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A Chart Display and Navigation Information System for Integrated Bridge

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Abstract

A combined electronic chart and navigation information system has been developed at Liverpool Polytechnic (UK). It has undergone bridge-simulator and live sea trials and was shown to simplify the processes of navigational chart-work including the presentation of geographical information. The system makes innovative use of video as the cartographic display medium using a window-like presentation of conventional Admiralty Charts. The user interacts with the chart display by means of overlaid computer graphics which are accurately locked to the underlying chart coordinate system. Menus provide access to drawing functions similar to those found on a modern radar and a second text screen, operating under the same software, is used as the Navigation Information System display.

An analysis of the structure and function of the nautical chart is given to illustrate the 'Systems Analysis' approach. The study is extended to other relevant information abstracted from maritime publications and shows how a comprehensive Navigation Information System (NIS) can be developed using Geographic Information System (GIS) techniques. Coastal navigation is used as an example to show how decision-support information can be provided to meet some requirements of the navigational task.

The role of the electronic chart as part of an 'Integrated Bridge' is discussed and comment is made on the emerging standards for electronic chart data exchange. A discussion of the merits of radar overlay is also given. Expert system technology is offered as the next step in the integration of Navigation into an overall ship-control system.

The Electronic chart was designed to provide functionality broadly in line with current IHO specifications and the prototype was successfully adapted for commercial use by the project sponsors and now forms part of their 'Integrated Bridge' product.

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Figures 3.24, 3.25 and 3.26 are reproduced from IHO Special Publication 57 by permission of the International Hydrographic Organisation.

This thesis is dedicated to my wife Sarah who has unstintingly provided encouragement and support during its preparation and over the last three years.

A CHART DISPLAY AND NAVIGATION INFORMATION SYSTEM FOR INTEGRATED BRIDGE

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CHAPTER 1

Introduction

Chapter 1

Introduction

This thesis is divided into six chapters. The first introductory chapter provides a short historical background to the development of modern charting followed by a review of the literature surrounding recent innovations in marine navigation. There follows a description of the initial project requirements and an overview of the electronic chart system developed during the last three years.

The second chapter explores the Systems Analysis that was made during the project and the third chapter discusses the operation of the electronic chart and its supporting software in detail. Chapter 4 is a discussion of the trials carried out on the system prototypes both on-board a sea-going vessel and in the Liverpool Polytechnic simulator and Chapter 5 explores the relationship between the Electronic Chart and the Integrated Bridge. Chapter 6 concludes the thesis with an evaluation of the project, a summary of the progress made and suggestions for further work.

Section 1.1 Historical Background

It is not the purpose of this thesis to give a detailed history of hydrography, geodesy or cartography. However, from the point of view of the work being discussed it was vital to recognise the evolutionary nature of the sea chart and that its existence is owed to well defined human needs. The early cartographers were motivated by the requirements of trade and warfare. The same is true today.

The following section owes much to Admiral Ritchie's introduction to

'The Sea Chart'(1).

The earliest references to the use of sea charts date from the end of the 13th century. The 14th century saw the introduction of the 'portulan charts' produced by the powerful maritime states of Venice and Genoa. These were a progression from the earlier 'portolano' which took the form of a written pilot or seaman's guide. The most important advantage of the cartographic representation was the ability to depict compass bearings derived from the relative directions of 'compass stars'. In this way direction and topography could be represented in a compact form sufficient for use at sea.

The competitive explorations by Spain and Portugal, and the accompanying mathematical and cartographic advances occupied almost two hundred years of progress until the mid sixteenth century when the Netherlands started to become the focus of charting. In 1569 Gerard Mercator published his 'World Chart' in eighteen sheets and incorporated his outstanding projection principle. Nevertheless the awkward 'plane' chart preceding Mercator remained dominant for a further 100 years. A striking difference existed at this time between North European sailors who depended largely upon written sailing directions or 'rutters' and those of the Mediterranean who were used to a pictorial chart representation drawn on sheepskin vellum.

The first recognisable modern chart series was published in 1584 by the Dutch chartmaker Lucas Janszoon Waghenaer in the form of a sea atlas. These charts included soundings, views, considerable coastal detail and in one case, a latitude and longitude scale. Another particularly important feature was the use of standard chart symbols for safe anchorages, buoys and submerged rocks. This chart series and its successors dominated the European maritime scene for nearly one hundred years. It was known that the Dutch knew more about the English coasts than the British and this situation continued until Samuel Pepys, Secretary of the Navy, assigned Greenvile Collins the task of surveying the British Coasts and Harbours in 1681. It took him seven years.

Following the Longitude Competition inaugurated in 1714 (won by John Harrison with his Number 4 Timepiece) and the first use of triangulated survey networks, Britain began to play a leading role in chartmaking in the late eighteenth century. Captain James Cook had disproved the existence of a great southern continent and placed New Zealand on the map and Matthew Flinders was laying down the coastline of Australia. Alexander Dalrymple was appointed the first Hydrographer of the Navy in 1795 and printed the first charts for the fleet in the early 19th century. Thereafter, the Admiralty charts were made available to merchant ships from 1823. The supply of charts grew rapidly, incorporating much new survey material from overseas during the first half of the nineteenth century (this was particularly the case under Admiral Beaufort). The work of this time forms a substantial part of Britain's intellectual 'equity' in charts and surveys. Some of these are still extant as the official charts of some remote places even today. In 1921 the International Hydrographic Bureau was formed in Monaco at the invitation of Prince Albert I of Monaco. It has achieved much in the field of standardisation and most recently was involved with the development of the International paper chart series. In 1993 it is expected that the performance standard for Electronic Chart Displays and Information Systems (ECDIS), will be published jointly by the IHO and IMO (International Maritime Organisation) as a continuation of their work as the international authorities on maritime hydrography and navigation.

This section highlights the fact that the components, styles and symbolisation being used in the most modern of charts including some of the electronic type were devised over a period of over 500 years. Due regard should therefore be paid to the existing system of information and the question asked whether a modern system of storage, retrieval and processing can actually be applied unilaterally to such a rich diversity of information sources. Instead, given the opportunities presented by the application of powerful computing techniques, it is perhaps better to seek a simplification of the chart that retains the essential data required by specific groups of users and strive to supply the information required by them in as compact and relevant a form as possible.

Section 1.2 Review of Previous Work

The purpose of this section is to summarise the progress made in recent years within that part of the broad field of Maritime Information Technology concerned with Navigation. Particular emphasis is laid on the areas of Electronic Charting, Decision Support using Artificial Intelligence (AI) techniques and Integrated Navigation Systems as they apply to commercial shipping. The section is broken down further, into progress made internationally and that made in work at Liverpool Polytechnic.

Computer technology was applied to Navigation early in the history of computing. The impetus for this came particularly from the defence industry which saw possibilities for the precise guidance and tracking of ships, submarines, aircraft and weapons. Whilst such systems are outside the domain of this work, it is worth noting that the civilian sector has benefited in large part from the transfer of technology from these areas. Modern hydrographic surveying, satellite positioning systems and marine radar are examples. The development in the seventies and eighties of first the 'mini-computer' and then the Personal Computer (PC) created opportunities to apply the new technology at a more affordable level in the commercial sector and initiated the current interest in computerised navigation systems for the wider marketplace. The development of 'ARPA' radars, navigational calculators, and digital positioning receivers also depended on the advancing progress of the computer as an engineering tool.

An important justification for developing navigational software is that the navigator can be relieved of the lengthy, tedious and error-prone processing of raw information that used to be a characteristic of his job. Instead, he can focus on the decision making that he must perform to allow him and his vessel to proceed safely. Although the systems currently available are helpful, they do not address the decision making process itself. The next challenges to the marine software industry are in this area.

1.2.1 Electronic Charts

Chartwork has always been at the centre of the navigator's overall task-load and it is therefore unsurprising that a great deal of effort has been expended on a variety of attempts to provide

technological assistance in this area. Up to the mid - seventies these were electro-mechanical in character and remained dependent on paper charts.
Currently, the focus of interest in Electronic Charting is related to formally specifying 'ECDIS' (Electronic Chart Display and Information System). Such an item of equipment is supposed to replace and also be legally equivalent to the paper chart as defined by the SOLAS convention(2) (and will eventually also meet the requirements for carriage of publications(3)). Thus two strands of development have been visible: first to develop the legal and administrative structures required; and secondly to overcome the technological problems in producing ECDIS to meet the necessary standards. Furthermore, this effort has had to take place against a background of emerging standards for single man bridge operation(4)

The first, well publicised instance of commercial interest in using computer storage of chart information came from the fishing industry. The Kingfisher project(5) developed a prototype electronic fishing plotter. This ran on a BBC microcomputer, was written in BASIC and held all its chart data on an 800 kbyte floppy disc drive. However it clearly showed the effectiveness of an electronic chart and successfully demonstrated the use of data overlays. Kingfisher have since expressed interest in providing sea-bed information for fishing purposes as a data overlay in commercial ECDIS systems(6).

The North Sea Project(7) was hosted by the Norwegian Hydrographic Office to encourage the standardisation of international data transfer and review progress in electronic charting up to that time. It allowed the participating nations the opportunity of demonstrating

their systems at sea. Six companies submitted systems for evaluation: Sperry (US); Marcom (Netherlands); Offshore Systems Ltd (Canada); C-Map (Italy); DISC Navigation (Norway) and Caris (Canada). Whilst it had been agreed to use MACDIF(8) as the data transfer standard, not all participants were able to make use of it.
The diversity of systems at the time therefore emphasised the need for a common exchange format for use in association with ECDIS. The North Sea project was also important because it drew together the separate and divergent activities of a number of countries and raised the profile of the many different issues involved.

A number of products have since come onto the market. They share many common features with most including a graphics based chart display, waypoint navigation facilities and a positioning interface. Both commercial shipping and the yachting fraternity have shown strong interest in these systems. Examples include those of Kelvin Hughes, Furuno and Auto-helm.

In parallel, some developments have focussed on making the traditional paper chart easier to use. The Yeoman Plotting Table (9) from Qubit Ltd is an example of this. This system uses an electronic 'puck', similar in operation to a digitising tablet, as the principle method for locating chart positions. A major drawback of this type of system is that it offers little assistance in course construction: it is largely designed to assist in locating points.

Aside from the large systems being developed for use on board ships, some companies have been working on providing systems for specialist applications based on PCs. Examples of these are the software packages offered by PC-Maritime Ltd(10) used for navigation training by yachtsmen and the electronic chart for fishermen offered by Mac-Sea. Whilst useful examples of innovative software, they do not attempt to meet the full ECDIS specification and are therefore of limited use to commercial shipping.

Equally, a number of companies now provide 'chart plotters' for the yachting market. Most of these are based on the Electronic chart software produced by C-Map - The Italian representative in the North Sea project. Again, whilst most of these systems offer waypoint navigation facilities and interfaces to other equipment, they do not attempt to meet the IHO ECDIS specification.

1990 saw a further development. The Seatrans project (11) - Norway's follow up to the North Sea Project - was completed. This involved a fully operational prototype ECDIS system being used for routine navigation in Norwegian coastal waters and strengthened the further development of a data exchange standard for electronic chart data.

Keen interest has also been shown in ECDIS development by the US and Canadian Hydrographic Offices. A number of different systems have been produced there and it is possible that ECDIS will become compulsory for some types of ships, in certain areas in their waters. This interest was given particular emphasis by the Exxon Valdez grounding in 1987(12)

The Netherlands(13) have also recently completed a set of ECDIS sea trials (these are discussed in chapter 4.)

Electronic chart systems are specifically designed to support the processes of navigation; closely related systems from the field of Hydrographic Surveying used for collection, analysis and display of bathymetric data also show promise in contributing to more advanced ECDIS variants in the future. These might provide detailed, 3 dimensional views of the sea-bed to interested users such as fishermen, submariners, offshore structures engineers and diving operators.

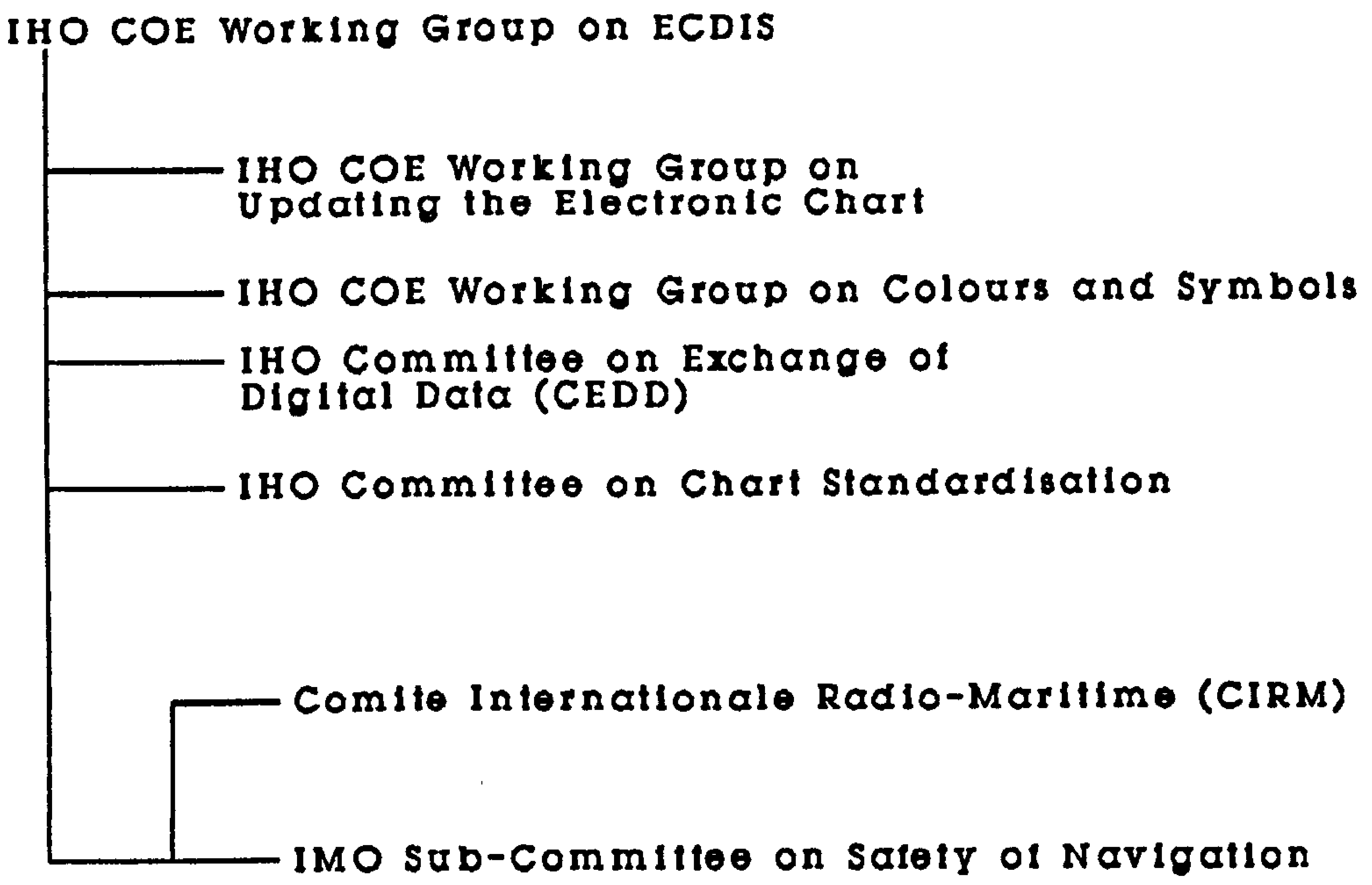
The current authority for the definition of a 'true' ECDIS system - that is, one capable of use as a legally acceptable substitute for paper charts, is the International Maritime Organisation. They have been working in collaboration with the International Hydrographic Organisation through a structure of committees to produce a standard. The Performance Standard for ECDIS is expected to be finalised in 1993. A summary of the organisation of committees is given in Figure 1.1 overleaf.

1.2.2 Radars

The raster - scan radar is also a product of the developments in digital electronics in recent years. Computer processing of the presented image has allowed improvements in most areas of radar performance and, more importantly, has given users more navigationally useful features. Amongst these have been: colour discrimination of picture components; real-time position input; mapping facilities; advanced target plotting and trial manoeuvre facilities. For example, many modern radars allow the input of 'map lines' to highlight navigational dangers. By using the output of a

Fig 1.1

Organisational Structure of IHO/IMO committees on ECDIS (COE)



positioning receiver it is then possible to locate these lines relative to own ship position in a fully ground stabilised manner allowing clearing ranges to be established for port entry etc. The super-position of live radar on the electronic chart and vice versa has been suggested as a means of improving the correlation between both systems by the user. Reservations concerning the relative accuracy and cluttering of the display have led to a fairly generally held belief that the most useful approach at present is to overlay only selected ARPA targets. This was reflected in comments made during the North Sea Project(7) and and was incorporated into the current draft of the IHO ECDIS Specification(14).

1.2.3 Communications

Communications are both an essential part of operational Command and Control and necessary to fulfil the basic requirements of the Search and Rescue authorities. The recently introduced Global Maritime Distress and Safety System (GMDSS)(15) legislation has formalised a set of world-wide carriage requirements for communications equipment and makes use of a combination of satellite and conventional radio systems including automatic distress beacons. It is generally considered that GMDSS will substantially enhance safety at sea.

1.2.4 Other Bridge Equipment

Innovation has also extended to many of the more mundane items of bridge equipment. This has been seen in both the large vessel market and in yachting. Examples as stated earlier, are automated chart tables, forward looking sonar, 3d displays for echo sounders etc. Whilst not all are expected to catch on, they are indicative of a trend to incorporate software into traditionally analogue equipment.

1.2.5 Integrated Bridges

An Integrated Navigation system is one where the outputs of different sensors can be transferred to processing units capable of combining their results and generating new information. This, in its turn, can either be displayed for human decision making purposes or transmitted onwards as a control input to another system.

Integrated Bridges were being developed in the 1970's (16) and the concept has been advanced over several years so that it is now possible for a customer to purchase such a system almost as an 'off the peg' item from a wide choice of suppliers. Interfacing standards for bridge equipment are also developing rapidly and it would seem that the Integrated Bridge will make a significant and lasting impact on marine navigation as it is currently practised, not least through the introduction of officially sanctioned One-Man Bridge operations.

Abramowski (1976)(17) describes an early trial of an integrated Ship's bridge layout. His comments relating to its installation remain pertinent

"We may first note a complaint from the Master about the layout of the first installation of an integrated and partly automated navigation collision avoidance system in a U.S merchant ship, that while the electronic integration and information presentation are of the highest sophistication and accuracy, ergonomics are summarily disregarded; he complained that to obtain information he had to move rapidly from one end of the bridge to the other and from one wing to the other, some 120 feet apart. .....it is difficult to say whose idea it was to build the system as a double row of straight consoles..."

Considerable progress has been made in relating the study of ergonomics to ship's bridge layouts since then, however many systems continue to disregard the essential requirements for easy access to information in an appropriate place.

Moskvin and Soroschinsky (1988)(18) also give a complete description of an integrated bridge layout being pursued in the old Soviet Union (CIS), including for the first time, reference to the possible role of the electronic chart as an automated positioning reference. Other papers published at a similar time reveal that real interest in provision of integrated bridge systems to the commercial market started in the early to mid-eighties.

Of particular interest was research work undertaken on the implications of high speed navigation on bridge design. The Norwegian Sea-cockpit design(19) is a good example and indicates a trend towards 'an aircraft cockpit' style with permanently seated Officers and a dual control console. The design speeds of the vessels whose navigational requirements it seeks to address, are greater than 40 knots in some cases.

A serving Master commented on his experience of using a Japan Radio

Company (JRC) Integrated Navigation System (INS) by saying that

"..it is equivalent to having a second navigator on the bridge, checking and calculating the ships course all the time and bringing (course) alterations to one's notice immediately. It relieves the duty officer of the stress of having no other check for his positions and actions, when he only has to glance at the display to determine whether or not his position coincides with the INS or not." (20)

The first part of this statement is of significance. The perceived usefulness of having a second, albeit electronic navigator on the bridge should give a useful basis for further investigation into maritime expert systems. Successful results have been obtained in aviation using this approach coupled with Artificial Intelligence techniques(21)

The bringing together of information in integrated navigation systems creates its own problems. First, the number of possible combinations increases exponentially as sensors are added; thus although some combinations are naturally precluded as meaningless, there is a danger of creating systems too complicated to achieve an appropriate result. In a traditional bridge this type of problem does not arise since the individual skill of the Officer of the Watch acts as a discriminating filter. Second, the same multiplicative effect applies to the probability of component failures, resulting in a near certainty of some kind of failure in a large system such as an entire ship. Indeed even now, most vessels sail with several known defects which might severely degrade the vessel's operational capabilities. Duplication of hardware would help to reduce these probabilities but the marine environment is notorious for finding weaknesses in equipment. Similar thoughts must apply to software. All these factors therefore merit further study if safety and efficiency are to be achieved.

1.2.6 Decision Support

Within the context of navigation, it is important to distinguish between Decision Support using conventional processing - ie using the juxtaposition and interpretation of complementary data - and that which uses Artificial Intelligence (AI) techniques. The first type, whilst perfectly capable of producing extremely useful results, is normally restricted to its major and obvious applications and relies upon the user planning his own strategy. An example might be superposition of user data on an electronic chart eg concerning well-heads, wrecks or pipelines. Decision support under AI uses a Knowledge Base of 'sound principles' or 'heuristics' which assist in providing a route through a decision making tree. The output of such a system is the machine's conclusion which the user is then at liberty to accept or reject. At present, it is the user's 'power of veto' which stands between a more traditional practice, albeit computer assisted, and automated navigation. Whether it is possible to define an AI based system capable of resolving every possible situation at sea in a safe and cost effective manner is a question whose answer lies in the future. The KBSShip(22) project has recently attempted to address the problem of developing a ship-wide expert system with encouraging results.

A paper by Grabowski(23) described an experimental system for use in

New York Harbour making use of 'Expert System' techniques in computer assisted pilotage. This represents a very recent step in relating Intelligent Knowledge Based Systems (IKBS) to practical navigation problems and shows an imaginative and potentially useful application of computer technology.

Tokyo University of Mercantile Marine, Mitsubishi Heavy Industries and Hitachi Shipbuilding Co. of Japan have also been active in working towards 'Intelligent ships'(24). Their work has taken the 'Whole Ship' view and includes efforts on defining the engineering requirements for building and maintaining ships on this basis. However, they have also published results concerning the field of knowledge based collision avoidance(25,26) as have several other researchers, notably the Chinese (27).

