ability the "star" mode or "radial" system of lines are better than the "circles" mode. As Figures 5.8 and 5.9 show, the average off-track deviation in

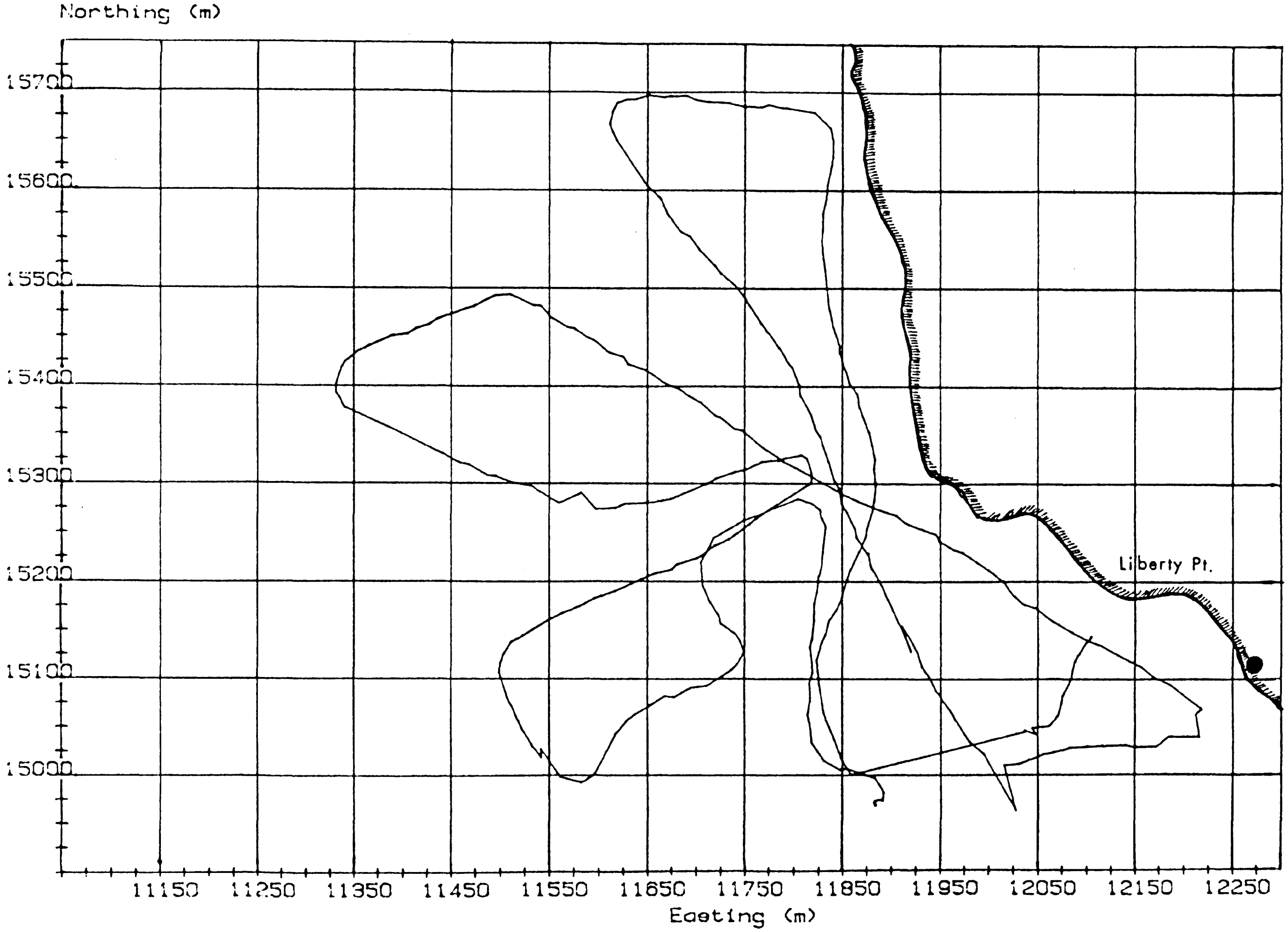


Figure 5.7 : Ship's tracks while doing shoal examination (modified "star" mode).