1.2.7 Work at Liverpool Polytechnic

Work at Liverpool Polytechnic in the field of computer assisted 'Navigation Control' has been in progress since the early nineteen eighties. One of the first reports produced concerned the 'Paperless Bridge'(28) This studied the relationship of navigational information with the electronic chart. The conclusions of the report are summarised as follows:

(a) that the electronic chart is an attainable and worthwhile concept;

(b) that facilities for automated position display, database access, rapid calculation of tidal information and user defined overlays would be of substantial benefit to mariners;

(c) that algorithms to determine the proximity of chart features would also be of benefit and allow 'intelligent' interaction of own-ship's position with the chart;

(d) that Graph Theory offered a possible avenue for the automation of passage planning;

(e) that limitations only existed in the availability of affordable display hardware and an actual digital database appropriate to navigational requirements.

Six years on, although a degree of international cooperation has been achieved through the national hydrographic offices, a publicly accessible, regional database of digital chart information does not yet exist although this is expected to become available in the near future. Developments in hardware and display technology have exceeded expectations, a major problem now being one of choice among the many formats.

The Paperless Bridge project achieved two major things: a software model against which further work could take place; and a perceptive anticipation of more recent developments in Electronic Charting.

Further work at Liverpool concerned the development of a prototype electronic chart based on the findings of the paperless bridge report. Whilst this system no longer survives for demonstration purposes, its principles form a key part of the current work. In particular, Quadtrees (29) (which are reviewed in detail later) were identified (30) as a suitable data structure for developing sophisticated GIS functions in the electronic chart. The ability to provide information structured according to the task requirements, was seen as a key advantage over paper charts. Quadtrees are suited to storage of information relating to areas of homogeneous characteristics where this is defined by some spatial geographical attributes. Furthermore, they can be used to perform set operations over areas of varying size and are thus capable of use for providing 'Grounding Alarm', 'Track Validation' and 'Look ahead' facilities.

The project following was concerned with developing a Rule Based Collision Avoidance System (31,32) and was significant in that it successfully encapsulated the explicit manoeuvering rules of the IMO Collision Avoidance regulations(33) within a computer Rule Base. The prototype was thus able to perform a situation analysis concerning up to six ships - producing textual advice on the most appropriate collision avoidance strategy. This study was important to the current work in two respects. Firstly it demonstrated the enclosure of navigational 'know-how' acting towards a safety goal within a processing loop; it also provided further interest to the work on electronic charting by using low resolution chart based land constraints in its algorithms. It is the juxtaposition of the necessity for collision avoidance on the one hand and the avoidance of grounding on the other all within a set of time constraints and subject to the need for 'event prioritisation' - that define the most difficult navigational problems faced by mariners. These merit further study.

Section 1.3 Project Requirements

An early task in the project was the production of a formal definition of the system requirement. This had to be closely related to the aims of the project as well as to the needs of prospective users. The task of defining the Project Requirements Specification was considered worthwhile as a means of focussing attention on subsequent areas of work. The requirements were therefore dictated by considerations forming three groups:

1. A practical specification for a prototype item of navigational equipment including the user interface (this section is expanded slightly to include its use in an integrated bridge);

2. The explicit performance standards defined by the IHO;

3. The special needs of the project concerning the sponsor's requirements, testing facilities and hardware limitations;

The project requirements are listed below under these headings with comments where appropriate.

1.3.1 The Practical Specification

A user requirements specification in thirteen parts was written at the commencement of the project as a formal, albeit internal description of the system to be developed. The intention in doing this was to explore the use of formal methods in the design and implementation of the project software.
The following specifications were prepared:

a) Frame handling and display

b) Navigational Functions

c) System accuracy and integrity

d) Database interrogation during screen handling

e) Radar overlay

f) User Interface

g) Real time functions

h) Top level functionality

i) Chart Intelligence

These specifications provided the backbone of the electronic chart's design and the software application which exists at the end of the project is recognisably that discussed in these documents. However, whilst providing a useful statement of intent, these specifications became of reduced significance during the latter stages of the project when work commenced covering the more speculative aspects of the initial project proposal(34).

1.3.2 The IHO Performance Standard

A later section discusses the IHO standards in detail. It is sufficient to state here that they were reviewed thoroughly and those requirements which it was thought the project could meet given its resources were incorporated into the requirements specification.

1.3.3 The Special Needs of the Project

There were some significant differences between the development of the Liverpool Electronic Chart and that required of a similar commercial system. Nevertheless, the prototype developed had to be seen to be a possible starting point for the introduction of a commercial product.

1.3.3.1 The Sponsors' Requirements

The sponsors' principal requirement was for a solution to the problem of achieving cartographic accuracy on the video display and the definition of a method of frame handling. The project also explored some of the Man-Machine Interface (MMI) problems that required solution for the system to be usable under test conditions. For example - in order to produce a system capable of being tested within the department, a simple user interface was devised based on graphical user-interaction on the chart display and key driven menus on the information system display. By using a three button trackerball, this approach was intended to parallel the sponsor's own approach to the 'Man-Machine Interface' in their Integrated Bridge products.

1.3.3.2 Testing

For testing purposes, communications facilities were required between the Bridge Simulator at Liverpool and the electronic chart. Some effort was therefore expended on achieving the required accuracy of conversion between the simulator output and the chart display coordinate system. The electronic chart was constrained in its performance at sea by the fact that it was considered undesirable to connect it to any ship's equipment. Sufficient performance was achieved through the use of GPS to provide position, approximate course and speed to render this drawback unimportant. It is however anticipated that the system will be closely linked to ship's sensors in an installed commercial fit.

1.3.3.3 Hardware Constraints.

All the hardware employed in this project came from either retail or specialist hardware suppliers. No significant modifications were possible or necessary to the major electronic components of the system. This only became a drawback in the latter part of the project when the electronic chart was installed on board a sea-going ship, where space constraints and environmental factors started to cause concern. More sophisticated hardware than that employed is readily available although cost precluded its use. During the three year duration of the project, both the cost of hardware has fallen and its computational power has risen. There is no reason to expect that this trend will not continue.
The only significant hardware constraint concerned the provision of two chart displays within the system as required by the original IHO specification. (This requirement has since been removed by the IHO). Nevertheless, the provision of a text display to supplement the chart was relatively straightforward.

1.4 System Overview

1.4.1 Technical Description

The chart is based upon a P.C. compatible computer (incorporating the INTEL 80386 and supporting 80387 numeric co-processor). This hardware platform permits the use of standard commercial software libraries under MS-DOS. Communications interfacing to other associated hardware (eg positioning devices and existing ships equipment) takes place via a 3 channel asynchronous communications device. A vital component of the system is the multi-media expansion card which converts PAL RGB video to the VGA line display standard and provides a graphics overlay facility. A laserdisc player under software control provides random access to chart frames on the mass-storage videodisc. Two screens are used as output devices, one for the chart image, the other (monochrome) for the display of textual information. A degree of multi-tasking was investigated to enable continuous position monitoring, display refresh and logging functions to operate concurrently with the user's inputs which are monitored by a trackerball and keyboard. Graphics routines and window/menu functions are provided by specially developed software libraries. A relational database was developed using a memory resident driver for data insertion and retrieval operations. Ship positioning input is provided by either a commercial GPS receiver or via a dedicated link with the training simulator at Liverpool Polytechnic. Thus either sea or shore based testing can be carried out. Heading reference and speed input are similarly input via RS232 using an NMEA 0183 communications interface(35). The project software was developed using the 'C' programming language.(36)

The chart display of the Liverpool system is generated from photographs of Admiralty Charts stored on Videodisc. These are captured using precise photography on to 35mm cine film using a scan sequence that results in a 'row-prime'(37) ordering of the images (each of which is known as a 'frame'). After conventional processing, the frames are transferred to a videodisc which provides the mass storage medium. Approximately 150 charts per disc can be stored in this way. In order that the eventual accuracy of the chart display is

maintained, the inter frame camera movements must be accurate to 0.002 cm in both the horizontal and vertical dimensions. By using a camera of appropriate size a whole chart can be scanned in a single sequence regardless of whether the sheet is in 'landscape' or 'portrait' orientation. All the paper sizes used by the UK Hydrographic Office can be handled.
To create the impression of a continuous chart image, the overlap between frames has to meet two conditions. It must be sufficient to prevent user disorientation during frame to frame movements on the chart but small enough to give reasonable economy in storage. At present, a figure of 60% overlap is used as a result of evaluative work with experienced mariners. The frames need to be 'scaled' before they can be used in the chart display. The scaling process uses a separate data preparation program to establish the relationship between the pixel raster of the computer display and chart distances. The relevant numeric constants are stored in a database along with details of the mathematical model upon which the chart projection is based. Considerable care was taken in developing a suitably precise chart presentation, developing a package of navigational algorithms and defining the supporting data required for effective navigation.

To summarise, the work was concerned with modelling the implicit data structures of the Admiralty Chart. These have evolved over hundreds of years and become strongly oriented towards providing maximum utility to the user, principally by providing coverage in the right place at the right scale. An important feature of the present work was the assumption that the presentation of a familiar chart display will encourage users' acceptance.

Electronic Chart System Block Diagram

(Seagoing Test Configuration)

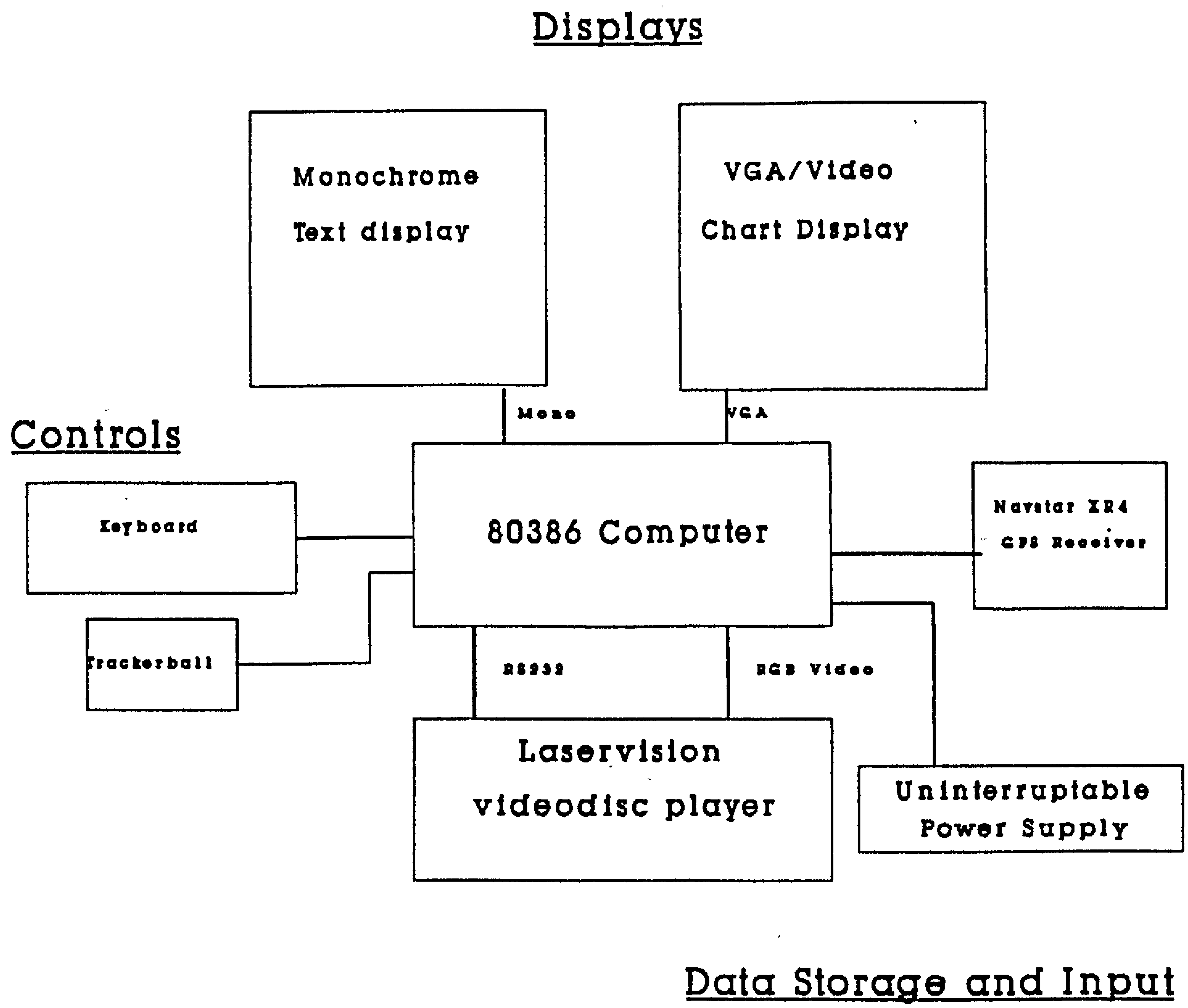


Fig 1.2

Electronic Chart System Block Diagram

(Simulator Test Configuration)

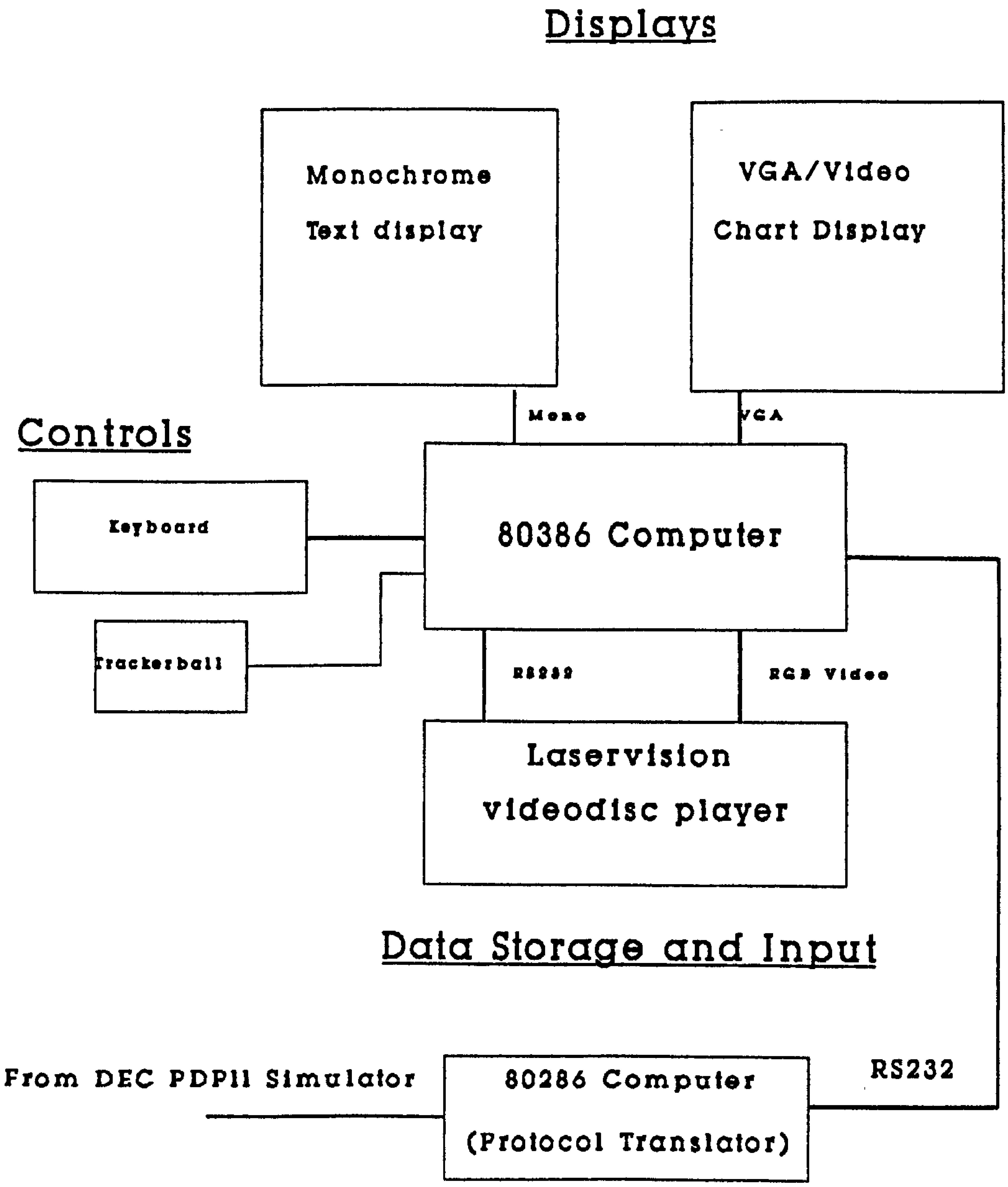


Fig 1.3

1.4.2 Overview of System Operation

See figures 1.2 and 1.3 on the preceding pages.

The overall design of the system reflects the term 'ECDIS' closely, since it comprises a colour 'Electronic Chart Display' and corresponding 'Information System' output on the second screen.

The majority of the user's requests for information are initially generated via the chart display. For example, the position-cursor can be used to invoke data access functions such as tidal stream / height calculations, light characteristics and pilotage information by using the cursor to point at their equivalent symbols on the paper chart. Alternatively, dedicated functions can be operated using a menu system on the text screen; these give more general information. This includes weather forecasts, navigation warnings derived from the NAVTEX system and extracts from Admiralty Sailing Directions. Point and region enquiries are being modelled using data supplied in the IHO DX90 exchange format. In particular, point data enquiries use relational 'links' with an external disc based database, allowing a significant amount of information to be displayed with a minimum of memory overhead.

The dual screen design creates an impression of using two closely related but physically distinct systems (despite their being implemented on a single computer). The further integration of the chart into the integrated bridge, where data from the ship's systems and sensors is collected is considered to be a step towards creating intuitive links for the user between the chart, the vessel and its operating environment.

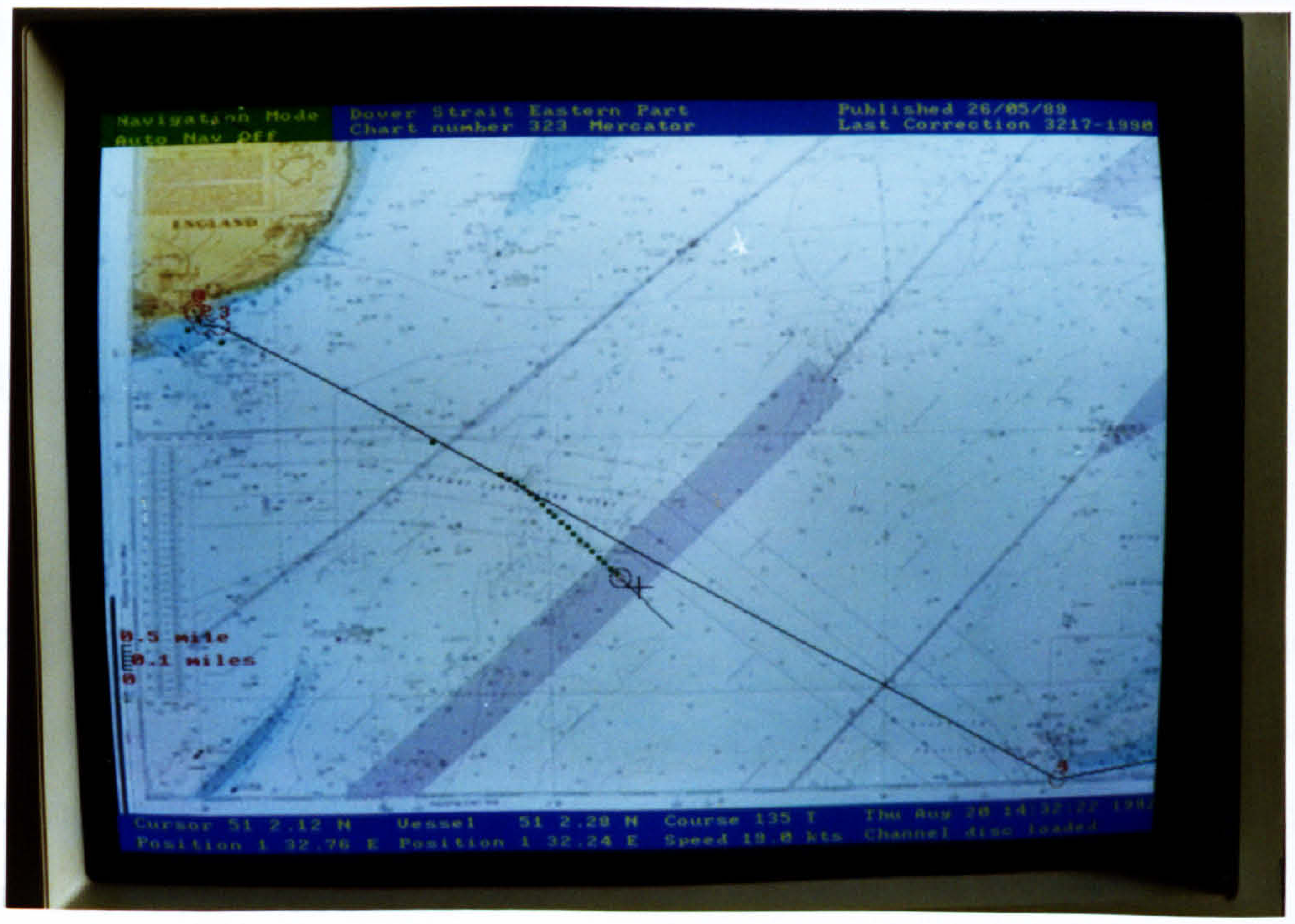
1.4.2.1 The Chart Display

See Plate 2.

This is a screen on which the video images of the source charts are displayed. Each single photograph of chart data is referred to as a frame. A trackerball is used to direct the frame handling through the use of a cursor crosswire whose geographical lat/long position is updated continuously as the trackerball is moved. Changes of frame occur when the cursor crosses the current frame boundary and when the user operates the 'zoom in / zoom out' function keys. The photographs are provided at two 'levels' comprising images shot from different camera heights allowing two stages of 'zoom'. This gives the user the opportunity to view the general topography of the charted area on the wide focus frames and the ability to read the full detail of the chart where required on the close up frames.
During zoom operations - which are centred on the cursor location - the display alternates between these levels; changes of scale occur when the request cannot be met within the current chart. This is done by switching to the next chart in the scale hierarchy which covers the area of interest. The cursor remains as closely centred as possible on the same lat/long position - allowance being made for differences in the ratio of pixel area to area in the charted terrain. OSGB36 is used as the unifying horizontal datum (38) for position transfers and lat/long storage since relatively few of the total number of charts used were on different datums. WGS84(39) should be used in a commercial system since this will provide a

Plate 1 - The Equipment

Plate 2 - The Interactive Video Chart Display



common datum for all processing of locational data. After the new chart has been displayed, a scale-change warning is briefly shown and the scale bar at the chart edge is redrawn. All overlaid information such as course-lines, the range and bearing indicator etc. are redisplayed appropriately. Considerable care was taken to achieve a satisfactory degree of chart accuracy, the data preparation algorithms having to account for the chart projection, spheroid and datum. At present, the Mercator projection is fully supported, errors in lat/long display being no greater than one pixel in any direction. The algorithms for the 'Gnomonic' and Transverse Mercator projections have been prototyped and give similar theoretical results.

Supporting data is stored in a separate file to provide the information concerning the chart projection, its horizontal datum, the chart title, chart number, last correction and date of production which are displayed continuously at the top of the screen in an information bar. A second information bar at the bottom of the screen shows the lat/long position of the cursor; the position of own ship, its course and speed; and the system time. It is also used for display of the range and bearing readout.

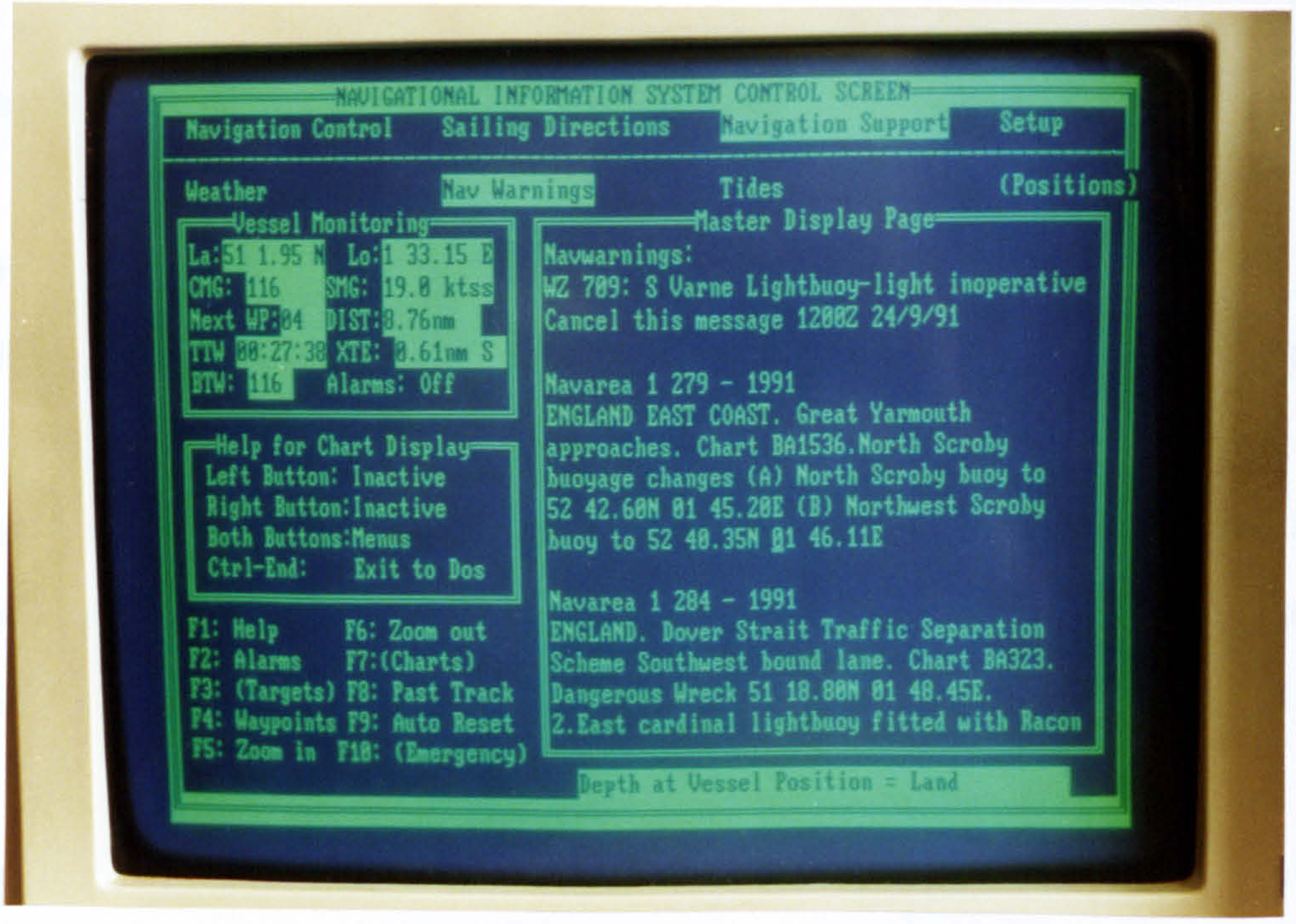
1.4.2.2 The Text Display

See Plate 3

The text display is used to provide access to support functions via an independent set of menus. These are broken down into four categories: Navigation Control, Sailing Directions, Navigation Support and Setup. The Navigation Control option (although not yet implemented) would allow the user to determine the system output

Plate 3 - The Text Screen

Plate 4 - The Text Screen showing Live Navigation Data and a Navwarning



depending on whether the vessel was in pilotage, coastal or Ocean waters; the Sailing Directions (again not implemented) would allow variable resolution access to Sailing Directions; the Navigation Support option provides access to tidal height calculations, navigation warnings and a weather forecast; the setup functions would allow the user to specify his ship-type, turning data, position fixing systems, number of engines etc.

The text display is also used to display live readouts of own-ship position, course made good, speed, time to next waypoint, bearing to waypoint and distance off track to port or starboard. It also incorporates a quick reference 'help' facility relating to the action of the trackerball buttons on the chart display. A more comprehensive, context sensitive help system is incorporated to assist with user enquiries relating to the menus.
A proportion of the screen is left blank to act as a general purpose display area for waypoints, lights etc thus ensuring that vital live data is not obscured.

1.4.4 Passage Planning and Navigation Modes

Two distinct tasks arise in conventional navigation. The first, that of planning a voyage, demands that the chart is used in a different manner to when it is being used to monitor progress. The distinctness of these processes mean that the Liverpool Electronic chart is designed to be operated in one of two distinct 'modes': Passage Planning and On - Line Navigation.

Passage planning involves the construction of the intended track depending on whether the vessel was in pilotage, coastal or Ocean waters; the Sailing Directions (again not implemented) would allow variable resolution access to Sailing Directions; the Navigation Support option provides access to tidal height calculations, navigation warnings and a weather forecast; the setup functions would allow the user to specify his ship-type, turning data, position fixing systems, number of engines etc.

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Passage planning involves the construction of the intended track using human judgement to justify its position relative to the navigational hazards and environmental forces which might be encountered along the way. Thereafter, the chart is used as a visual and active 'index' to other information which is collected from a variety of sources (usually books and other publications). This activity 'pre-processes' the required facts, presenting them in a form which is ready to use. The data is then used to support the Watchkeeping Officer in his decision making during the execution of the voyage. A well planned passage will take account of as much relevant information as possible.

During the 'live' navigation phase, the chart is used largely to monitor progress relative to the planned courses, the charted dangers, any man-made schemes and the timing requirements of the voyage. The navigator interacts with the chart continuously as he plots his positions and uses it to maintain the relationships in his mind between what he can see from the bridge, the navigation radar and the charted terrain.

Summary

This chapter has illustrated how the Sea Chart and the information supporting it have evolved into complex navigational tools backed by many years of human experience. The pervasive influence of electronics and computer technology have come to the navigation scene over only a few brief decades. The work carried out within the project being discussed has therefore had to take account of both the available technology and the existing culture and disciplines of navigation. This is the subject of the next section.

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CHAPTER 2

Systems Analysis

Chapter 2

Systems Analysis

This chapter describes the design philosophy of the Electronic Chart prototype. It contains a discussion of the overall system objectives followed by an analysis of the structure and function of the conventional nautical chart. The work at Liverpool is then related to the current IHO specification for ECDIS(14). The navigation task is analysed in the next section and a more complete model is proposed based on both the International ECDIS specification above and the Admiralty Manual of Navigation(40). Finally, the models developed for the operational modes of passage planning and navigation used in the Liverpool system are discussed.

Section 2.1 Objectives and Anticipated Benefits

This section describes the general objectives and principal benefits that are being pursued in the development of electronic charts and discusses them in relation to the existing navigation task.

The underlying purpose in developing an electronic chart is to accomplish a first-level transfer of the conventional processes and practice of navigation into the machine's domain. Following on from this - and in large part due also to the speed of computer processing - the electronic chart is expected to provide considerable benefit to navigation in three major areas.

First, the continuous updating of own-ship's position on the display will give an immediately available and accurate position reference upon which navigational decisions can be based. Traditionally, this manual task has incurred a time delay in transferring the 'fix' from the positioning sensors (gyro, echo-sounder, Decca etc) to the chart. The electronic chart's instant positioning capability justifies placing it at the front of the bridge to provide a visual grounding-prevention display complementing the anti-collision display given by conventional radar. It can be anticipated that the electronic chart will diminish the regular use of radar as an aid to position fixing since the advantage to the user of live, accurate position output on the chart will be significant. Some kind of image correlation between chart and radar could however, be useful in detecting gross positioning errors close to land.

Second, the automated collection and processing of sensor data and its comparison with the intended voyage plan should provide the most commonly used monitoring information in a readily understood form and be less prone to human error in calculation. This is particularly the case where the projection of dead reckoning (DR), expected position (EP) and course made good (CMG) are concerned and can also include advisory data such as course to steer (CTS) based on the distance off track, predicted tidal stream, wheel over positions etc. Whilst ship-control automation software does exist, it is not suggested that it should form a natural part of an electronic chart yet (but see Chapter 5).

Third, the availability of a large mass store containing permanent and semi-permanent navigational information combined with a sophisticated request/retrieve mechanism will reduce the likelihood of relevant but inaccessible information being overlooked. Equally, the regular inspection of own-ship's immediate, charted environment will become possible by using spatial data derived from the chart. This would allow additional navigational advice to be generated for safety purposes.

There are also certain, not insubstantial 'fringe benefits' connected with reductions in workload that are also anticipated. For example, that the mariner will be relieved of handling the large volumes of paper information associated with a worldwide chart portfolio and that chart updates will be performed rapidly and 'invisibly' via satellite or (say) floppy disk. The considerations relating to this type of workload reduction have often been emphasised at the expense of the main feature of the electronic chart which is its potential for improving safety at sea.

Section 2.2 The Structure and Function of the Nautical Chart

This section discusses the existing design of paper charts and the way in which they are arranged to give navigational coverage. The final part relates this to ECDIS.

A full discussion of chart constructions is given in The Admiralty Manual of Navigation(40) and the Admiralty Manual of Hydrographic Surveying(41). A comprehensive history of the survey effort of the 18th and 19th centuries is provided by Ritchie(1) and is very briefly summarised in the introduction to this thesis. Another reference by Howse(42) contains a pictorial history of chart development over the years and includes reproductions from the chart collection at the

Greenwich Maritime Museum.

2.2.1 Modern Charts

It is important to recognise that the system ultimately being studied is not a disassociated collection of paper maps and books but the complete database of charts and publications. Developing the means for 'navigating' the data is thus of some interest. The traditional system uses the Chart Catalogue(43) as a convenient index to it, usually as a primary source of reference in passage planning which gives a first indication though, of a need for ECDIS design to take account of potentially complex spatial relationships between chart locations and their data content in order to provide a useful system.

Close examination of a modern chart reveals that it is constructed from a variety of source survey data. In the case of a typical chart such as that of Harwich (BA chart 2693), the surveys have been performed by different organisations at different times according to their requirements and capabilities as listed in figure 2.1 overleaf. The Hydrographic Office is responsible for collating the data and publishing the chart. Thus the current chart of Harwich represents source survey data dating from as recently as 1989 back to the 1950s. Of the vast number of charts available worldwide, some are still in use which were published in the late 19th century and contain even earlier survey data. The disaggregation of the Empire means that these are unlikely to be brought up to date for some years to come. The nautical chart has several purposes, however its principal benefit is that it allows the mariner to travel without carrying information in his head. Whilst this sounds trivial, historically it

Chart 2693 - Port of Harwich
Survey Data Listing

Harwich Haven Authority Surveys

a) 1980-1988 1:1 250 - 1:10 000
b) 1975-1979 1:1 250 - 1:50 000

Admiralty Surveys

c) 1983 - 1989 1:12 500 - 1:25 000
d) 1972 1:25 000
e) 1956 - 1965 1:7 300 - 1:25 000
f) 1933 1:7 300 (lead-line)

Ipswich Port Authority

g) 1984 - 1988 1:2 500

Other

h) 1985 - 1989 1:12 500 - 1:25 000
i) 1957 - 1972 1:2 500 - 1:25 000

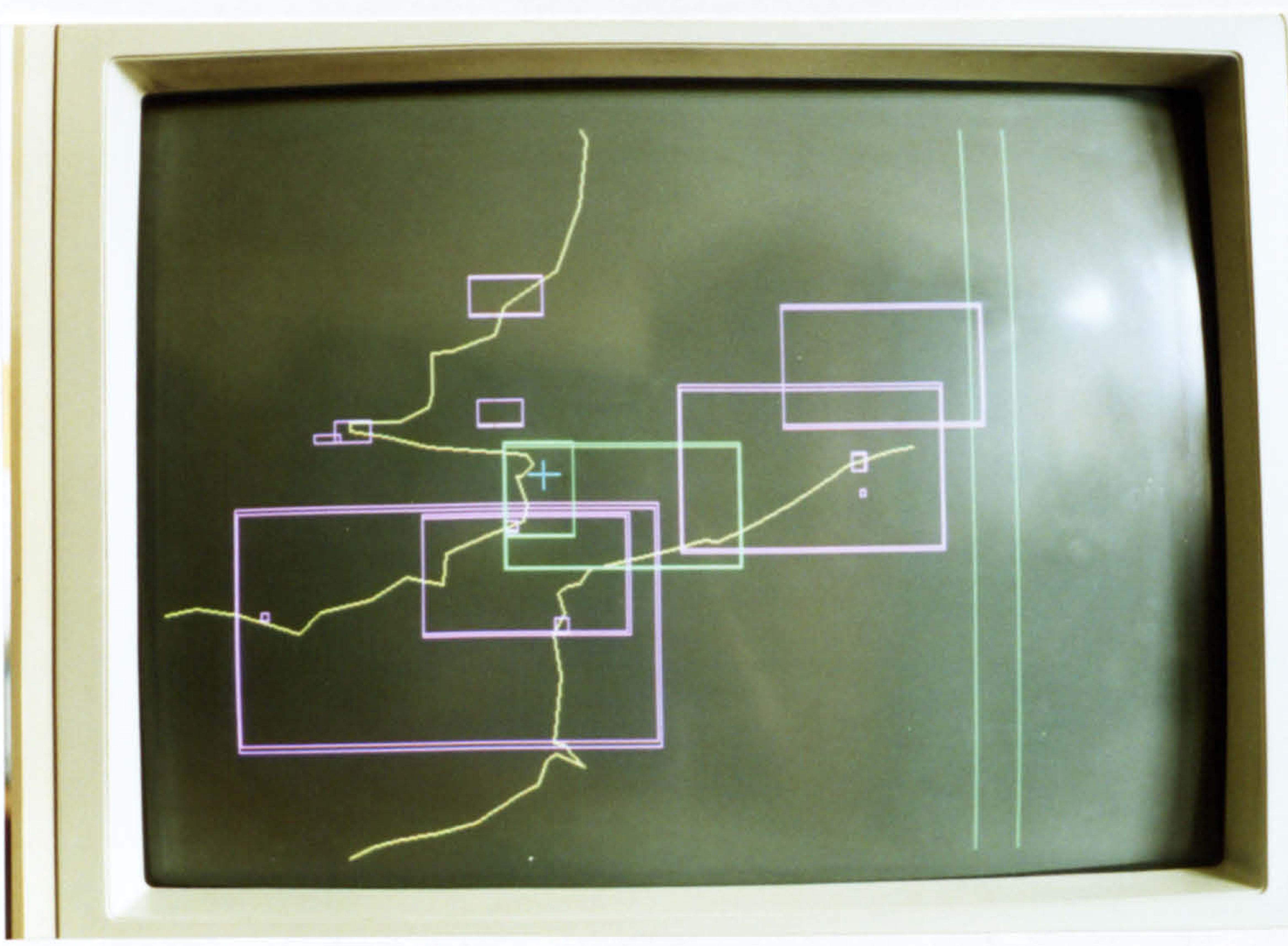
Fig. 2.1

made a massive impact on trade capabilities. Early charts and sailing directions were jealously guarded as commercial secrets, since they provided the principal safety reference against grounding. The modern nautical chart can thus be thought of as the visible result of a massive data collection effort which today also includes the sailing directions, tide tables, light lists, radio signals lists etc. Prior to computerisation, the principal means of random access to this was via the visual index provided by the chart itself. For example, the mariner wishing to know about entry to a port unfamiliar to him would obtain information from these publications only after studying the relevant chart in detail.

Whilst the various chart scales can appear rather loosely organised (see Plate 5) it must be remembered that the third major purpose of the chart as a visual tool requires that charted areas must conform to user need. Rather than vary the size of the paper sheet, the charting agencies have generally varied charted scale slightly to enclose the geographic regions of interest in the most convenient way. Furthermore, by examining a chart's scale, it can be classified according to its intended use, whether this is in pilotage, river, coastal or ocean navigation. This hierarchy has therefore been carried over directly into the IHO Electronic Chart Database (ECDB) specification(14) for the purpose of classifying the scale levels at which data is supplied. In future this will almost certainly have a further impact, affecting the way in which the electronic chart performs under different navigational circumstances.

Finally, one of the most challenging problems facing ECDIS development is that of providing rapid chart updates. The current

Plate 5 - The Interactive Video Chart Series



paper system involves the correction of both permanent and semi-permanent information. Advances in satellite communications should allow the effective timescale of correction to be reduced; perhaps giving opportunities for charting more transient though still navigationally significant information such as ice-berg movements and seasonal changes in ocean currents etc. Nevertheless, the efficient collation and distribution of update data will demand a firm commitment to do so by the cooperating hydrographic offices.

2.2.2 Political and Strategic Considerations

In order to provide an effective, worldwide system of paper charts the seagoing nations have needed to cooperate in chart production. Most recently this has resulted in the International chart series which aims to reduce costs to individual countries by allowing a pooling of effort. Thus the International chart extending from the south coast of England to the Gibraltar Strait is published by France. UK charts of foreign waters are now almost invariably produced through consultation with the hydrographic offices of other nations. Certain charts of a specialised nature are produced solely for the use of the naval forces of the nation concerned. It is therefore also likely that ECDIS systems for similar purposes will be developed in the not too distant future.

There can be little doubt that the translation of chart data into a usable electronic format will be a significant task, particularly when one considers that human life will depend on its accuracy and integrity. In parallel with air navigation, it is also likely that there will be the opportunity, indeed the necessity, for introducing stricter and safer routeing measures for ships carrying dangerous cargoes particularly where these are manned by reduced crews. This implies that new international legal requirements will need to be both defined and adhered to if ECDIS is to contribute significantly to safety.

2.2.4 The Relationship of the Existing Chart with ECDIS

Whilst the existing system of navigational information represents a superb human achievement, future requirements for ECDIS chart coverage will be driven by user need. At present, the resources available for surveys and digitising are tightly constrained and cost effectiveness will be the dominant criterion in the undertaking of new work. It is not likely that the entire worldwide chart portfolio will be digitised in the immediate future but that the chart database envisaged by the IMO will be based on a selection of charts closely associated with the major trading areas of the world.

The full portfolio of paper charts represents an extremely valuable human asset: it is a masterpiece of design and a tribute to its makers. The paper chart has usefully served mankind in its various forms for over 500 years and it is therefore important to fully understand its structure and purpose prior to an attempt to redefine it with computer technology.

Section 2.3 ECDIS Chart Display Requirements

2.3.1 The IHO ECDIS Specifications

At the commencement of the project, the most recent version of the official specifications for ECDIS was draft 3 of IHO special publication 52 (SP 52) published in 1988.(44) This was the basis from which the first version of the Liverpool requirements specification was drawn. The IHO document has since been expanded both through revision and supplementation by reports from the various Working Groups and Committees on ECDIS (see figure 1.1). Draft 3 was largely concerned with a basic definition of database content, database structure, possible means of updating and an outline of the performance requirements of ECDIS equipment. It was acknowledged within this document that a shortage of shared general experience in ECDIS development and usage, meant that its terms could only be relatively vague.

Since then, SP 52 was updated (in 1990)(14) and now includes the following sections:

(a) Provisional Specifications for Chart Content and Display of ECDIS which includes the IMO Provisional Performance Standards for ECDIS (MSC Circ. 515);

(b) Appendix 1: Report of the IHO COE Working Group on updating the Electronic Chart;

(c) Appendix 2: Provisional Presentation Standards For ECDIS - by the IHO COE Working group on Colours and Symbols;

(d) Appendix 3: Glossary of terms related to ECDIS;

(e) Appendix 4: Data structure (Object Catalogue) and digitizing rules;

(f) Appendix 5: Data Exchange Format (DX90).

Substantial progress was made over this two year period in defining the function of ECDIS from an international point of view. Prototype systems have been or are being developed by several nations including Norway, the United States, Holland, Denmark and Canada to conform with the current standard. In most cases the stated objective of the developers is to test the validity of SP52 under operational conditions.

There follows a list of the major display requirements, as defined by the IHO, for an electronic chart display and information system (ECDIS) as they stood at the start of the project. The other requirements are discussed in the remainder of this section. The system developed at Liverpool deviates significantly from these specifications only where the choice of approach (interactive video) conflicts with the underlying assumption of the IHO; that ECDIS will generate its chart display image from digital data. The IHO requirements are printed in bold type with their section numbers from the specification.

3.1 Horizontal Datum

"only one horizontal datum should be used. In accordance with IHO TR B1.1 this will be WGS-84."

The horizontal datum employed in the Liverpool System is OSGB 36. The possibility of using WGS 84 exists provided that the datum shift printed on the chart is applied to GPS positions. The UK hydrographic office is still in the process of converting its charts to WGS84 and it must be emphasised that background digital data used to complement the interactive video display should also use the same datum as the printed charts.

3.2 Vertical Datum

"metres and decimetres" should be used on ECDIS displays

The units of depth in the Liverpool system are metres. This also forms part of the legend on the chart display

3.3 Projection

"it is preferred to conform with paper chart specification number (left blank) and use the Mercator projection, to which the mariner is accustomed for all charts of smaller scale than 1:50 000."

The projection conversions used in the Liverpool system are based on the Mercator projection. It is assumed that the paper charts photographed conform with the IHO paper chart specification.