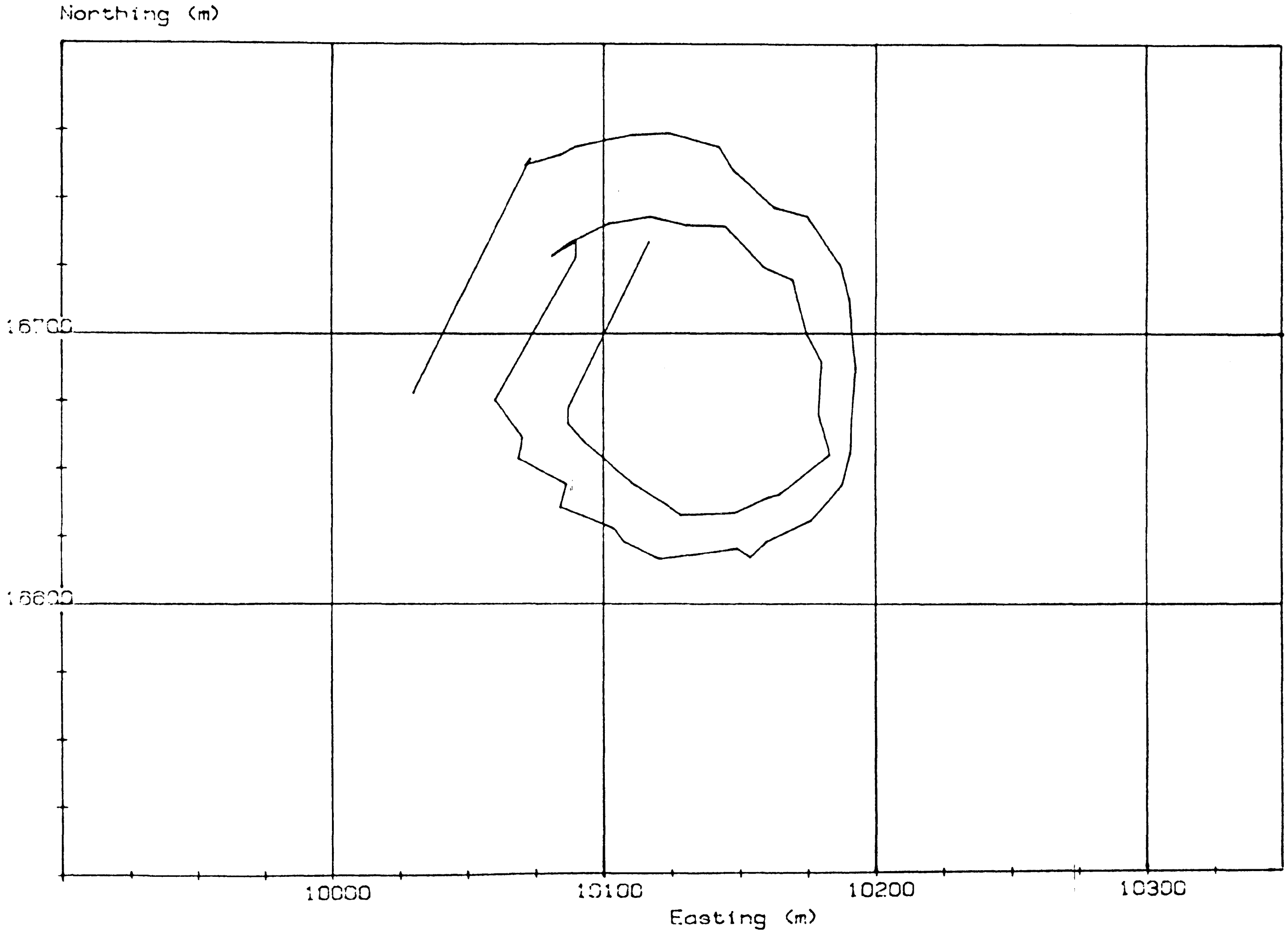


Figure 5.8 : Ship's tracks while doing shoal examination ("circles" mode).