3.4 Scale

"The manufacturer may give the navigator the ability to use intermediate scales, or zoom between scales. A prominent warning should be displayed in case of underscale or overscale. A graphical

index of the original charts and their scales should be shown on demand as a secondary display"

Change of scale (zoom) is described in the next section of this chapter and in detail in chapter 3.
A scale change warning is displayed when the user changes chart.
A graphical index to the charts was prototyped as part of the work on spatial data structures. See Plate 5

"a scale bar showing 0.1; 0.5; 1.0 nm etc should be available at the user's option when navigating on a large scale (1:80 000 and larger) chart. For smaller scale charts, a latitude bar must be shown on the border"

A scale bar is permanently displayed on the Liverpool chart.

3.5 Units to be used on ECDIS displays

Position: Lat/Lon (degrees, dec. degrees, minutes)
Depth: metres
Height: metres
Distance: nautical miles, decimal miles, metres
Speed: knots, decimal knots

The Liverpool system conforms fully with respect to the units employed.

3.6 Legend

"A legend of general information, applicable to the ship's position should be available for display on a separate display. This should contain at minimum:

	Liverpool
units for depth	conforms
units for height	printed on chart
scale of display	printed on chart
data quality indicator	not available
sounding datum	as paper chart
horizontal datum	as paper chart
safety contour value	currently 10m
magnetic variation	stored only
date and number of last update	stored only
date of issue of ENC"	as date of publication

4.1 Navigation

"The primary function of the ECDIS is navigation. Therefore the navigator should have the ability to execute all navigational routines which are currently done by hand on the paper chart"

The requirement for a conforming ECDIS to be 'capable of replacing the paper chart for navigation' is met fully by the system since it displays a paper chart image. As a consequence, the requirements concerning the ECDIS default display and minimum content are also met in full. Whether or not the display mechanism permits the same flexibility of use as a paper chart will need to be evaluated under long term testing. Nevertheless, any electronic chart using current technology will be forced to display a small area of the equivalent paper chart owing to hardware constraints on the screen size employed.

4.2 Display

"..a separate display may be used for look ahead, route planning and graphic and alphanumeric information"

"all display updates and refresh must occur over no more than 5 seconds"

A separate monochrome text screen is used for alphanumeric information. The chart display update is significantly shorter than 5 seconds (in fact not more than 1 second)

5.2 Default Display

"..Information that is vital for safe navigation should be on the screen when first switched on and always available as default display by a single operator action"

With the exception of the own-ship safety contour (all contours are shown), the paper chart images meet the IHO default display requirement in full.

5.3 Features and attributes

"By identifying features with a cursor on the graphics display all available attributes should be displayed either on the graphics display or on an alpha-numerics display"

The Liverpool system allows the user to access light data in this manner. The mechanism for doing this is capable of extension to other features as other data become available.

5.5 Symbols and Abbreviations

"..the size of symbols must be approximately 130% that of the paper chart symbols. Any zoom facility should allow the symbol size to remain constant as the scale of the display varies"

A characteristic of the interactive video approach is that symbol size and clarity diminish on the topographic reference frames. This gives a slightly blurred and unreadable quality to printed text. However, given that full coverage is provided in close-up, this disadvantage is offset by the ability to view a wider tract of the chart in one frame. This is considered important in ensuring that the user is not disoriented during chart operation. The colours and symbols used in the Liverpool ECDIS are unavoidably those of the paper chart. Graphical symbols used in chartwork were chosen for their clarity against the video background and do not therefore follow the IHO recommendations.

2.3.2 Other Differences between the Liverpool System and SP52

Since approved data has not been available to the project, it was not been possible to investigate the receipt, verification, update and conversion of HO produced ECDIS data as stipulated in Appendix 1 of

SP52 except at a superficial level. The provision of a comprehensive Quality Assurance mechanism to ensure the validity of the Electronic Chart Database (ECDB) is outside the scope of the current work.

The single greatest difference between the Liverpool system and that envisaged by IHO is in the relationship between existing paper chart data and electronic chart data. A cell structure is described in SP52 which will complement the 'vector digitised' display approach. Whilst formats do exist for the exchange of paper chart data by digital means, they appear to have been rejected as the basis for ECDIS Data in favour of the cell system. The use of cell-based data in conjunction with Interactive video will require careful matching of the two scales of compilation to ensure that smaller scale data than the displayed chart is not being used to generate safety information.

2.3.3 The Liverpool Chart Display

2.3.3.1 The Chart Display User Interface

The chart display can be operated in one of two modes - 'Passage Planning' and 'On-line Navigation'. See Plates 6 and 7 overleaf. Overall, the approach taken can be described as 'task-based'. That is, the system was designed with the navigation task in mind at all times. Specifically it was designed to support the user's existing mental models. For example, the controls associated with performing chartwork were made accessible through a single menu bar and were designed to be similar to the functions found on modern radars for line drawing, measuring ranges and bearings and accessing point data. The result is a chart display that is simple for a mariner to use

Plate 6 - The Passage Planning Menu

Plate 7 The Navigation Menu

after only minimal prior instruction.

2.3.3.1.1 Frame Design

The investigation of the optimum chart presentation occupied a significant amount of time during the early part of the project. The choice of display medium prevented the provision of continuous change of scale and scrolling thus the video frame sizes and overlap between photographic frames were critical design considerations. In the first videodisc produced, three levels of photography were provided. After consultation with potential users (members of staff at Liverpool), this number was reduced to two. One level is taken of frames with a vertical dimension of 10cm to provide maximum readability of chart detail (Plates 8 and 9) and a second level of 40cm frames provides an overall view of the charted topography (Plate 10), though without the small print on the chart being readable. The impression created by these arrangements is of a window upon the chart capable of being moved in both the vertical and horizontal dimensions as well as allowing changes of scale and detail.

2.3.3.1.2 Scrolling

Scrolling is the term coined within the group for inter-frame movements on a single chart. This is the mechanism by which the user traverses a series of frames in such a sequence that it creates the impression of a continuous underlying chart. The action of the cursor is connected to the scrolling mechanism such that the frame is changed if the cursor is moved beyond the frame edge. The layout of the frames on the videodisc and the photography itself had to be

Plate 8 Dover Harbour Before Upward Scrolling

Plate 9 Dover Harbour After Upward Scrolling

Plate 10 Dover Harbour (Topographic View)

designed so that the movements between frames were unobtrusive to the user, that is, after each movement, the user would quickly be able to re-orient his / her perception of the geographic area. The main means by which this was achieved was through the use of a substantial overlap between frames (two frames typically cover up to 60% of the same material - See Plates 8 and 9). Early experimental work established this as a good workable figure compromising between ease of use and economy in storage.

2.3.3.1.3 Inter-chart Movements

Various techniques were implemented and tested for changing chart. Separate controls for change of photographic level and change of chart scale were tried but eventually combined into two single function controls labelled simply 'in' and 'out'. As the user progresses through the various chart frames at a particular point of interest, the display switches automatically between photographic levels and chart scales. The ease of changing scale is considered to be of significant importance, being vastly simpler than in the traditional paper based system. Because the user's chartwork is implemented as an overlay, the passage plan does not need to be tied to specific charts, allowing the same work to be viewed against various chart backgrounds. This means though, that the coordinate systems of the different pieces of chart material have to be matched.

2.3.3.1.4 Chartwork and information access

The bulk of chartwork functions were provided for passage planning. In particular, a waypoint editor was devised which allows the user to construct a route using a trackerball controlled line-drawing facility. The waypoint editor also permits the easy addition, deletion, insertion and movement of waypoints. Range and bearing functions allow simple measurements to be made at all times. Whilst layering and selective display of chart features is not generally possible in the Liverpool system, software was prototyped to permit the 'interrogation' of chart features for supplementary information. Since layering is related to cluttering, the simple provision of data implemented in the Liverpool system should be sufficient. This makes the textual attributes of a chart feature available on the monochrome screen using the cursor and trackerball buttons at the printed symbol location. The chart cursor is currently used to access lights and buoys.

2.3.3.2 Navigation functions

All the navigational algorithms in section 8 of SP52 were prototyped during the project with the exception of positions calculation from hyperbolic curves of phase-difference or pseudo-ranging. Formulae to perform these calculations can be found in the Admiralty Manual of Hydrographic Surveying(41). Some of the functions specified were not included in the chart but formed part of the support software. An example is the Universal Transverse Mercator (UTM) grid conversion routines employed in the simulator interface. The system employs a 'pseudo true motion' approach for display of the own-ship symbol during navigation. This functions in the precise manner described in the specification.

Section 2.4 Navigation Task Analysis

2.4.1 Cognitive Processes

Conventionally, navigation falls into four distinct groups of tasks namely measuring, modelling, decision making and action. Together, these processes form a 'control loop' with the navigator being the instigator of activity within it. While the ship is in motion, this loop is continuously operational and separate navigators are involved at different times of the day and night in order to distribute the stressful workload efficiently. One of the most skilled parts of the navigator's task lies in the ability to develop an appropriate and accurate conceptual model of the ship's environment and the forces acting upon her using the chart, the radar and his visual perception of the view from the bridge windows. This aptitude is expressed in the problem solving expertise of an experienced mariner when faced with potential collision, or navigation in otherwise confined waters. The four mental processes carried out by the watchkeeper are now discussed.

2.4.1.2 Measuring

Much of traditional navigation is concerned with taking measurements and then converting these into useful information. The most important measuring instruments are the compass, log, chronometer, radar and echo sounder. Considerable resources have also been committed to providing a variety of fixed and floating aids to navigation which are designed to reduce the need to take navigational measurements directly from the natural environment. Most notable amongst the developments since the second world war was the introduction of a variety of electronic position fixing systems (EPFS). The most recent of these is the Global Positioning System (GPS) which now provides an almost continuous, worldwide, accurate position fixing capability to those ships fitted with receivers. It was suggested by the Seatrans Project(11), for reasons to be discussed later, that ECDIS is only made viable by the availability of GPS.

2.4.1.3 Modelling

The purpose of the chart is to supply a 2-dimensional model of the geographic environment suitable for navigation, thus an early objective of traditional navigation training is to develop the trainee's spatial reasoning skills to the point where reading a chart and relating its content to the view from the bridge is natural and intuitive. The chart also gives a framework for planning and control and is frequently referred to in establishing and pursuing the vessel's objectives. Radar supplements the static model given by the chart by providing a real-time display of much of the above-water environment including other ships. Radar data is, though, also treated with a degree of caution owing to its known limitations in discrimination. Whilst on passage, radar monitoring consumes relatively more of the mariner's time than interaction with the chart since it concerns the avoidance of frequently encountered, short term hazards. The modelling task is therefore one of continually piecing together an overall dynamic 'picture' from the chart, the radar and most importantly, the view from the bridge.

2.4.1.4 Decision making

A principal function of the watchkeeping officer is decision making. Almost all the technology present on the ship's bridge is there to support him in this task. There are two particular features of the human navigator which mean that he alone is capable of making the actual decisions which guide the ships progress - his eyes and his brain. The sensor and computer industries appear unlikely to be able to match these organs' capabilities for the foreseeable future. The purpose of the introduction of ECDIS / Integrated Bridge technology should therefore be to allow him to make use of these assets more effectively (thereby improving safety.) It is anticipated that the navigator will assume a primary role more concerned with managing the necessary deviations from an initial voyage plan than with data collection in future.

2.4.1.5 Action

Having collated and interpreted the information coming to him from the various bridge systems and formed a plan of response, the Officer of the Watch takes action. For example in collision avoidance this is generally through alterations of course and, less frequently, speed. He may also initiate communication with other vessels or shore authorities and must ensure that appropriate sound signals are made, shapes hoisted etc. He must also, in extreme circumstances, deal with internal or external emergencies. Depending on the employment of the vessel, he can also for example, be responsible for managing deck operations, working with aircraft, heaving and veering nets or caring for a large tow. That the Officer of the Watch is responsible for the overall safety of the ship is a well established principle of international maritime law. Sophisticated navigation systems can only make a contribution to his and the ship's effectiveness if he is well trained and motivated.

2.4.2 The Navigation Task

2.4.2.1 Description

Before a vessel puts to sea, the needs of safe and efficient navigation demand that a passage plan must be developed. The passage plan defines the precise route that will be followed. Information is collected to support the navigator in following the route and to assist him in interpreting the changes in his environment caused by the vessel's movement. The passage plan (in the form of courselines drawn upon a series of charts) generally represents an estimate of the most economical route in terms of distance and safety. The positioning of the courselines must be finely judged to allow proper margins of safety in collision and grounding avoidance and must also take account of traffic separation schemes and other regulations. The objective of the live navigation phase is generally to follow the route in a safe and reasonably precise manner subject to the occasional necessity to deviate from the track. In some approaches to integrated navigation track-following provides a measured output or 'controlled variable' in the form of cross-track error which is used by the autopilot. Modern, commercial air navigation is controlled by a model very close to this. The real process of marine navigation as opposed to this idealised one is, however, less simple and vessels generally spend relatively little time precisely on track. Instead, the passage plan acts as a baseline from which necessary departures are made and to which the navigator usually endeavours to return. Numerous forces act upon the vessel's progress. These are described in the following sub-sections:

2.4.2.2 Collision avoidance requirements

The presence of other vessels and other uncharted floating hazards creates a need to avoid collision as a second major activity 'superimposed' on the first. Current practice in collision avoidance consists of maintaining a visual lookout supported by the use of radar. Action to avoid collision is based on the International Regulations for Collision Prevention at Sea(33). Having established the safe geographical limits within which the vessel can be navigated to ensure safety from grounding, the collision avoidance task usually becomes the dominant navigational activity. It is therefore fair to assume that under all but the most exceptional circumstances, the electronic chart will be used in conjunction with radar. On the basis of experience in conventional navigation, it can be expected that the chart will be referred to at less frequent intervals than the radar display. However, the possibility of overlaying ARPA data on the chart could give significant insight into the intentions and likely actions of other vessels in the vicinity and thus prove of value in assessing collision avoidance strategies.

The importance of a visual lookout even in the context of recent developments in radar, integrated bridges and electronic charts cannot be stressed too highly. These innovations should be primarily directed towards the support of the visual watch.

2.4.2.3 Environmental factors

A vessel will also depart from her planned track unless certain environmental factors are taken into account in calculating the course to steer. These calculations may form part of the passage planning activity where they are based on a historical model used in prediction (eg the tide atlases) or they can be based on observations in terms of the 'drift' component of the ship motion dynamics. In some situations it may not be safe to wait for the currently observed drift to be calculated prior to applying course corrections (eg during harbour entry/exit) in which case the predicted 'Course to Steer' is important. This is particularly the case where a large tidal 'set' across the track will be encountered.

The main environmental factors to be considered are:

tidal streams;
currents;
wind;
waves and swell;

Drift is caused by the joint action of the above effects and prior knowledge of their likely magnitudes is generally required, particularly if the vessel is to be under pilotage. Indeed, from a planning point of view, the tide and predicted weather can determine whether a particular voyage is feasible at all. The degree to which the navigator can optimise his plan with respect to these phenomena is very largely governed by the type of navigation he is engaged in.

Generally, (subject to the availability of time) the more time available, the more he can do. For example, navigators of smaller craft will wait for favourable tide and weather if at all possible; on a larger scale, weather routing of ships has proved effective in saving fuel and reducing damage to vessels crossing the Atlantic. Purely from a track keeping point of view, given the present availability of high accuracy position fixing systems (better than 5 metres d.r.m.s.) these factors can be readily compensated.

2.4.2.4 Breakdowns and errors

The equipment used in navigation control is subject to the normal laws of probability of failure. Generally, even for equipment ruggedised to withstand the rigours of use at sea, the likelihood of breakdowns remains quite high. In some cases, the failure of one sensor can severely degrade the performance of others. For example, gyro compasses are particularly prone to slow deterioration of performance after a breakdown leading to a loss of gyro stabilisation of the radar, poor course keeping etc. An essential part of conventional navigation is therefore a requirement for the watchkeeper to continually monitor and cross check the bridge instruments for signs of performance degradation. The new Integrated Bridge technology must also take proper account of this.

2.4.2.5 Unpredictable events and emergencies.

Occasionally the ship may be required to participate in activities caused by events outside her normal remit and which cannot be predicted in advance (eg Search and Rescue operations).

2.4.2.6 Other Factors affecting human watchkeeping

Although human factors do not affect track keeping directly, they are an important influence on the degree of control being exercised at any one time. A detailed treatment of ergonomics is outside the present scope of this work. However, the subject is of significant importance to marine navigation. Each of the following can be expected to affect the normal course of a vessel's operation, it is important that they do not adversely concern the overall navigation. The lists are intended to be illustrative only.

Environmental factors which can reduce human performance:

- day/night conditions
- reductions in visibility eg fog.
- rough weather

Other factors which can reduce human performance

- stress
- fatigue
- inexperience
- 'information overload'

It is important therefore that account is taken of 'human factors' during integrated bridge / electronic chart hardware and software design and efforts made to: (a) take them into account and; (b) ensure that the Human Computer Interface minimises their impact on the navigation control process.

The next 2 sections describe the type of model upon which the design of the passage planning and on-line navigation software was based.

Section 2.5 The Specification of a Passage Planning Model

For the purposes of this work, the Admiralty Manual of Navigation(40) is considered authoritative. It opens its chapter on Passage Planning with the following comments:

"Navigational passages must be carefully planned. Everyone is liable to make mistakes; over three quarters of all groundings are attributable to human error of some kind. A sound passage plan may not prevent a grounding, but it does reduce the chances of making mistakes."

It can be seen that the Admiralty Manual considers safety to be the prime objective in navigational planning. However, depending on a vessel's trade, there can be a wide variety of secondary aims. Whilst each user of an electronic chart will have a different set of objectives, there is a common code of navigational practice laid down both formally and informally which all mariners are supposed to use. The same basic principles apply whether the vessel being navigated is a supertanker or a yacht. The ultimate objective of a systems analysis exercise of this type is thus to capture the essence of the conventional procedures and expertise in software.

The role of the chart in passage planning is principally to act as the topographic planning reference for the avoidance of grounding and to act as a means of accessing other data visually. The orthogonal properties of chart projections allow compass courses etc to be plotted readily. In contrast, during live navigation, the chart has traditionally provided the framework for visual and radio assisted fixing with data access being of secondary importance. These considerations emphasise again the need for different functions to be provided in the passage planning and monitoring modes. The traditional paper chart is predominantly an instrument for visual navigation and this has determined many of its features. The application of computer technology to the processes and information involved, including satellite positioning, mean that whilst the chart's basic roles remain the same as before, its presentation can not only safely change but also be improved.

The following, taken from the Admiralty Manual, both describes the traditional method of setting about the task of passage planning and also serves as a starting point for a description of the passage planning software required of a comprehensive ECDIS navigation system.

2.5.1 The Admiralty specification for Passage Planning

1. All the charts and publications necessary for the passage must be selected and assembled. They must be up to date.

2. Other items of information that may be required are:

a) Distance between ports of departure and destination;

b) The likely set and drift to be experienced resulting from the combined effects of tidal stream, current and surface drift;

c) Times and heights of tide along the route;

d) Advice and recommendations along the route obtainable from the Sailing Directions;

e) Routeing and traffic separation schemes to be encountered along the route;

f) Past, present and likely future weather; in the event of bad weather, the likely diversionary ports and anchorages;

g) Duration of daylight and darkness; times of sunset and sunrise, etc;

h) Radio aids available during the passage;

i) Likely ship's draught, fore and aft, at the beginning, during and at the end of the passage, and the requirements for under-keel clearance;

j) Search and Rescue arrangements along the route.

3. An appraisal of the passage is then carried out and the chart and publications annotated.

4. The route is now chosen and drawn on the chart. The following factors may also require consideration:

a) Times of departure and arrival;

b) The possibility of fog or poor visibility;

c) The presence of fishing vessels / fleets;

d) Passages through narrow or ill-lit channels;

e) Focal points for shipping;

f) Speed, endurance and economical steaming;

g) Clearance from the coast;

h) Territorial limits;

i) Mined areas;

j) Special operational requirements not covered by the above. (These would tend to relate to non freight-carrying vessels)

The remainder of the chapter in reference(40) gives more detailed guidance on some of the above. It can however be seen that the list of requirements is substantial.

2.5.2 System requirements for Passage planning

In order to comply with the Admiralty Manual, the system requirements for passage planning are stated below. Those included in the IHO ECDIS specification are marked with an asterisk (the IHO are less specific at present about the implementation of navigation functions than about the chart presentation itself) .

*1. A comprehensive waypoint editor with line drawing; waypoint insertion, deletion, amendment and addition functions.

*2. The ability to annotate the ship's track either by hand or automatically.

3. Track validation function (manual and automatic)

4. Tidal Height, Stream and course to steer calculations

5. Weather forecast and routing software

6. Speed, time and distance calculation software

7. Bunkering, ballasting, stability and draught calculations.

8. Database access to Sailing Directions along the route.

9. Database access to Search and Rescue facility listings.

10. Local and Area Navigation Warnings.

11. Functions to notify user of distances from danger and navigation aid coverage along the route.

12. Sunrise/Sunset, Moonrise/Moonset Calculations.

Some or all of these could be implemented directly in an ECDIS navigation system, although it should be noted that this list is significantly beyond current ECDIS requirements. The electronic chart and the supporting project software is intended to reflect these requirements rather than simply those specified by IHO.

In practice, although a passage plan is invariably prepared prior to a voyage, it is possible that this will be modified on more than one occasion whilst the ship is at sea. Therefore, whilst passage planning was treated as a separate topic in this thesis and within the software, it must be recognised that revision and re-planning are also a fundamental part of on-line navigation. The principal benefit gained from a functional separation is that there should never be any doubt as to what activity is being undertaken whilst the system is in use. In any event, a core of functionality common to all modes and states of the system ensures that own-ship safety is constantly monitored.

Section 2.6 The Specification of an On-Line Navigation Model

The Admiralty Manual of Navigation is unambiguous in its specification of requirements for the navigation of ships under conventional circumstances and it therefore provides a set of clear guidelines from which many requirements for a comprehensive ECDIS navigation system could be derived. The requirements for navigational decision support vary considerably between different sea areas but can be broadly classified according to the vessel's navigational activity. Pilotage, coastal and ocean navigation were therefore deemed to require separate treatment during the software design and are also discussed separately in this thesis.

2.6.1 The Execution of Pilotage

The Admiralty Manual of Navigation states:

"The essence of a good plan is knowing the limits within which the ship may be navigated in safety. The essential questions which the Navigating Officer must be able to answer at all times during a pilotage passage are:

1. Is the ship on track?
2. If not, where is the ship in relation to the track and what steps are being taken to regain it?
3. How close is the ship to danger?
4. How far is it to the next alteration of course?
5. Are the tidal streams and depths of water as predicted? "

Whilst similar in principle to the issues of concern in passage execution described above, it can be seen that these questions are of great immediacy in preventing grounding.