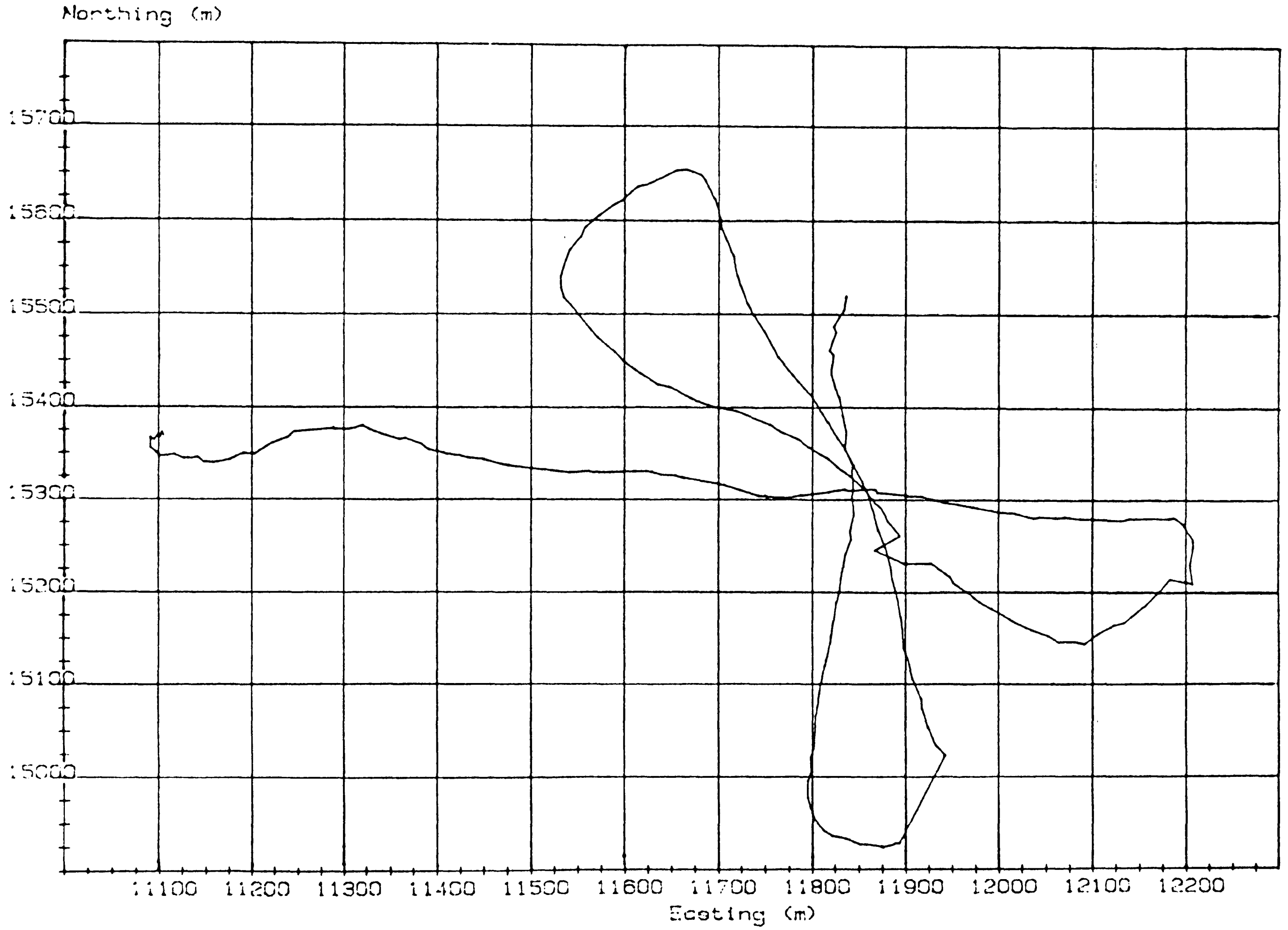


Figure 5.9 : Ship's tracks while doing shoal examination ("star" mode).

"circles" mode is larger than this in "star" mode. This is due to the fact that, when running straight lines, the helmsman is consulting the L/R indicator and the survey line bearing (corrected for magnetic declination). In "circles" mode the bearing is not constant and therefore does not provide any additional information to the helmsman.

In the current hydrographic data acquisition and navigation controller (**SEAHATS**), the "star" and "circles" modes were adopted. The "circles" mode was chosen because it has the ability to locate the shallowest point, even if the circles are not perfectly centered on the shoal point. The "radial" system of lines can be regarded as a subcase of the "star" mode.

The reliability of the system was determined by the number of malfunctions that could be directly attributed to the computing equipment. Any errors attributable to the Mini Ranger or the echosounder, such as loss of signal or electronic failures were not considered.

The Apple IIe microcomputer operated continuously for the three day test No. 5 without any down time. The most unreliable components in the system can be expected to be the mechanical components like the disk drives. Test No. 2 under rough weather conditions and at a speed of about 10 knots showed that these devices perform well. Instead, most of the problems appeared to be caused by wrong operator input. To reduce this source of problems, an attempt was made to write software that reflects possible operator errors by displaying error messages. For example, if the operator inputs control stations with the same code numbers, he is immediately informed and is given the chance to correct his entry. Table 5.2 and Figure 5.10 is the final product of the data acquisition and processing system (**SEAHATS**).