2.6.2 The Execution of the Passage Plan (Coastal)

The Admiralty Manual States:

'The execution of the passage plan must involve a well organised bridge procedure to detect any error in sufficient time to prevent a grounding' (page 316)

This statement embodies two principles that must be reflected in ECDIS design. The first concerns 'bridge procedure'. This largely concerns the monitoring of the ship's speed and maximum permissible deviation from the track in relation to the frequency of fixing. The accuracy of fixing and the reliability of equipment also need to be monitored. The second principle can be stated simply: If it appears that the first principle is about to be broken in such a way that gives rise to the danger of grounding, then the user must be warned immediately.

"Information obtained from radio aids can be misleading and should always be checked whenever possible with position lines or fixes from other sources"

The Admiralty Manual of Navigation is principally concerned with 'visual' navigation; however it states that a back-up method of fixing should always be used. This is a wise axiom that should be followed in ECDIS even when highly accurate electronic position fixing systems are in use. This would allow sudden gross errors or gradual deteriorations in performance to be detected.

"Clearing marks and bearings, vertical and horizontal danger angles and radar clearing ranges may be used to keep clear of danger"

Stated simply, this implies a requirement for an ECDIS design to embody the means for defining and monitoring the necessary safety margins to approach and pass dangers safely.

2.6.3 Ocean Navigation

Ocean Navigation presents other interesting possibilities. The danger to ships from grounding is substantially less in deep water navigation although losses due to foundering in heavy weather continue. The challenge in Ocean Navigation is to ensure that fuel consumption and weather damage are minimised through careful use of appropriate course generation algorithms based on the use of Great Circle and Composite Track navigation combined with weather routeing. Ocean navigation was not dealt with significantly in this project.

2.6.4 System Requirements for On-Line Navigation

The system requirements devised by the project for On-line navigation (To comply with the Admiralty Manual) are stated below. Those included in the IHO ECDIS specification are marked with an asterisk. Their main navigational requirement is that:

"The navigator should have the ability to execute all navigational routines which are currently done by hand on the paper chart, including the addition of navigator's notes."

The facilities required are:

(a) Passage Planning facilities;

*(b) Electronic Range and Bearing Lines (ERBLs) fixed and free;

*(c) Map line drawing facilities for 'margins of safety';

*(d) Position logging and event recording;

*(e) Facility to add navigator's notes;

(f) Instrument comparison software for error detection;

(g) On-line 'Help'.

Again, to comply with currently accepted practice in navigation and to extend the functionality of the system to the point where it can provide useful decision support, it is suggested that a continuous monitoring loop is required which will perform some if not all of the following:

1. Update of chart display during own-ship motion;
2. Safety checks on own-ship current position;
3. Safety check on projected Ground Track / EP;
4. Detection and analysis of radar targets in vicinity (to be normally provided by radar);
5. Database access to external regulations;
6. Cross track error calculation + action to regain;
7. Speed/time distance calculations;
8. Database access to external communications requirements;
9. 'Look ahead' software designed to anticipate the requirements for action in future;
10. Visual, Radar and Astro Navigation facilities to back up satellite / electronic position fixing in the event of failure.

Proper account would also have to be taken of the transition from one type of navigation to the next. It is frequently the case that accidents attributable to human error are often caused in part or in whole by the failure of the Bridge to adequately prepare for the next phase in a vessel's voyage. Pilotage, Coastal and Ocean navigation have all been mentioned as 'navigational contexts' in the preceding sections, however it must also be stated that poor visibility and heavy weather will also substantially affect the conduct of the ship under each set of circumstances. A set of check-off lists (as are currently used on conventional bridges) could be activated by the look ahead software to assist the navigator in preparing the ship to transfer from one state to the next.

2.6.5 Summary of Chapter 2

The traditional role of the paper chart in the live navigation phase of a voyage is to provide the reference surface upon which progress is measured. Position fixing by compass bearings and astronomical observations provided the main means of achieving this until well into this century. It was for these methods that the paper chart was originally designed. The advent of sophisticated electronic position fixing systems such as Radar, Decca and Loran has diminished this role; the possibilities of computerisation and the worldwide use of precise systems such as GPS look set to redefine the function of the chart.

The most obvious requirement of any electronic chart beyond the presentation of the chart image is an ability to perform chartwork.

This was implemented in the form of a 'Waypoint Editor', a number of functions for measuring ranges and bearings and listing and annotation routines. Simulator testing has shown this approach to be valid although minor reservations have been expressed concerning some aspects of the chart handling. Against any disadvantages of handling the frames comprising an individual chart must be set the ease of performing chartwork in a general sense. This partly reflects the true nature of the massive change being attempted in converting 'analogue' paper charts to a 'digital' form. An expanded functional specification for an advanced version of an electronic chart system was described by reference to the established models for navigation. Notwithstanding the experimental nature of the Liverpool prototype, it is possible to see that it parallels the IHO specifications sufficiently closely to allow it to be developed further into a full ECDIS.

Much of the further work in this project was concerned with providing new, more rigorous techniques for the interpretation of spatially referenced data than the simply visual and it is therefore considered that as these become routinely available and trusted, the large Admiralty chart will gradually become a museum piece. The next chapter discusses the implementation of the electronic chart and its associated software in detail.

New References - Chapter 2.

(40) Her Majesty's Stationery Office (HMSO).(1987), 'The Admiralty Manual of Navigation - BR45' Volume 1. Ministry of Defence (Navy) London.

(41) Her Majesty's Stationery Office (HMSO) (1962). 'The Admiralty Manual of Hydrographic Surveying'. Ministry of Defence (Navy) London.

(42) Howse D. and Sanderson M. 1973 'The Sea Chart' McGraw Hill Book Company. New York.

(43) U.K Hydrographic Office 'Catalogue of Admiralty Charts and Publications' MOD (UK) Navy. HMSO.

(44) International Hydrographic Organisation Special Publication 52, 'Draft Specification (Third) for Electronic Chart Display and Information Systems (ECDIS)', October 1988, Monaco.

CHAPTER 3

Prototype Development

Chapter 3

Prototype Development

This chapter focusses on the development of the Electronic Chart and consists of the following sections:

3.1 Display Accuracy and Positioning - This section describes the development of the interactive video chart display technique including its photography, the frame handling and chart accuracy.

3.2 Data Preparation and Chart Display Support - This section discusses the preparation of video data for use and how other data supporting the chart is prepared.

3.3 Navigational Utilities and Algorithms - This section describes the navigational tools provided for the user. It also describes the external communications developed for own ship and target display.

3.4 Interaction with Spatial Data - This section discusses the principles behind and application of spatial data structures in the electronic chart. Each sub-section first describes the principles behind the method discussed and secondly, shows how it was applied to the electronic chart.

3.5 The IHO DX90 Data Structure - This section discusses work undertaken in decoding and displaying the test graphic data supplied by the International Hydrographic Office with the DX90 definition.

Section 3.1 Display Accuracy and Positioning.

Much of the emphasis of the early part of the work was concerned with creating a satisfactory and usable chart display from still video photographs. A common feature of all electronic charts is that they can only provide a small 'window' upon the total chart data available. In other words, currently available technology does not easily permit the electronic display of a volume of data equivalent in size to a paper chart.

Development effort on the interactive video display proceeded sequentially in the order of the subsections below. Initial work was based on chart frames supplied by Action Information (Management) Ltd. Further work was based on two additional sets of photography prepared at Liverpool. These each exploited the experience gained on previous occasions.

3.1.1 Photographic Design

The design of the photography which was used to capture the frames held on videodisc proceeded through three distinct stages.
The first set of frames supplied by AI(M) were used to evaluate frame size and overlap parameters and provided a basis from which work on the frame handling could proceed. A second set of photography was then prepared of the Irish Sea charts adjacent to Liverpool. This set of photography, whilst providing further useful experience suffered from severe limitations owing to the small number of frames that could be scanned in a single set of camera movements. The third and

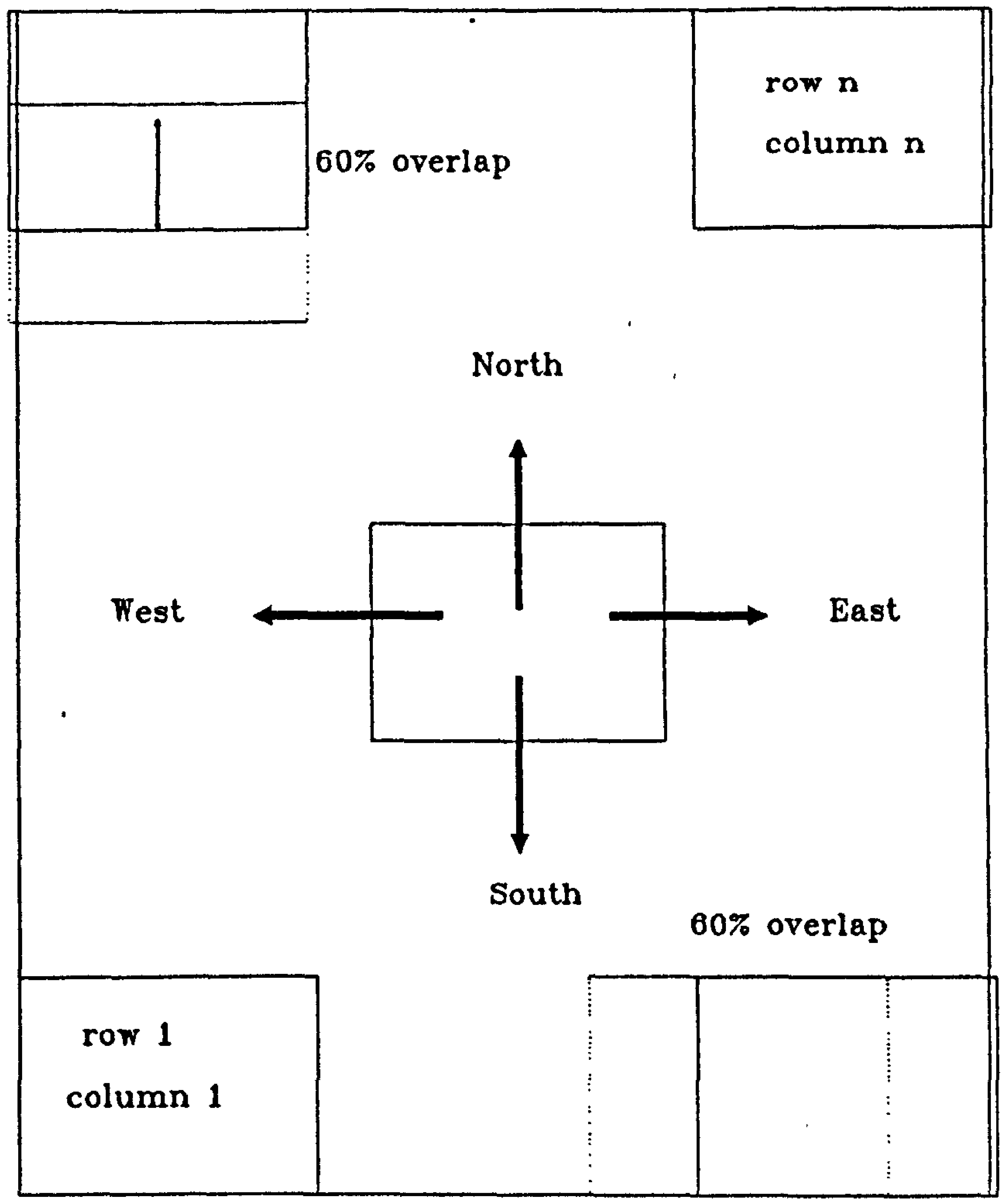
final set of photography covered the southern North Sea and Dover Strait. It overcame many of the earlier problems and has provided a satisfactory basis for the remainder of the project's work. The video data capture method is described in section 3.2.

3.1.1.1 Preliminary Evaluation of the Photography

The evaluation of the optimum photographic parameters was conducted in conjunction with senior members of the Navigation Teaching Staff at Liverpool. The preferences expressed with regard to the photography found most comfortable to use turned out to be consistent and were thus considered to be a reliable set of indicators from which further display design could proceed. Indeed, the majority of subjects indicated that the 'window' approach could satisfy their requirements given that more than one 'level' of photography was present. Therefore, a design based on two sets of photography per chart emerged. The first set consisted of frames with a vertical side of approximately 10cm on the paper chart. These allow the user to read all text, numbers and symbols clearly. The second set of frames have a vertical side of approximately 40cm giving the user the opportunity to see an overview of the chart topography and the relative density of contours, soundings and other symbology. Whilst these frames do not permit fine detail to be read, they give a generally adequate view of the location of hazards. The only reservation expressed concerned the fact that a potential user of this type of display would need to be generally familiar with paper charts in order to make best use of it.

Figure 3.1 shows the basic photographic design and how it relates to

Photographic Design and Frame Scrolling



This diagram shows the conventions adopted for the frame scrolling design.

The frames are referred to by row and column number in the scrolling algorithm.

The horizontal and vertical frame overlaps of 60% are also shown.

The inter-frame offset for latitude is also shown in the top left of the diagram.

Fig. 3.1

the frame scrolling.

The processes of video data capture and preparation are closely related to the display functionality seen by the user. This includes the accuracy of the display from a mathematical perspective. The remainder of this section looks first at how data for the chart display was prepared, then at how it was used.

Section 3.2 Data Preparation and Chart Display Support.

The disc production details and the subsequent scaling of the chart frames are obviously closely related.

3.2.1 Video Data Capture

A large Rostrum Camera was used to take the chart photographs. This is a piece of equipment used by commercial photographers for careful control of still and moving picture sequences. The object to be photographed is normally moved under computer control; the camera head remains static. The charts to be photographed were placed on a motor driven moving table the motion of which was computer controlled in the x and y directions.

The photographic sequence (see figure 3.1) taken of a chart starts in the bottom left hand corner and moves from left to right until the right hand chart edge is met. The photographs are overlapped by 60%. The next row of photographs commences at a point 30% of a frame higher up the chart and proceeds in a leftwards direction until the left hand edge of the chart is met again. The next row commences 30%

of a row higher still and the process is repeated until the entire chart is captured on film. Each contiguous set of photographs is known as a block. The chart data capture sequence accounts for all types of British Admiralty Chart including the various sheet sizes and landscape and portrait orientations. Hence a program was written to assist in calculating the required overlap, frame numbers etc for the photographer.

3.2.2 River Charts, Insets and Plans

Whilst many of the charts published by the British Hydrographic Office consist of a single sheet of data, an equal number are complicated by the inclusion of insets, irregularly shaped sections and port plans. Fine examples are the charts of the Manchester Ship Canal, The Menai Strait and the Port of London. Each separate section was dealt with as a separate block of photography, however, the proper treatment of these added considerably to the overall data capture effort. Scope remains for improving the user interface to these sets of video data. Nevertheless, improved performance of the chart under pilotage conditions would result, giving rise to significant navigational benefits.

Finally, the developed positive images are transferred to videotape by a process known as 'tele-cine transfer'. Thereafter, the videodisc is produced from the tape.

See figure 3.2 of the video data capture process

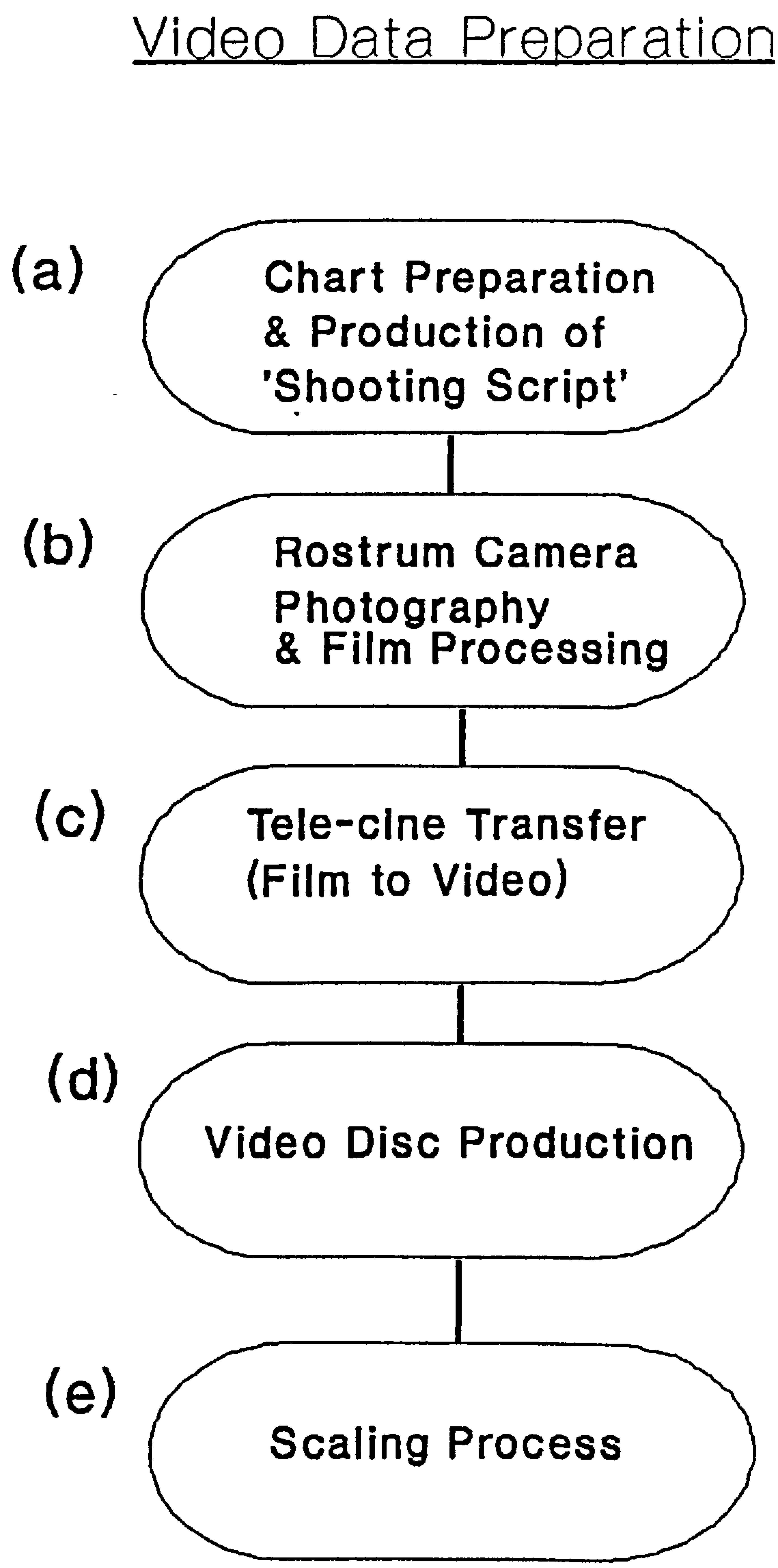

Video Data Preparation
(a)
Chart Preparation & Production of 'Shooting Script'
(b)
Rostrum Camera Photography & Film Processing
(c)
Tele-cine Transfer (Film to Video)
(d)
Video Disc Production
(e)
Scaling Process

Fig. 3.2

3.2.3 Scaling

Each block of photography has a data record associated with it containing the information required by the chart software to provide an accurate display. Prior to use in the chart, it is therefore necessary to prepare this information. A purpose written piece of software is used. The process is known as "scaling" within the group.

Figure 3.3 illustrates the scaling process. Table 3.1 shows the storage format of the resulting data

3.2.4 The Scaling Data

Each of the fields in table 3.1 is necessary to the correct operation of the chart as follows

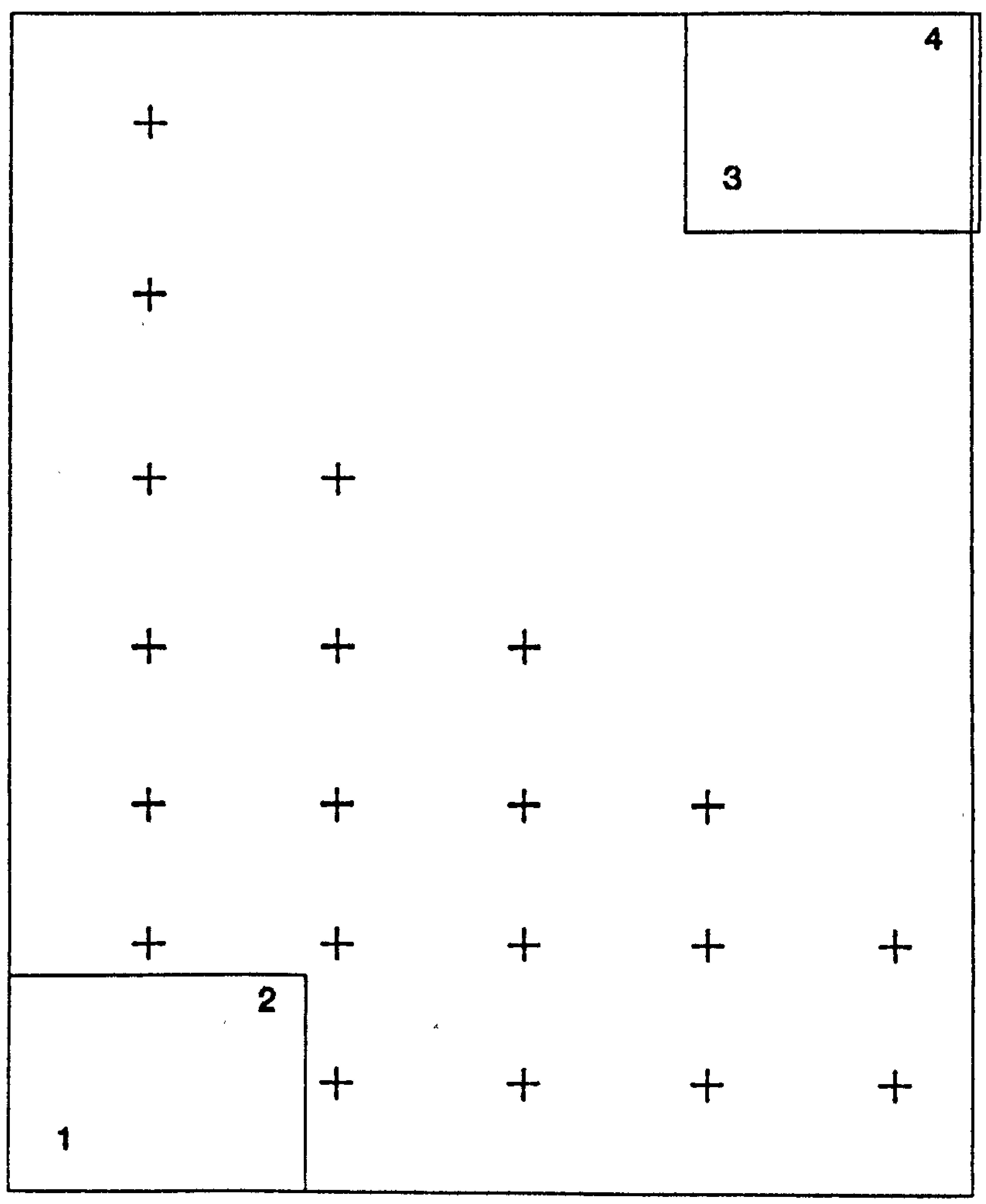
Block Name

This provides a unique key which can be used to identify the individual blocks of photography. The source chart number is used with a letter suffix. Eg block 1892a is the block of level 1 frames on chart 1892 ("Dover Strait - Southern Portion").

Chart Number

The chart number is the relation used to key into a second table of records containing 'meta data' relating to each chart (See section 3.2.6). These include the last correction, date of publication projection etc.

Frame Scaling



The frame centres are marked with a +.
The geographic coordinates of positions 1,2,3,4
are used to calculate:
(a) Mean x and y scaling factors
(b) Inter-frame offsets in x and y directions
(c) The geographic limits of the video presentation
as described in the main text.

Fig. 3.3

Scaling Data Record

Data Type	Description
char block_name[10];	- Unique Key
char chart_number[10];	- Source chart number
int level;	- Photographic level
long scale;	- Scale Denominator eg 75000
int rows;	- Number of rows of frames in
int columns;	- Number of columns of frames in block
unsigned startframe;	- Starting frame number of block
double sfxscale;	- Ratio: pixels per minute of longitude
double sfyscale;	- Ratio: pixels per meridional part
double lat_pos_1; double long_pos_1;	- Bottom left corner of block in Lat/Lon
double lat_pos_2; double long_pos_2;	- Top right corner of block in Lat/Lon
double x_offset; double y_offset;	- distance between frame centres expressed in minutes of longitude & meridional parts

The total record length is 96 bytes.

Table 3.1

Photographic level

The photographic level describes which of the two types of frames (Wide angle or close up) make up the block - it is used by the zoom algorithm.

Scale

This is a single long integer value denoting the denominator of the scale ratio. eg 75000 for a chart of scale 1:75000. This field is used by the change of chart algorithm and, for example, to determine which version of the own ship symbol to use. In future, it could be used to determine whether the chart should be operated in pilotage, coastal or ocean going mode.

Rows and Columns

These are the total numbers of 'rows' and 'columns' of photographs in the block - as previously discussed.

Start Frame

This is the frame number on the videodisc which marks the start of the photographic block. This value is essential to the correct operation of the frame handling software.

X scale factor

This is an absolute value defining the number of pixels which represent one minute of longitude on the interactive video chart display. This value is essential to the correct and accurate overlay of computer graphics on the displayed chart image because it is required to measure longitude units from the left hand edge of the frame on display.

Y scale factor

This is the absolute value defining the number of pixels which represent one Meridional Part on the interactive video chart display and is similar to the x scale factor mentioned above.

Bottom Left and Top right positions

These are used as part of the search criteria for a new block of photography in the zoom and change of chart algorithm. ie to ensure that the block covers the position requested.

X and Y offsets

These are the distances in minutes of longitude and meridional parts between frame centres in the X and Y directions respectively. These values are used to update the bottom left hand corner position of the frame on display during scrolling operations. This is the position from which the cursor lat/long position is measured during scrolling.

3.2.5 Scaling Errors

Whilst in general, the accuracy requirements have been met, certain errors are occasionally found during scaling and subsequent quality checks. Some of these can be eliminated by re-scaling, others will require further software development to eliminate them.

Errors to which the scaling process is prone are as follows:

1) Occasional gross errors in the photography. These have been seen in a few rare cases. The error involved can be as great as 1cm on the chart. The solution is to treat the incorrect portion of the chart as a separate block. More precise control of the rostrum camera using a modification to its software would assist in eliminating this problem.

2) Human error during scaling. This is sometimes caused by incorrect keyboard entry of positions or errors in measurements taken on the chart. The indistinctness of some chart symbols, particularly when viewed on the level 2 frames contributes to this. However, most of these errors can normally be cured by re-scaling the block.

3) Rounding errors from floating point to integer conversions. It is unavoidable that a single pixel on a level 2 frame has a greater geographical area than a single pixel on a level 1 frame. During zoom operations from level 2 to level 1, ambiguity can therefore occur in resetting the cursor position. This might be solved by estimating the geographic centres of the pixels on the level 2 frames.

4) Incorrect registration of the video image. In the case of one videodisc player (Sony LD1500), the video image was not stable in its horizontal alignment and appeared to creep upwards between frame accesses. The image would then appear to slip back to its initial position after approximately 20 frames had been displayed. This can only be cured by precision alignment of the playback hardware.

5) Errors in the chart. Charts are subject to distort if folded, subjected to extremes of temperature and humidity and if handled roughly. Every effort was made to avoid these situations.

6) Note: Charts on the Gnomonic and Transverse Mercator Projections scaled using a process based solely on the Mercator projection will contain errors at the top left and bottom right of the chart in proportion to the projection convergence. This can be eliminated using the correct algorithms in the scaling software or by the use of a correction factor.

3.2.6 Meta Data

The information bars at the top and bottom of the chart display (See Plate 11) use data prepared in support of the primary display. Each chart has a complete set of the following data associated with it. The data is retrieved using chart number as the key. Table 3.2 shows the contents of a typical meta data table.

The data files containing the frame constants and 'meta data' are organised as a sequential file accessed using a B+ tree based commercial software package - 'Btrieve'(45).

Plate 11 Meta Data, Scale Bar and Track History

Plate 12 Text Display of Live Navigation Data

Meta Data Storage Format

Data field	Typical Value
Chart Number	2
Chart title	British Isles
Date of last correction	2/8/92
Date of pub. or last new edition	31/5/90
Chart Projection	Mercator
Horizontal datum in use	OSGB36
Units of depth eg fathoms / metres	Metres
IALA Buoyage system in use	Region A
Current mean magnetic variation	3 (deg) W
Datum shifts in minutes North	0.10N
and East	0.08E

Table 3.2

3.2.7 Frame Handling

Having established the frame sizes and overlaps capable of providing a usable display of the chart with economical storage, further effort concentrated on providing the user with the facilities required to move smoothly between frames, both laterally (N,S,E,W) within the current display (termed scrolling) and between blocks of photography (zoom and change of chart).

3.2.7.1 "Scrolling"

See figure 3.1

Scrolling, as stated above, is the term given to the action of moving laterally within the displayed chart. The effect is one of a sequence of images being presented to the user which gives the impression of viewing the chart through an 'electronic window'. The control of the frame sequence is given to a cursor which the user operates by means of the trackerball.

Given that the frames themselves are arranged sequentially on the videodisc, it was necessary to derive algorithms capable of calculating the adjacent frame number to a displayed frame in any of the four Cardinal directions (North, South, East, West).
Calculation of frame numbers moving East and West is trivial (basically amounting to addition or subtraction of 1). Moving North and South is less straightforward owing to the design of the photography and depends on whether or not the current row number

within the block is odd or even.

The algorithm, presented in pseudo-code is given in figure 3.4

3.2.7.2 "Zoom" and "Change of Chart"

See figure 3.5

"Zoom" is the term given to the action of moving between the level 1 and level 2 frames of a particular chart (ie between the wide angle topographic frames and the detailed, small-field frames). "Change of Chart" is the term given to the situation where a zoom request cannot be met within the chart on display. In this case, a larger or smaller scale chart covering the area of interest is displayed. The cursor is again required to be within one pixel of the previously displayed position. (This is usually tested using a major light or other prominent feature).
The current implementation uses the same algorithm for both zooming and change of chart. This, however, is prone to causing ambiguity in terms of which block of photography is actually retrieved. For example, a zoom operation can result in a different chart being selected if it overlaps the current cursor position. It is therefore suggested that change of chart might, in future, be handled using the 2D tree algorithms described later.

The zoom algorithm operates as follows:

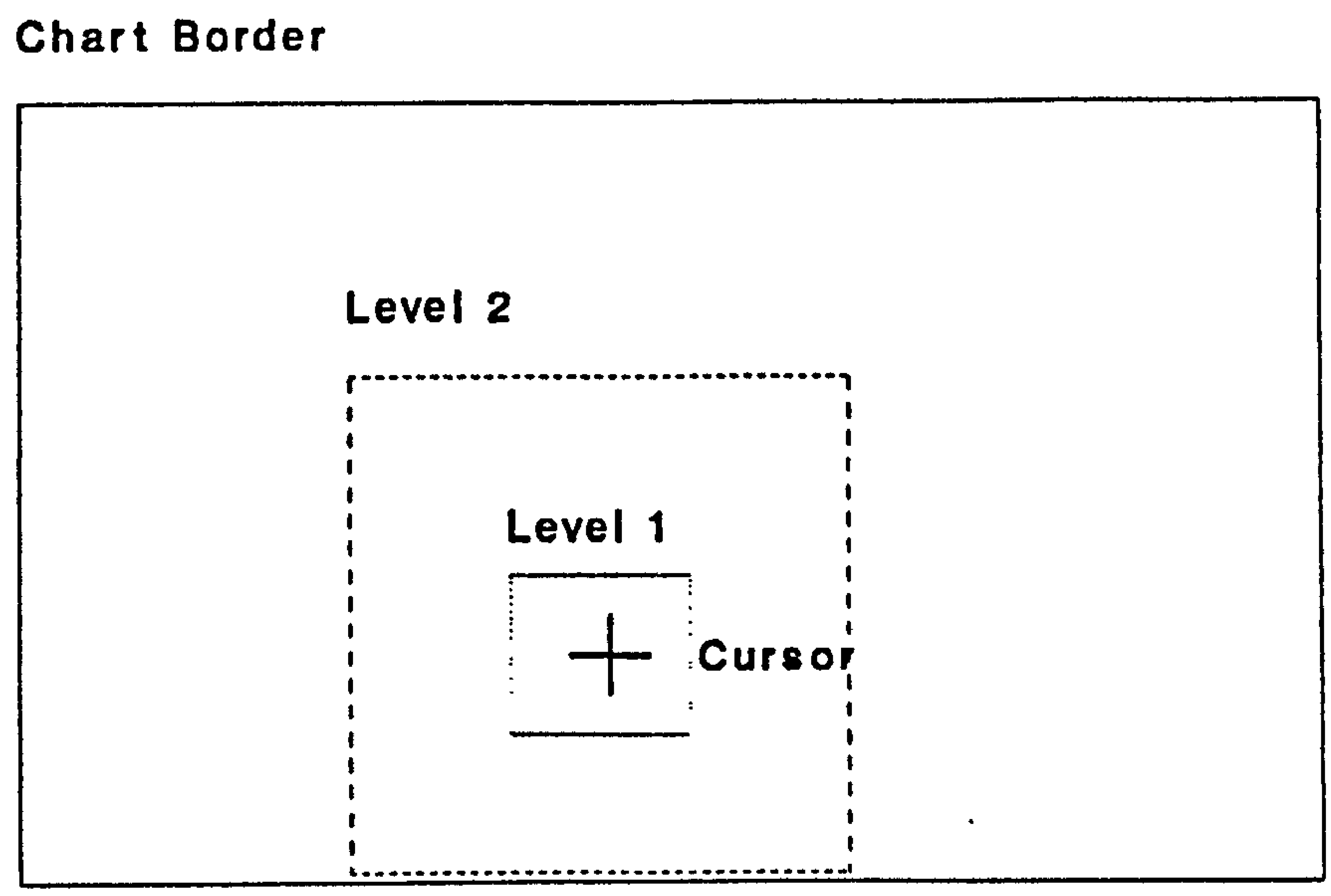
1. The Latitude of the cursor is used to retrieve the first block whose latitude is less than that of the cursor.

'C' Pseudo-Code for Scrolling

```
 switch (direction)
 {
 case NORTH:    /*upwards*/
       if (current_row==block_rows)
       {
       return (0);
       }
    if(current_row:ODD) /*if current row odd*/
    {
    current_frame=
    current_frame + ((block_columns+(block_columns-1)) -
    2 *( current_column -1 ) ) ;
    }
    else{                        /*even*/
    current_frame=current_frame + (current_column +
                      (current_column - 1));
         }
 current_row+=1;
 case SOUTH:    /*downwards*/
       if (cur_row==1)
       {
       return (0);
       }
    if(cur_row%2) /*if current row odd*/
    {
    current_frame=current_frame - (current_column +
                      (current_column - 1));
    }
    else{
    current_frame =
    current_frame-((block_columns+(block_columns-1))
                  - 2*(current_column-1));
    }
 cur_row-=1;
 }
}
```

Figure 3.4

Frame Handling: Zoom Operations



Where a zoom operation is requested within a single chart ie to move between Level 1 and Level 2 of the photography the frame selection proceeds as follows:

1. The lat/lon position of the cursor is used to as the basis for frame selection.
2. The row and column number of the required frame are calculated using the known total number of rows and columns in the photographic block and the lat/lon chart limits (This overcomes the need to know the precise frame overlap)
3. Once located, the frame number is calculated and the frame displayed
4. The datum position of the frame is updated.
5. The correct cursor location is calculated and the frame is displayed.

2. This block is tested against the following criteria

a) block corners enclose the cursor?

b) photographic level correct?

c) chart scale correct?

3. If any of these criteria are not met, the next block in the sequence is obtained and again, it is tested against the criteria above.

4. The process is repeated until a satisfactory block is obtained.

A further function then calculates the correct frame number to display based on the cursor's geographic position, the bottom left corner position of the new block and the distance between frame centres within the block. It is given in figure 3.6 in shortened pseudocode form.

3.2.8 Further Evaluation of the Frame Handling

A number of possible schemes were tested relating to both zoom and change of chart. Initially for example, the chart would be changed when the user scrolled off the edge of the chart on display. Confusion tended to arise as to the scale of the new chart presented especially if the user had not specifically intended to change chart. Occasionally users had some difficulty in finding their previous location. Thereafter, change of chart was allowed only by a deliberate user action. This seems to have been acceptable to the majority of users since.

Find-frame Pseudo-Code

```
findframe(lat,lon)
double lat,lon; /*lat in merparts ,long in minutes*/
{
//first calculate the row and column numbers of the
 required frame

        calculate_row()

        calculate_column()

//now calculate the frame datum position. ie its bottom
  left corner

        correct_frame_origin()

//calculate the new frame number

        calculate_frame(cur_row,block_start_frame,
                               max_ columns, cur_ col);

// and now display the frame

        fast_display_frame(frame);

// now we require to reposition the cursor on the
   position requested

        reset_cursor(position);

return;
}
```

Fig. 3.6

3.2.9 Positional Accuracy

The chart accuracy required for navigation was stated to be as follows:

"The cursor is to be displayed no further than one pixel in any direction from the geographic position displayed numerically on the chart screen"

The technology employed in displaying the chart allows normal VGA graphics to be overlaid on the video presentation, thus the relationship between the projection grid coordinates of the chart and the VGA raster needed to be established. The specified accuracy was achieved on charts produced on the Mercator projection and the required formulae for the other common projections were investigated and found to produce similar theoretical results.

3.2.9.1 The Mercator Projection

This is the standard projection used on charts with scales smaller than 1:50 000. It yields charts that are rectangular in shape and therefore easily photographed and prepared for use in the interactive video context. A characteristic of this projection is that at any point, the scale is the same in any direction, ie it is orthomorphic and thus can be used for navigation. Furthermore, bearings or rhumb lines are represented as straight lines giving the particularly convenient property which allows the mariner to mark off courses or bearings with a ruler . However, to allow for North - South distortion, the latitude scale is 'stretched'. This means that the rectangular_cartesian grid unit in the latitude scale needs to be defined in some other quantity. The unit used is called the meridional part and is taken to equal the length of one minute of longitude measured at the equator. This establishes a uniformly rectangular Mercator Grid and allows a variety of calculations to be performed on the projection called the Mercator Sailings. These are the calculations generally used in navigation and in most navigational equipment including this system. The complete formula for conversions from latitude to meridional parts on the Mercator projection is given in figure 3.7 and the conversion from meridional parts back to latitude is given in pseudocode form in figure 3.8. The formulae for the other commonly used projections are lengthy but are given in complete form in 'The Admiralty Manual of Navigation'(40).

3.2.9.2 Other Commonly used Projections

3.2.9.2.1 Modified Polyconic

This is commonly known as the 'Gnomonic' Projection on Admiralty Charts and should not be confused with the true Gnomonic projection which is entirely different and discussed in one of the next sections. The Modified Polyconic projection has been in use for some years on large scale charts, particularly those of ports and their approaches. It is gradually being replaced by the Universal Transverse Mercator (UTM) projection. The Modified Polyconic projection is subject to projection convergence which results in charts in the Northern Hemisphere being slightly narrower at the top than at the bottom.

The dimensions of the chart within the 'Neat Lines' are shown at the bottom right hand corner of the sheet. A typical value for difference

Meridional Parts on the Spheroidal Earth

Mer. parts L =

$$10800/\pi \log_e \tan(45^\circ + L^\circ/2) - e \sin L^2$$

$$- 1/3\ e^4 \sin L^3$$

$$-1/5\ e^6 \sin L^5 - \ldots$$

Where:

L = Latitude (radians)
e = eccentricity of the earth

(Page 646 Admiralty Manual of Navigation)

Fig. 3.7

Meridional Parts to Latitude

```
double  mer_par_to_lat(mps4)
double  mps4;
     {
double  mp;

if(e2==0.0){printf ("geodetic model not
                              set");return;}

mps4=mps4*PI/10800;
mp=atan(exp(mps4));
mp=2*mp-pi_2;
mp=merp(mp,mps4);
mp=merp(mp,mps4);
mp=merp(mp,mps4);
mp=merp(mp,mps4);
mp=mp*RD;
return(mp);
}

double  merp(angle,merps)
double  angle;
double  merps;
{
double  s1,s2,s3,s5,s7;
double  t1,t2,t3,t4;
double  mps;

if(e2==0.0){printf ("geodetic model not
                              set");return;}

s1=sin(angle);
s2=s1*s1;             /* sin ^ 2 (angle)              */
s3=s1*s2;             /* sin ^ 3 (angle)              */
s5=s3*s2;             /* sin ^ 5 (angle)              */
s7=s5*s2;             /* sin ^ 7 (angle)              */
t1=e2*s1;             /*e2 * sin (angle)              */
t2=A*s3;              /*e2^2 * sin^3 (angle)/3        */
t3=B*s5;              /*e2^3 * sin^5 (angle)/5        */
t4=C*s7;              /*e2^5 * sin^7 (angle)/7        */
mps=2*atan(exp(t1+t2+t3+t4+merps))-pi_2;
return(mps);
}
```

Fig. 3.8

in the two dimensions is 5mm giving an appreciable quantity that must be accounted for in future scaling software.

3.2.9.2.2 Universal Transverse Mercator

This is the projection used on recent large scale charts and is very similar in its properties to the Modified Polyconic Projection above. The Central Meridian should be taken as the middle of the chart in the North / South direction. The calculation of grid coordinates from geographic coordinates and vice versa was used in the interface between the Solartron Simulator and the Electronic Chart discussed later.

3.2.9.2.3 Gnomonic

This projection is traditionally used by navigators for laying off Great Circle courses prior to transferring them to larger scale mercator charts as a series of rhumb lines. It has the property of showing great circles as straight lines. There is no specific requirement to include Gnomonic charts in ECDIS at present; however it would be a useful addition if provided for use in conjunction with the Great Circle and Composite Track Sailings in long distance passage planning.

3.2.9.2.4 Polar Stereographic

The Polar Stereographic projection is used in very high latitudes (where Mercator cannot be used). Again, there is no requirement to include these in an ECDIS at present.

In performing these projection calculations in an ECDIS, it is essential that the appropriate spheroidal data are associated with each chart. This is because most projection algorithms are based on differences between measurements taken on the spheroidal surface from a common origin - usually the equator and a central meridian. In order that positions transfer smoothly between charts based on different horizontal datums, it is also necessary to adjust them to a common datum for storage purposes and then translate them to the appropriate form prior to display. In the case of the Liverpool Prototype, all the charts used (with the exception of the continental ports on the channel disc which use ED-50) used OSGB36 or the EIRE horizontal datum which both use the AIRY spheroid. The translation procedures described above were not implemented for stored points (although the datum shifts required to do so were recorded in the meta-data file) it is, however, essential that this is done in a commercial system.

3.2.10 Chart Accuracy and Position Fixing.

3.2.10.1 GPS Accuracy

In real use with GPS (as opposed to the testing mode) the GPS heading output is also susceptible to errors in positioning caused by the implementation of Selective Availability (SA) (Heading is calculated using successive positions). It was found that GPS positions reflected the 100m errors introduced by the controlling authority. This was particularly noticeable during tests in the Manchester Ship Canal where the narrow channel width gave the clearest possible visual indication of position. With the advent of differential GPS, capable of position fixing to an accuracy of 5m (drms), the vessel's own position fixing system could be more accurate than the methods used at survey. This emphasises the need for relative positioning from hazards as well as absolute positions. Similarly, the accuracy of other position fixing systems should be available to the user in order that he can make an informed judgement.

3.2.10.2 Accuracy Limitations of the Liverpool ECDIS

These are listed in summary form:

1) Positional Storage format should be WGS84 rather than any other datum.

2) Algorithms for the Modified Polyconic and Universal Transverse Mercator projections should be included in the scaling and application software so that charts of these types are fully supported.

3) Further work is required on the control of errors in scaling and positioning.

4) The Electronic Position Fixing System should have an accuracy exceeding 10 metres drms (eg Differential GPS) for safe use in confined waters.

5) The mariner should be discouraged from assuming that it is safe to pass closer than usual to a charted hazard simply because the

positions being displayed are more accurate than he is used to.

3.2.11 Main Software Structure

See figure 3.9 (System Flowchart)

The structure of the main electronic chart program follows a conventional pattern. The system initialisation sequence is followed by a loop in which user interaction is monitored. The system responds to user commands according to branch instructions and the states of a number of global variables eg a flag denotes whether line drawing is on or off.

The general structure of the software is illustrated in figure 3.10 using an abbreviated notation.

A simplified version of the function which processes the movement of the trackerball is given in figure 3.11 to illustrate the simplicity of the software structure for cursor movement and drawing.

The other input monitoring functions are similarly straightforward. The remainder of the code is held in 13 files which are linked together to form the system executable. The files and their contents are described briefly below.

CDU C Contains the main code loop and input monitoring functions as described above.

USER C Controls the output on the monochrome text screen.