Table 5.2 : Hard copy of collected soundings.

```
University of New Brunswick
Hydrographic Survey at Campobello Island N.B.
Tide file : tide23/5/85, sound velocity : 1500 m/s
Field Sheet Data Base

 y   m   d     time    li#  po#       RA       RB    North     East   Depth

 "

85   5  23  16.3397     5    49    706.0   2434.0  15279.1  11480.9   10.99
85   5  23  16.3472     5    54    615.0   2349.0  15241.7  11582.7   11.66
85   5  23  16.3539     5    59    549.0   2255.0  15226.7  11687.9   12.42
85   5  23  16.3606     5    64    488.0   2172.0  15200.4  11786.9   13.01
85   5  23  16.3672     5    69    429.0   2105.0  15159.3  11876.9   13.61
85   5  23  16.3822     6    74    421.0   1964.0  15139.1  12041.8   13.14
85   5  23  16.3889     6    79    475.0   1937.0  15194.0  12045.5   12.49
85   5  23  16.3956     6    84    490.0   1998.0  15222.1  11966.2   12.76
85   5  23  16.4022     6    89    485.0   2066.0  15217.3  11894.5   13.02
85   5  23  16.4106     6    94    497.0   2144.0  15216.2  11810.7   12.72
85   5  23  16.4172     6    99    551.0   2197.0  15251.3  11740.6   12.47
85   5  23  16.4239     6   104    615.0   2249.0  15291.9  11671.3   12.03
85   5  23  16.4306     6   109    678.0   2309.0  15324.9  11597.5   11.44
85   5  23  16.4381     6   114    737.0   2392.0  15337.7  11507.0   10.74
85   5  23  16.4447     6   119    797.0   2467.0  15351.1  11425.3   10.68
85   5  23  16.4514     6   124    868.0   2538.0  15375.8  11345.2   10.50
```