DISGRAPH C Contains all the display graphics routines

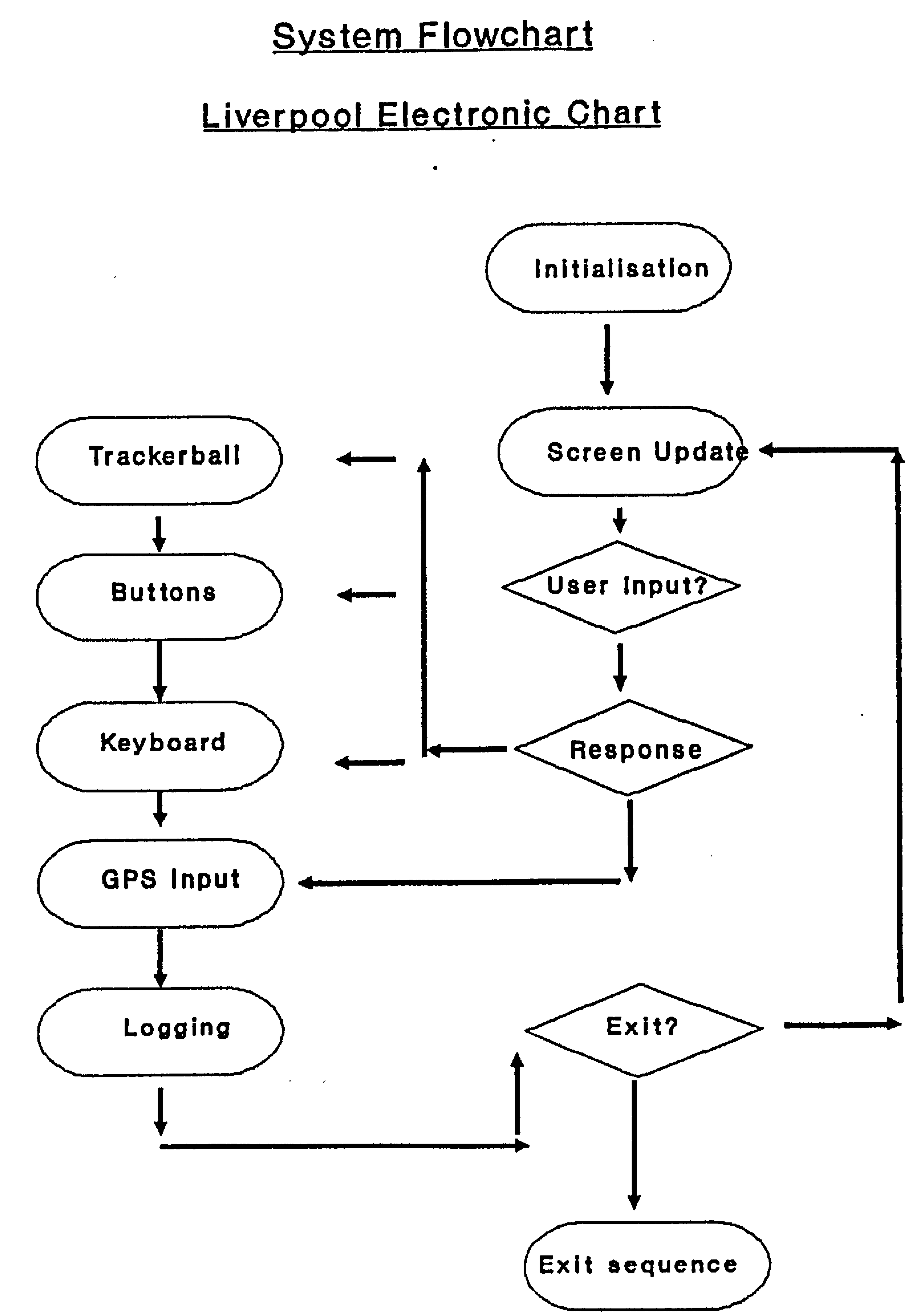

System Flowchart
Liverpool Electronic Chart
Initialisation
Trackerball
Screen Update
Buttons
User Input?
Keyboard
Response
GPS Input
Logging
Exit?
Exit sequence

Fig. 3.9

Main Software Structure

```
main()
{
initialise_system(arguments);
main_ecdis_loop();
ecdis_exit();
}

main_ecdis_loop()
{
This function tests for user inputs and branches to the
appropriate routines which process them

 while(1)
      {
      getcom();                          //get own ship
                                           position
      if(read_motion_counters())//if trackerball
                                             moved
      {
      process_counters();                //process the motion
                                           input
      }

      button=buttonpress();               //check for
                                            buttonpress
      if (button)                         //if a t'ball button
                                            was pressed
      {
      process_buttonpress(button);
      }

      c = keyboardpoll();                 //test for keyboard
                                            input
      if(c)
      {
      process_keyboard(c); //process keyboard input
      }

    }
}
```

Fig. 3.10

TrackerBall Processing Function

```
color_process_counters()
{
//If system is in auto navigation mode switch off
   if(Auto_Nav){
                     Auto_Nav_on_off();
                      }
//If options menu is currently active
   if(MenuActive) {
                     get_tball_pos();
                     return;
                            }
//Otherwise
                     do_line_drawing();       // old lines off
                     get_mouse_pos();         // updates mouse
                                                 position
                     do_line_drawing();       // new lines on
                     readout();               // does viewport
                                                 readouts
// now check whether we need to scroll the frames
                     do_scrolling(dir);
} //end of function
```

Fig. 3.11

GEO C Contains all the geodetic calculations and navigational algorithms.

MENU	C	Contains the code which puts up the chart menus
READOUTS	C	Performs all the readouts on the chart
WINDOWS	C	Low level windows software
COMMS	C	Contains the communications software
FRAMES	C	Contains the frame handling routines
WAYPOINT	C	Contains the waypoint editor functions
INIT	C	Initialisation routines
SYS159	C	Tidal Calculations
MISC	C	Miscellaneous functions

Section 3.3 Navigational Utilities and Algorithms

The navigational algorithms used by the system are taken from 'The Admiralty Manual of Navigation'(40) and NP159(46). There are, in fact, relatively few of these, the principal routines being:

Length of a minute of latitude / longitude;
Range Bearing / Course Distance;
The Tidal Calculations - NP159

Having established a sufficiently accurate chart display, the next task was to develop a set of navigational tools capable of reproducing the functionality of the existing paper chart. Whilst no explicit assumptions were made about the expertise of potential users, the generally accepted view was that the system would be used by individuals having a background of previous navigational experience. Hence the design of the navigational tools attempted to emulate systems with which users would be already familiar.

3.3.1 Waypoint Editor

A 'waypoint editor' was developed. to provide the course drawing functions. This permits the user to draw courselines in a sequential manner using the trackerball and buttons. Thereafter he can modify his chosen route by adding, inserting, moving and deleting waypoints.

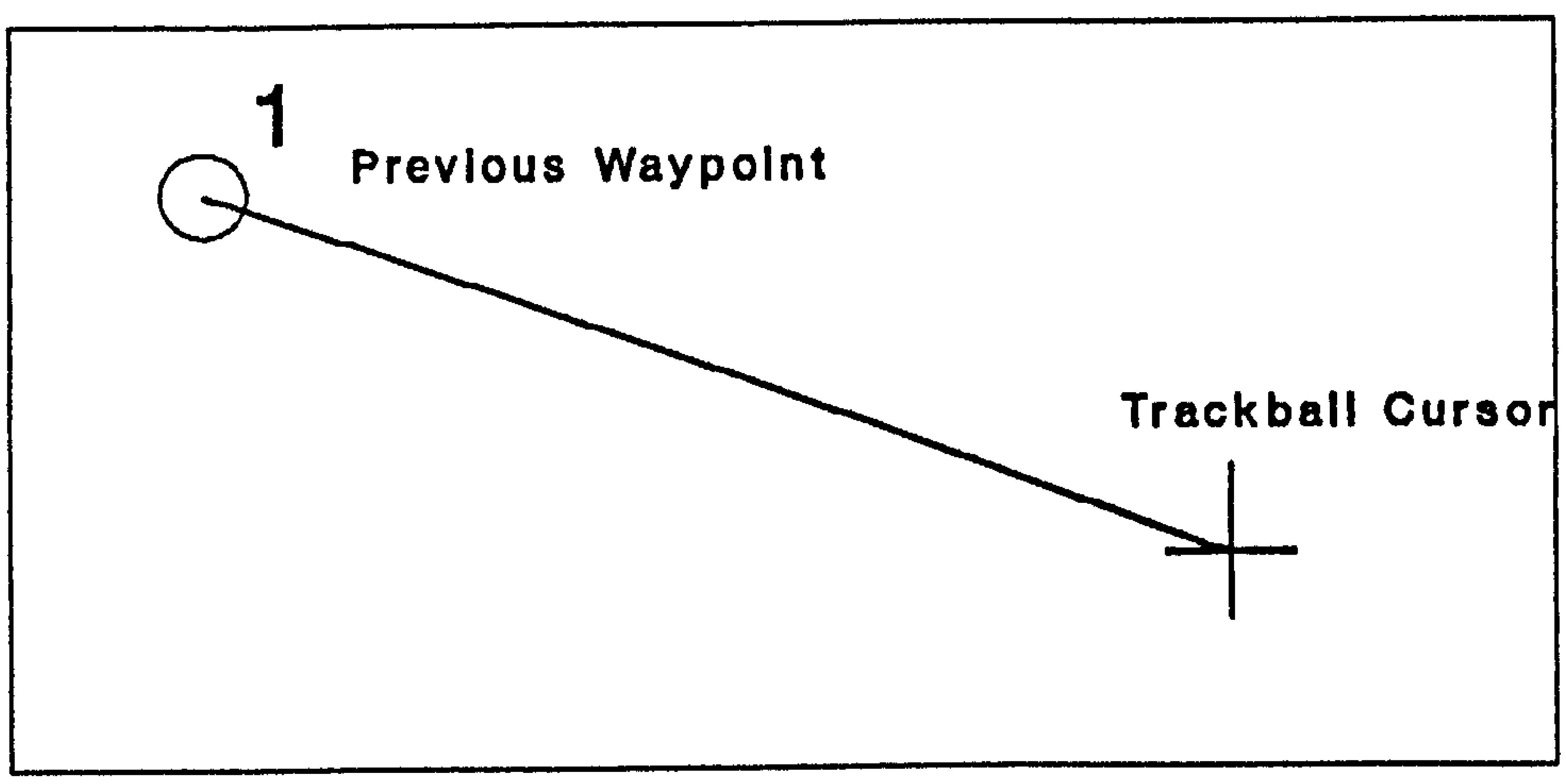
See figures 3.12 to 3.15 which show the main waypoint editor functions

A listing of the waypoints, and the courses and distances between them is maintained on the monochrome text screen. An early version using the 'Btrieve'(45) database system to store the waypoints was found to be slow and cumbersome in operation. The second version uses a linked list data structure and has proved entirely satisfactory for trials purposes.

As well as being capable of defining waypoints in absolute lat/long coordinates, the system also allows the user to define waypoints by range and bearing from a known point - the result is however still stored as lat/ long. For reasons explained earlier,(in particular, when defining waypoints on charts of no known datum) experience has shown that the system should be modified to output waypoints in the units in which they were defined.

Waypoint Editor Operations

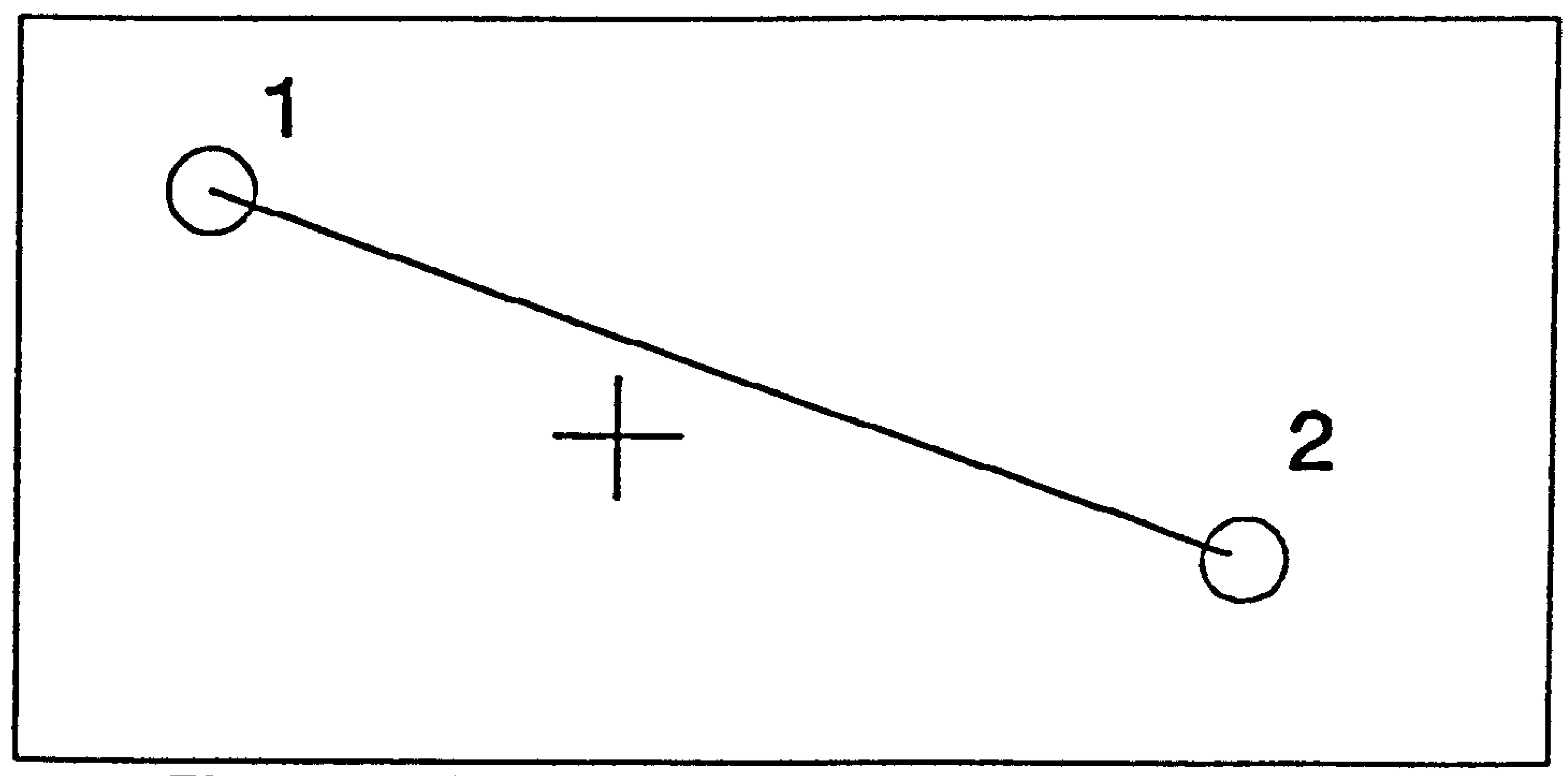
1) The Add or 'Append Waypoint' Operation



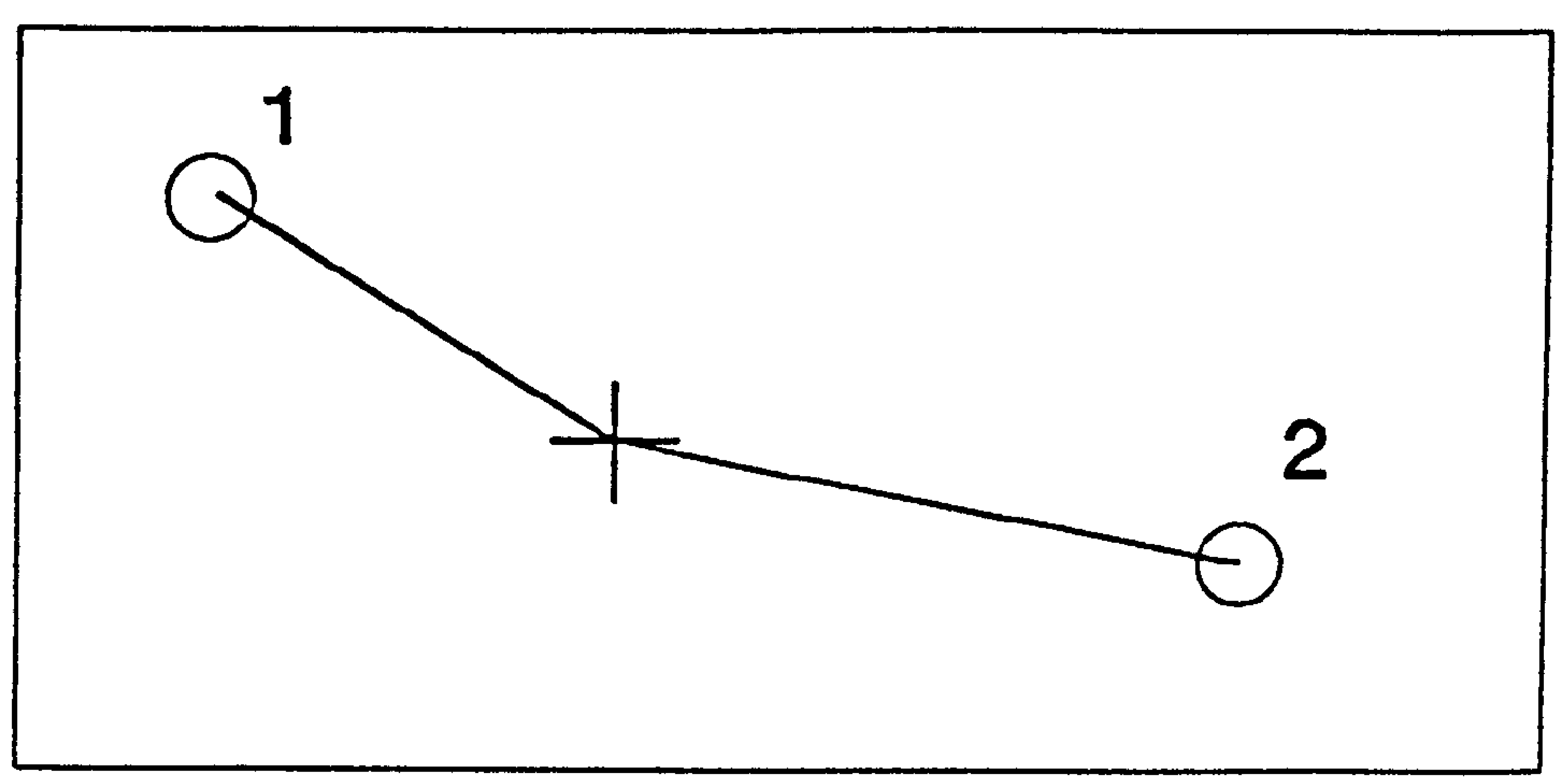
The cursor is attached to the preceding waypoint by a line which is free to move with the user's trackerball input until the next waypoint is selected. This is the normal way in which a route is constructed as a sequence of waypoints. The other waypoint editor functions depend on two or more waypoints having been defined by this means.

Fig. 3.12

2) The 'Insert Waypoint' Operation



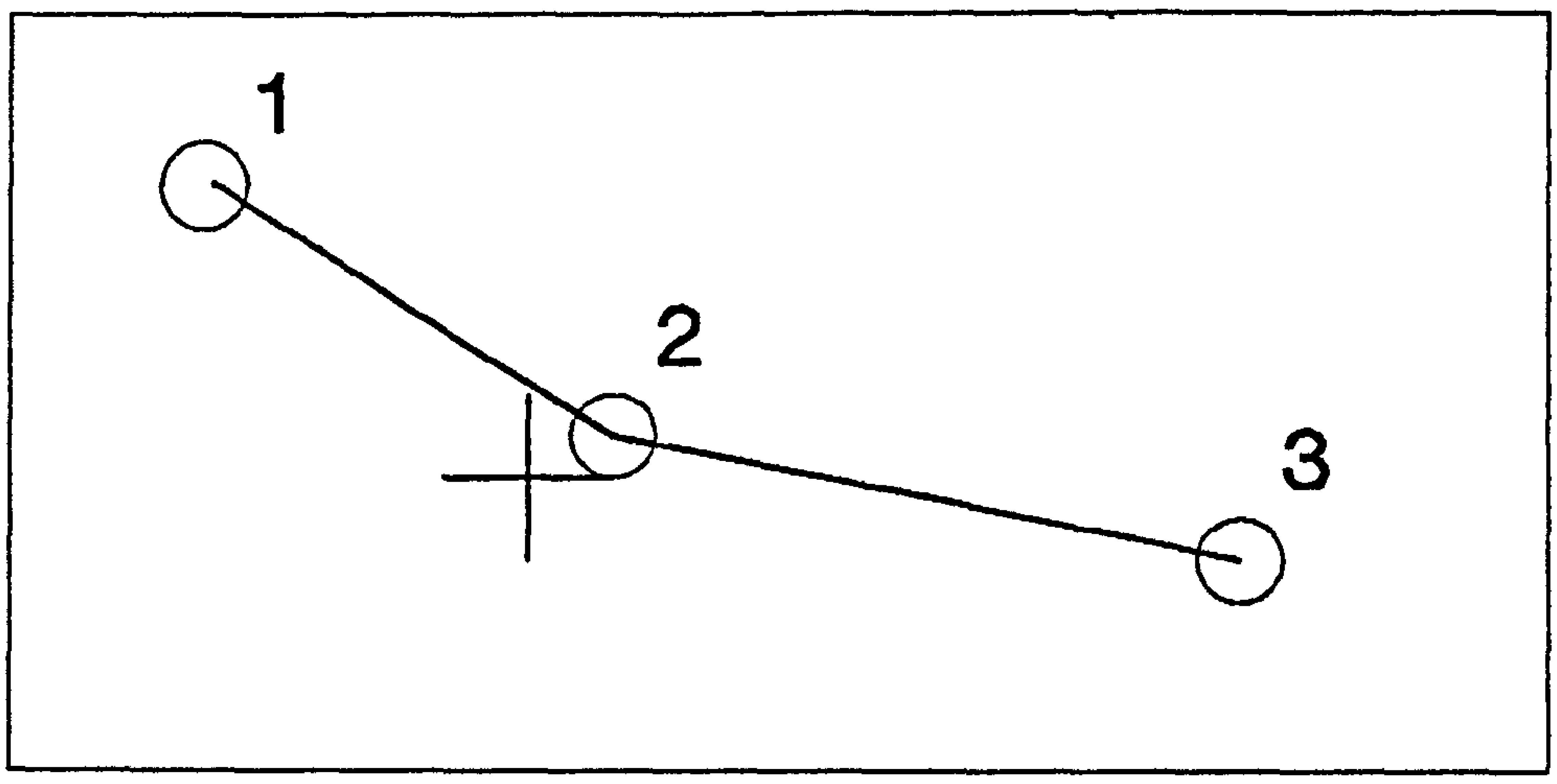
The user places the cursor adjacent to a route segment
A single buttonpress attaches the cursor movement to the line.