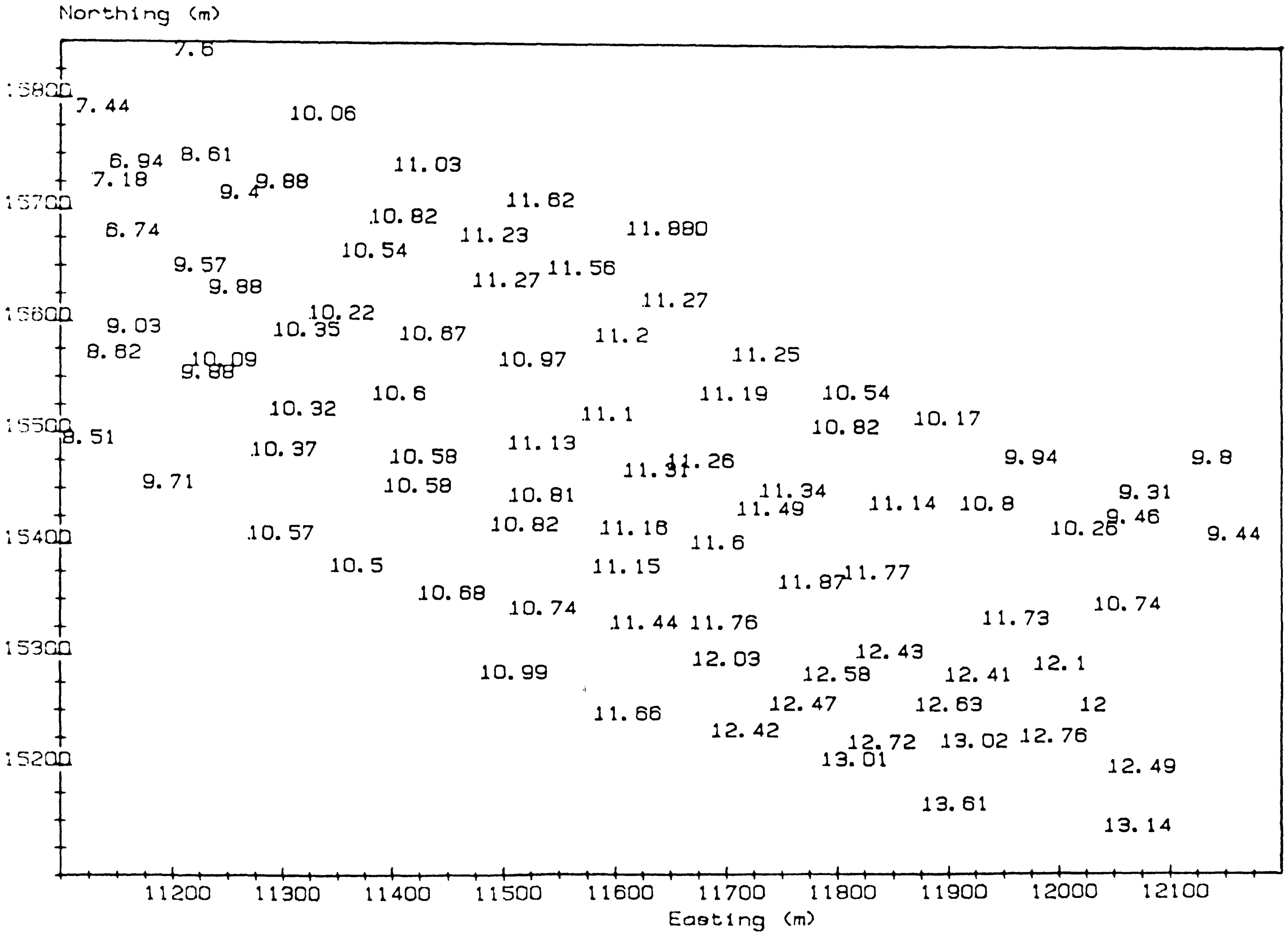


Figure 5.10 : Final field sheet.

6. CONCLUSIONS and RECOMMENDATIONS

The results of the tests indicate that a microcomputer with commercially available peripherals and standard software, such as the Apple IIe, offers great promise of replacing larger and more expensive hydrographic data acquisition and navigation controllers. Personal computers are already used in marine applications. *Stoltz et al. (1985)* use the IBM PC personal computer integrated with Loran C and Del Norte Trisponder for geophysical surveys. The computational algorithms exist and need only to be modified or simplified to fit the memory capacity and computational speed of microcomputers. The memory requirements (RAM) for **SEAHATS** acquisition software is of the order of 60 kbytes which is not readily available on 8 bit microcomputers. Memory overlapping techniques must be used to fit the code into the memory capacity of an 8 bit computer. Alternatively, use of a 16-bit or 32-bit computer would overcome this (and several others) **SEAHATS** limitations - but at increased cost.

The factors which created the greatest difficulty in developing an automated system were the development of specifications, the computer memory and computational speed constraints, and compliance with man/machine interaction specifications. Considerable programming effort was required in the man/machine interface routines.

Throughout the developing phases the following conclusions were reached :

1. If we want to rank the criteria for choosing a position or range filter for use in the hydrographic surveys that use low cost microcomputers and pulse matching microwave positioning systems, the following list (from higher to lower priority) must be adopted (slight rearrangements are allowed) :

(a) computational burden (e.g. Kalman filter requires heavy computational burden),

(b) implementation cost (e.g. multiranging requires the operation of additional control stations),

(c) gross-error detection,

(d) smoothing ability and

(e) dynamic response.

According to the above list, simple gating techniques or linear filters seem to be preferred.

2. The need for a depth filter and its degree of complexity depend on the specific digitizer-echosounder system and the area of application (water depth, sea bottom morphology). Simple comparisons of digital and analog depths are effective methods to detect false echoes.

3. The system of survey lines must be able to be altered on-line to suit the current configuration of the shoreline and sea bottom slope. Frequent adjustments, however, must be avoided because they tend to confuse the launch hydrographer and coxswain, since they do not have a clear picture of the survey lines run. In addition, if the changes are not well documented, problems can arise in the interpretation of results while post-processing the data.

4. The "star" mode is the best shoal examination pattern with respect to track keeping ability if the location of the shoal point is accurately known.

5. Applications that require very closely spaced sounding lines (10 to 20 metres) cannot be satisfied by the present configuration of the system. The limiting factor is the accuracy of

positioning system and the 3 second update interval of the command display. However, the navigation and processing algorithms are suitable for these applications.

Recommendations for further development of **SEAHATS**, as a specific hydrographic data acquisition and processing system are :

1. Since the computational burden is of vital importance, the depth filtering technique discussed in section 3.3.4 can be implemented in hardware inside the digitizing unit.

2. The Kalman filter developed in section 4.3.1 can be implemented on-line and the increased computational burden measured. The filter will provide real time stabilized estimates of the velocity over the bottom ready for use in the range rejection techniques.

3. Ways of uninterrupted data logging when the storage device becomes full must be investigated.

4. A track plotter used as L/R indicator can result in better track keeping ability.

5. Investigate different ways to specify the area to be surveyed. *Boudreau (1985)* suggests that the chart limits (that include the area to be surveyed) be stored in the computer. Then the chart is subdivided into a set of polygons, which also are stored in the computer. Finally, in each polygon the lines to be surveyed and the shoals to be examined are specified. Each sounding is accompanied by the chart, polygon and line numbers and therefore its position in the Hydrographic Data Base is easily specified.

6. The following utilities will further simplify the job of launch hydrographer :
   - an interactive network design package for optimizing horizontal networks in order to choose the best sites for the Mini Ranger transponders,
   - a coordinate transformation package between map projections,
   - a calibration package using baseline crossing, and
   - a package for pre-plotting of Mini Ranger lattices.

7. The current acquisition software can be interfaced to a high accuracy range/bearing system for use in marine construction surveys.

The following recommendations (not specifically to **SEAHATS**) are also made:

1. Techniques to identify likely shoal areas between sounding lines, and methods to determine optimum line spacing and sounding intervals in the primary survey lines and while investigating seabed features must be developed.

2. The existing depth filtering techniques require testing. New techniques must also be devised. For example, one technique would be to fit a high order polynomial to the sea bottom, or to correlate the 1st and 2nd echo returns from seabed and accept the echo returns with high degree of correlation.

The features of the developed hydrographic data acquisition and processing system (**SEAHATS**), can be fully explored if we are aware of its limitations. These limitations mainly are: (a) the stage of complete automation in depth acquisition has not been achieved. The echogram conveys much more information than the digital depths and it is always necessary to compare digital and analog depths, (b) the system is unable to run closely spaced survey lines and (c) in the case of computer malfunction or power failure the data files are lost. The software (or hardware) does not make any provision to save them.

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APPENDIX I: Navigation algorithms for track following

This section describes the geometry involved in the system of sounding lines. Three system of lines are presented : (a) parallel lines and way point navigation, (b) the "star" mode and (c) the "circles" mode.

(a) Parallel straight lines and way point navigation. The navigational parameters are shown in Figure I.1. For navigation from point (1) to point (3) the physical meaning of these quantities is the following: the across track distance is negative if we are on the left of the leg and positive if we are on the right. In the case that we have not passed the start of the leg (see Figure I.1b), the along track distance is negative indicating the distance to go in order to reach the start of the leg. For parallel lines the next line is triggered when the Distance to go = 0. For way point navigation the next way point is triggered when Distance to go = way point tolerance.

$D_{13} = \sqrt{}((X_1-X_3)^2 + (Y_1-Y_3)^2)$

$D_{12} = \sqrt{}((X_1-X_2)^2 + (Y_1-Y_2)^2)$

$\text{Beta} = Az_{12} - Az_{13}$

$\text{Along track} = D_{12} \cos(\text{ABS}(\text{Beta}))$

$\text{Across track} = D_{12} \sin(\text{Beta})$

$\text{Distance to go} = D_{13} - D_{12} \cos(\text{ABS}(\text{Beta}))$

$\text{Desired Bearing} = Az_{13} + (\text{magnetic declination})$

$\text{Actual Bearing} = Az_{23} + (\text{magnetic declination})$

(b) "Star" mode. The involved parameters are illustrated in Figure 1.2. The physical interpretation of these is: D_{13} is the maximum distance the boat travels from shoal point before the next line is triggered. The along track distance is the distance from the start of the leg. The along track increases until the boat reaches the end of the leg (see Figure 1.2b). From the start of the leg to the end of the leg the off-track error is always negative on the left and positive on the right. A sudden shift of actual and desired bearings of 180° indicates that we have passed the shoal point.

D_{13} = maximum distance from shoal point (specified by the user)

$D_{12} = \sqrt{((X_1-X_2)^2 + (Y_1-Y_2)^2)}$

$\text{Beta} = Az_{31} - Az_{32}$

Along track = $D_{13} - D_{12} \cos(\text{ABS}(\text{Beta}))$

Across track = $D_{12} \sin(\text{Beta})$

Distance to go = $D_{12} \cos(\text{ABS}(\text{Beta}))$

Desired Bearing = $Az_{31} - 180^\circ$ + (magnetic declination)

Actual Bearing = $Az_{23} - 180^\circ$ + (magnetic declination).

(c) "Circles" mode. For "circles" mode the start and end points are the same. The algorithm is different for clockwise and counterclockwise navigation around the shoal point (see Figure 1.3).

(a)clockwise

$D_{12} = \sqrt{((X_1-X_2)^2 + (Y_1-Y_2)^2)}$

$\text{Beta} = Az_{12} - Az_{13}$

Along track = $(2\pi/360)(\text{Beta})(\text{Radius})$

Across track = Radius − D_{12}

Distance to go = $2\pi(\text{Radius})$ − Along track

Actual Bearing = $Az_{12} - 180^{o}$ + (magnetic declination).

(a) counterclockwise

$D_{12} = \surd((X_1-X_2)^2 + (Y_1-Y_2)^2)$

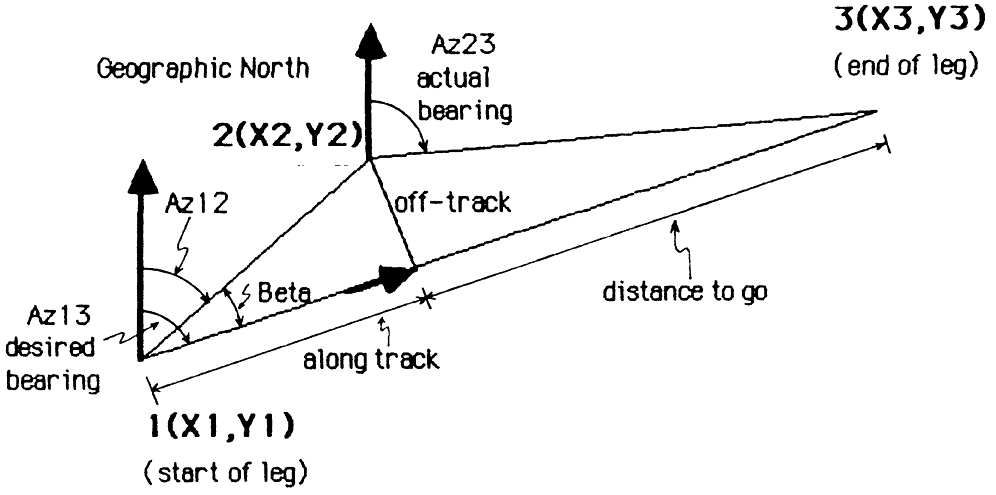
Beta = $Az_{13} - Az_{12}$

Along track = $(2\pi/360)$ (Beta)(Radius)

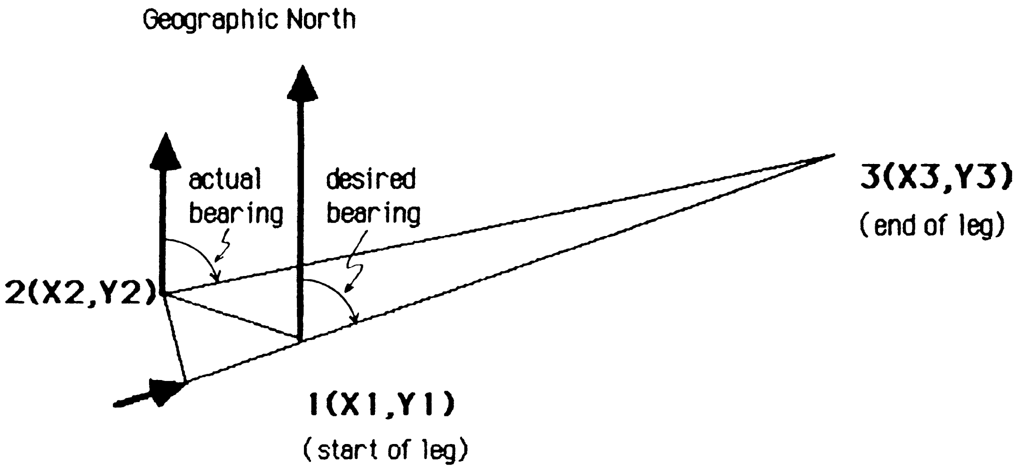
Across track = D_{12} - Radius

Distance to go = 2π(Radius) - Along track

Actual Bearing = $Az_{21} - 180^{o}$ + (magnetic declination).

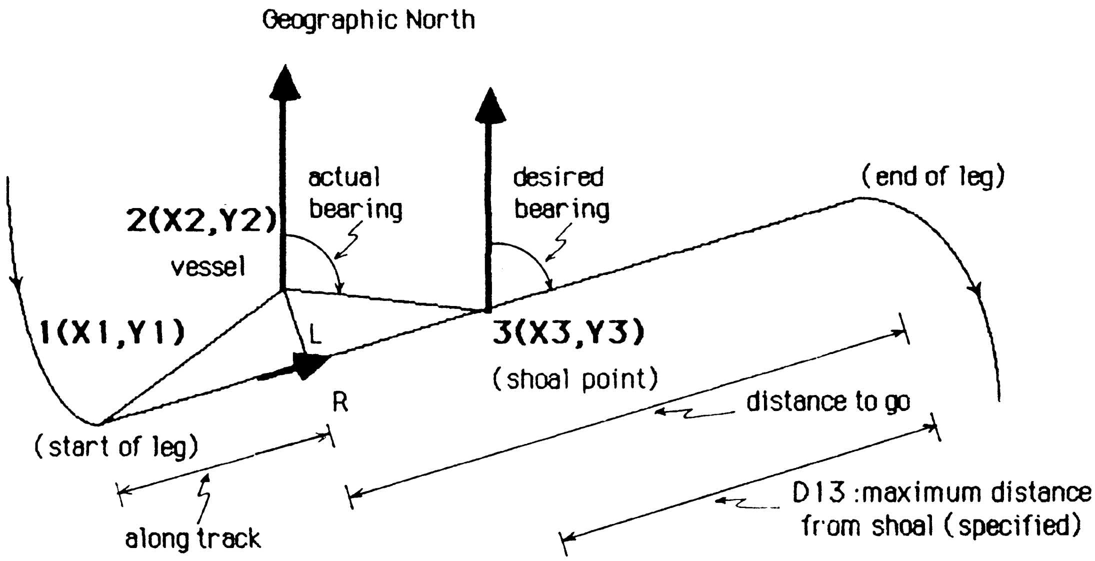


(a) The vessel is inside the leg

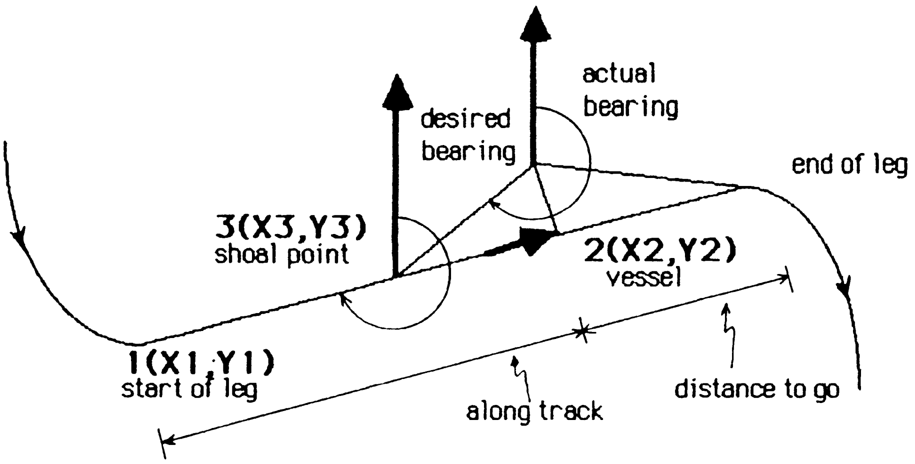


(b) The vessel is outside the leg

Fifure I.1 : The geometry of parallel straight lines and way point navigation.



(a) The boat goes toward the shoal



(b) Tne vessel leaves the shoal

Figure I.2 : The geometry of "star" mode shoal examination.

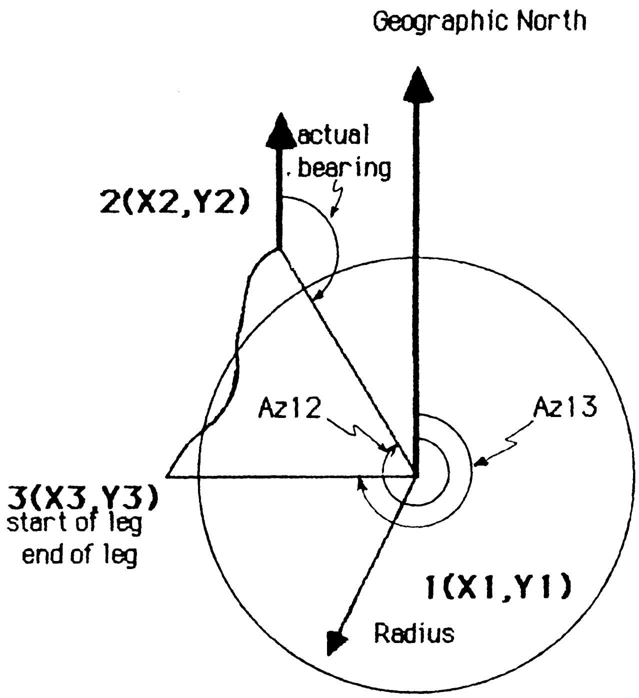


Figure I.3 : The geometry of "circles" mode shoal examination.