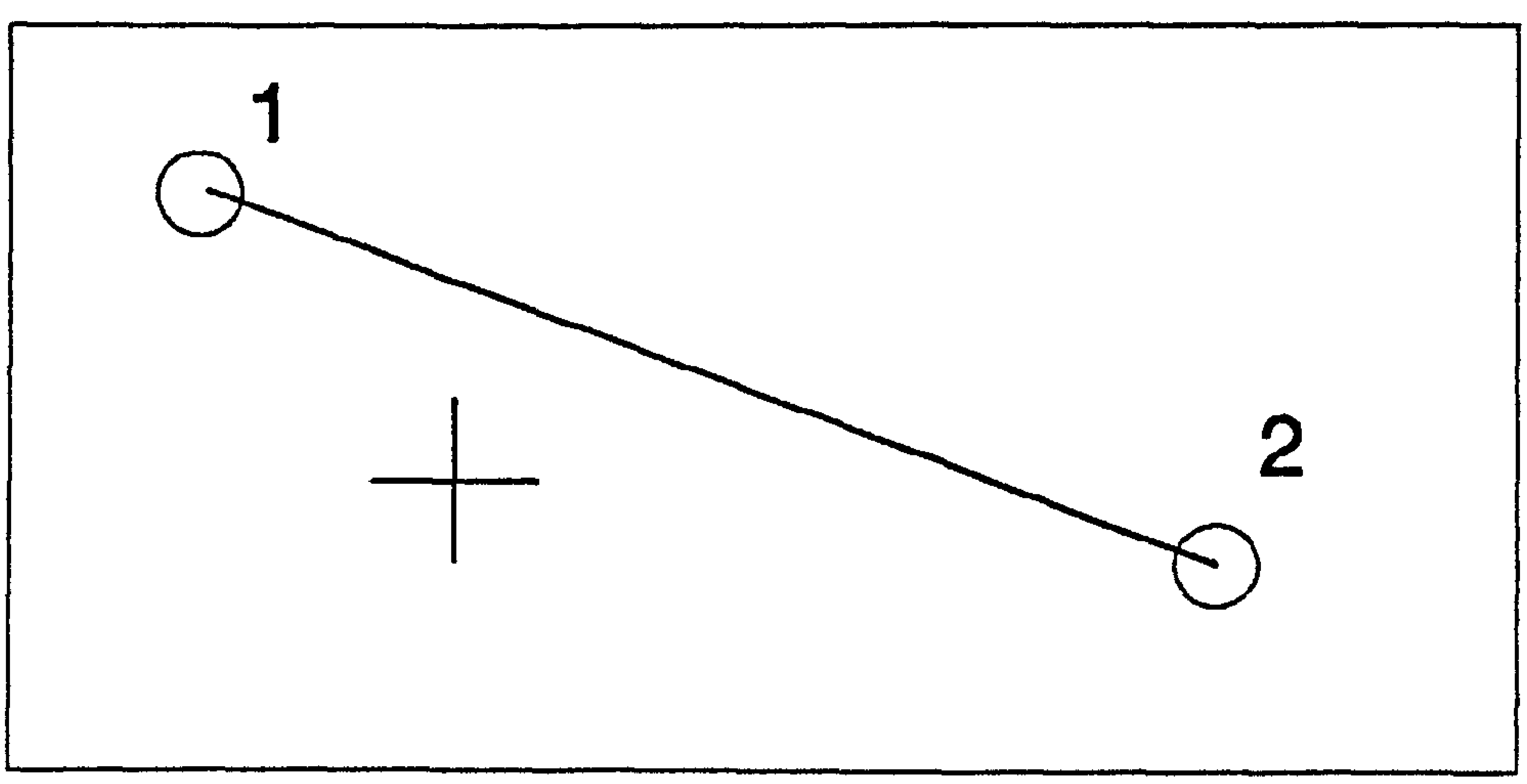
The cursor is now attached to the two waypoints defining the previous route segment. The user is free to insert a new waypoint at the cursor's location, again with a single buttonpress.

Fig 3.13

3) The 'Delete Waypoint' Operation



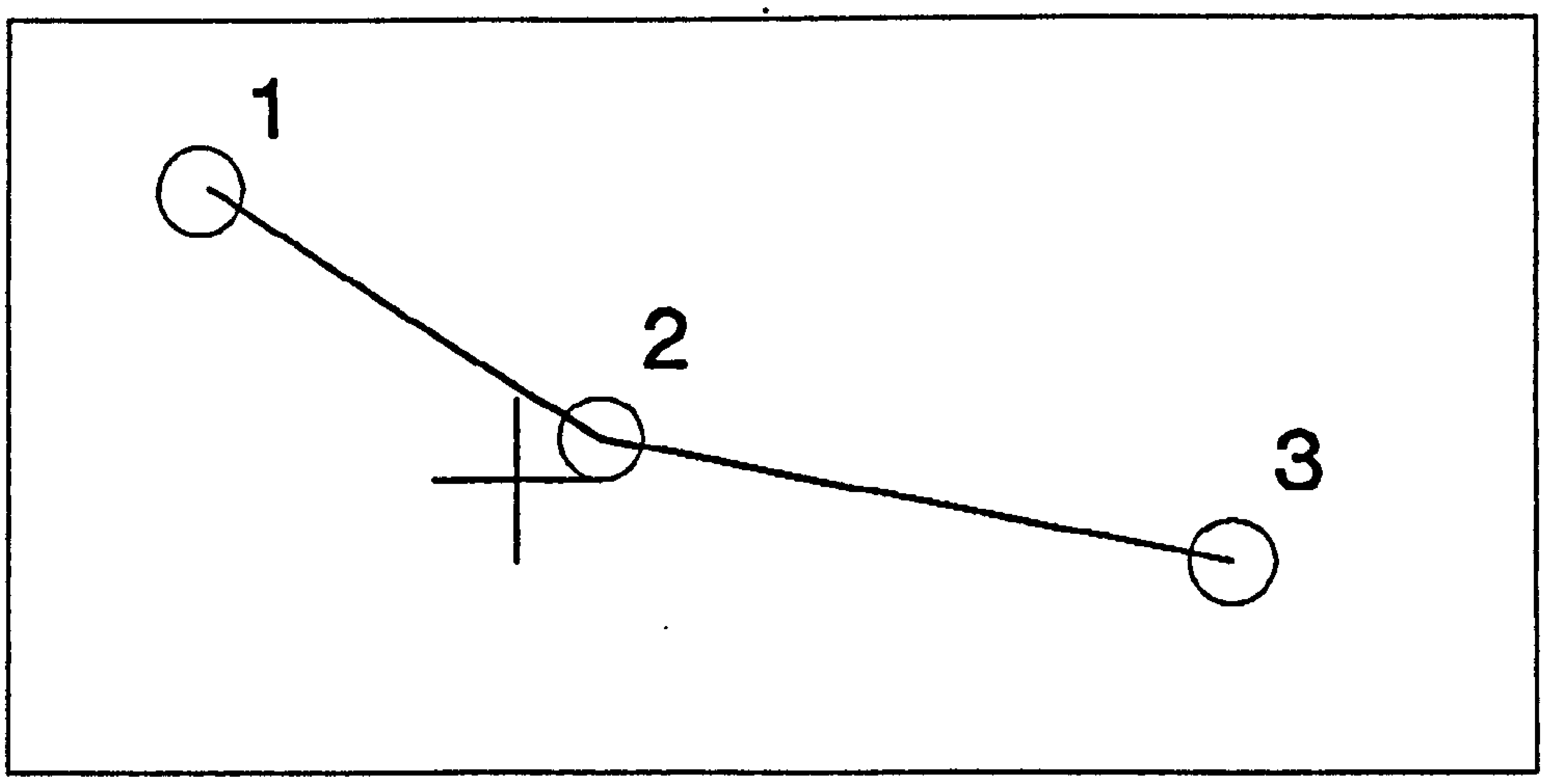
The cursor is placed close to the waypoint to be deleted.



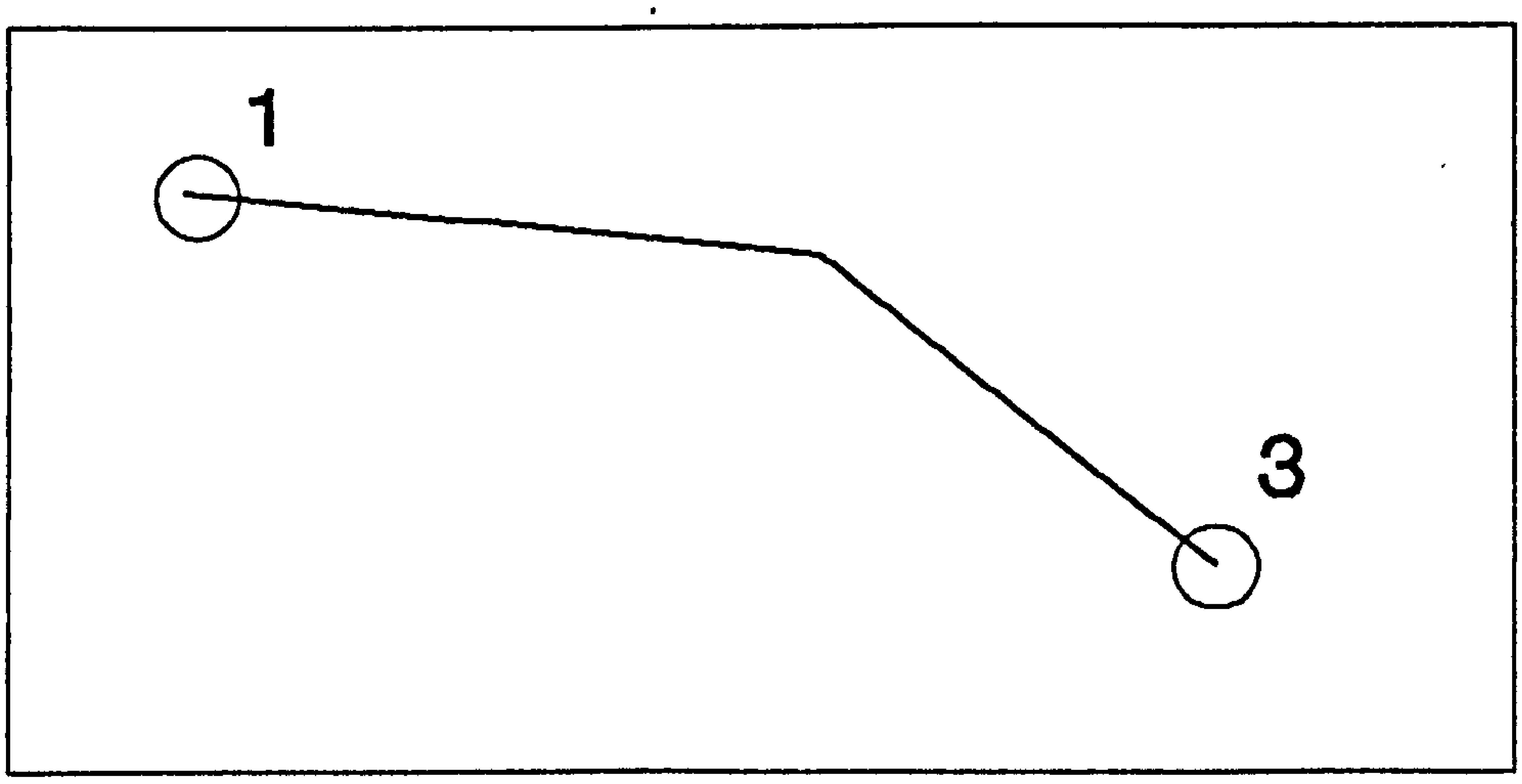
A single buttonpress deletes the waypoint

Fig 3.14

4) The 'Move Waypoint' Operation



The cursor is placed close to the waypoint to be moved. and 'captured' by a single buttonpress



The cursor is then used to move the waypoint to its new position.
A single buttonpress refixes the waypoint and the cursor reappears.

Fig. 3.15

3.3.2 Range and Bearing Marker

An essential navigational requirement was recognised as being the capability to rapidly measure range and bearing. This was designed so as to reproduce the functionality of the navigator's dividers, parallel rule and the chart compass rose. In fact, the model chosen was similar to the same functions on a radar, with the navigator being able to choose either a point on the chart from which to measure, or use the moving own-ship ship symbol as the measurement centre. These functions met the IHO requirements for azimuth and distance calculations in a simple and usable form. The Electronic Range and Bearing Lines (ERBL s) in combination with the scale bar at the chart edge provide the user with a clear indication of the relationship between chart distance and the Sea Mile: something a bald statement of scale such as 1:50000 did not do, even for experienced mariners.

It was necessary to ensure that all the line drawing and measuring functions operated satisfactorily during changes of the displayed video images.

3.3.3 Scale Bar

See Plate 11

A scale bar is provided at the left hand edge of the chart display screen in accordance with the IHO performance standard. It indicates scale by showing either 10, 1 or 0.5 International Sea Miles according to the true chart scale as follows:

10 miles	- 1: 1 500 000	or smaller
1 mile	- 1: 1 499 999	and larger
0.5 miles	- 1: 100 000	or larger

Each time the user changes the chart scale on display, a message bar appears at the top of the screen displaying a 'scale change warning'. This is also part of the IHO ECDIS specification.

3.3.4 Own Ship Symbol

The symbol used for own ship is also varied according to the chart scale. At scales of 1:20 000 and greater, the symbol consists of an outline drawn to emulate a ferry of approximately 100 metres in length. Otherwise, the symbol consists of a circle and heading marker. This type of own ship symbol was chosen since it offers the potential for displaying a circle of probable position and the dead reckoning track for a specified number of minutes. It is recommended that this symbol also incorporates an indication of ground track in future versions.

3.3.5 Positional Recording (Track History)

See Plate 11

Logging and recording functions are a necessary adjunct to the continuous use of the system. A system was proposed where positions would be recorded to disk at regular intervals (depending on the type of operating area) with a continuous 15 minute record of positions collected at 15-30 second intervals maintained in memory for output of the vessel's immediate past-track and capable also of being recorded in the event of an accident or near-miss for the subsequent reconstruction of the event.

Own-ship's Track history is recorded in the form of positions taken at 30 second intervals. These are held in memory in a circular buffer capable of storing a 15 minute long sequence. The track history is displayed as a sequence of green dots astern of own ship. Each position is also recorded to disk giving the potential for fully reconstructing the ship's track during trials.

3.3.6 The Information display screen

See Plate 12

3.3.6.1 Real time display of Navigational Information

The top left corner of the text screen gives a continuous readout of current vessel position and speed variables. These are slightly different if the system is being used with the training simulator as opposed to the GPS receiver (figures 1.2 and 1.3). With GPS, the course over the ground is output by the receiver whereas the simulator gives own-ship heading. Other outputs are: position (in lat/long), speed (knots), Cross track error (decimal miles to port/starboard), Time to waypoint (days, hours, minutes, seconds), Bearing to next waypoint (degrees). The data is transferred between the GPS receiver and the chart and between the simulator and the chart via a NMEA 0183 interface protocol on RS232. (The simulator interface uses a full Universal Transverse Mercator conversion algorithm to translate between simulator grid coordinates and lat/lon for input to the system.)

3.3.6.2 Other functions

Additional menus on the information display screen are used to give manual control of the database access functions. Examples implemented in the Liverpool system include a simulated weather forecast and nav-warning. Later work suggested that the information screen display be modified according to the vessel's navigational situation and in particular, that a modified screen should be displayed during pilotage. A simple implementation of a context sensitive help system is provided. This covers both the operation of the trackerball buttons and the menu system on the information screen.

3.3.7 Auto Reset and Auto Nav Mode

One of the function keys at the top of the keyboard is dedicated as a display 'reset' key. Regardless of the user's current action, the display will reset to the largest available chart at own ship's position if this key is pressed. Additionally, should the user not require to interact with the system further, the display control is left to the own ship symbol. Thereafter, scrolling and change of chart are caused by own-ship and its motion until the user interacts with the system again. It is suggested that in on-line navigation, this will be the dominant system state and that some consideration should be given to making this 'passive monitoring' display as useful as possible to the mariner.

3.3.8 Communications

As stated earlier, the electronic chart is capable of processing inputs from either the Solartron radar simulator or a commercial GPS receiver. This flexibility was achieved by using the NMEA message protocol in both cases. An example NMEA string containing a GPS position is given:

$GPGLL,5105.839,N,00130.05,E

where the 'GLL' sequence towards the beginning of the message identifies the subsequent characters as encoding geographic latitude/ longitude.

The NMEA standard allows the use of proprietary messages which permits the electronic chart manufacturer some flexibility in the types of data it can accommodate. A good example is the presentation of radar targets on an ECDIS display.

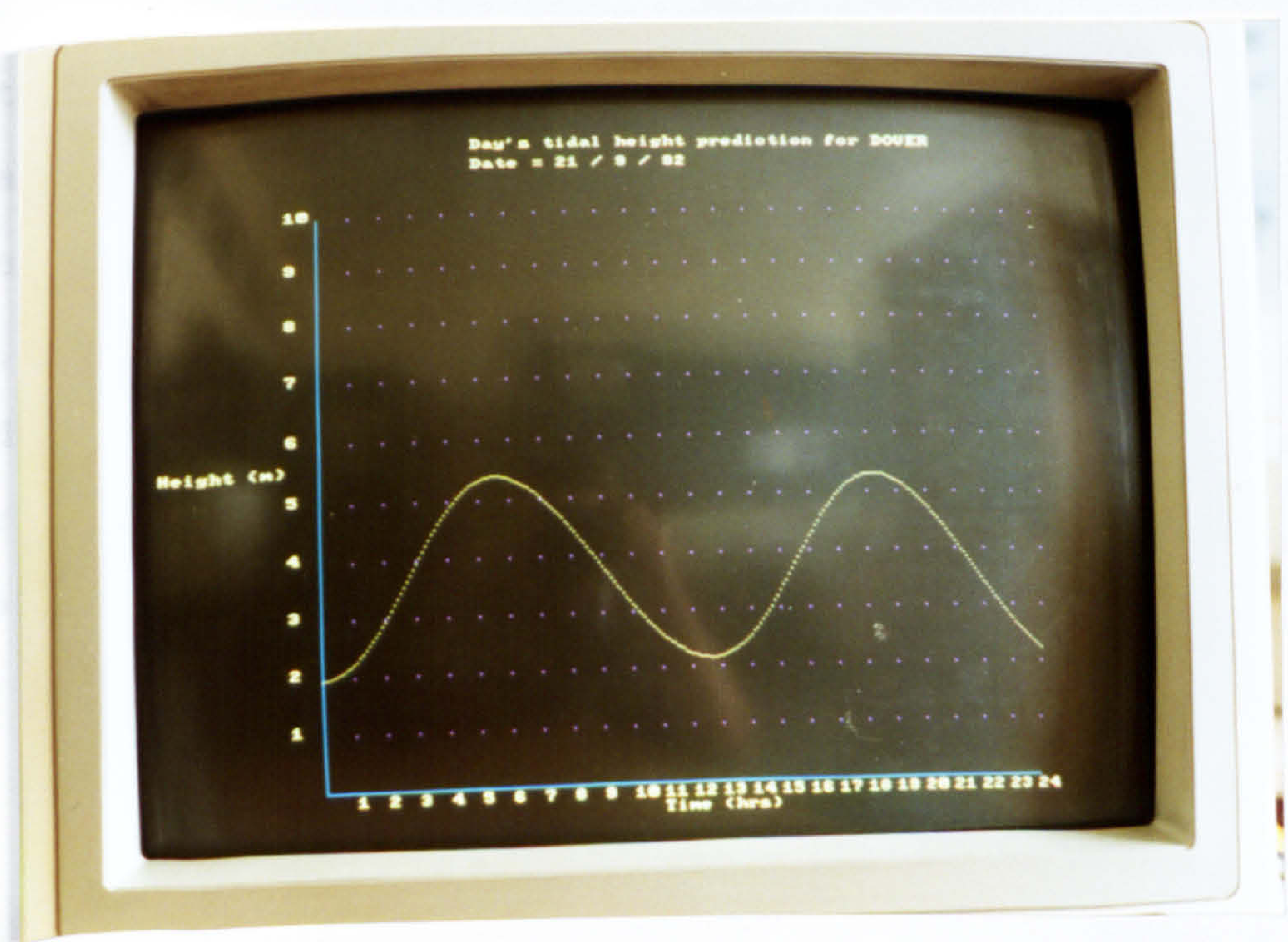
3.3.8.1 Targets and Multi tasking

See Plate 13 showing the format for target encoding used by the project.

The target data was translated from the 'Solartron simulator format' to a pseudo NMEA format by a separate computer. As can be seen from plate 13, it resembles the GPS position output closely, however a full set of this data took some 20 seconds to re-code. Some

Plate 13 The Target Encoding Format

Plate 14 The Tidal Curve for Dover on 21/9/92



difficulty was therefore experienced in passing a full set of target information from the simulator to the chart using conventional software. This was partly due to timing problems in the receipt of the data by the chart - target data encoding was done on a relatively slow 80286 computer. Experiments were therefore carried out on multi-tasking the chart software and whilst targets have not yet displayed on the interactive video screen, they were successfully displayed on a vector data based chart. This work demonstrated that a multi-tasking approach was viable.

An interface to the Kelvin Hughes Concept Radar could only be partially attempted owing to pressure on the simulator from external training needs. However in practice, this interface would effectively duplicate the link described above using direct output from the simulator control machine (DEC PDP 11/40).

3.3.9 Tidal Calculations

See Plate 14 which shows the tidal curve for Liverpool on 21/9/92

A set of tidal calculation routines are incorporated into the chart software as a means of calculating tidal heights for port entry. A comprehensive package was written to develop the database of harmonic constants, support primary and secondary ports and graphically show a day's prediction. The calculation element of the software was based on earlier work in the department, which implemented the Admiralty NP159 tidal calculation algorithm.

Section 3.4 Interaction with Spatial Data

Geographic Information Systems use point, spatial and geometric searching to yield useful information from an underlying model of the real world. The data structures used for performing the desired operations may permit map reproduction or not; their importance lies in their ease of processing during spatial enquiries and economy of storage. The present work included the identification and development of GIS techniques for navigational purposes and the most significant achievement in this area was the development of an anti-grounding algorithm capable of being implemented in any electronic chart system. Another of the objectives of this project was to produce spatial data access functions capable of providing the supplementary information for 'piloting' a vessel along its track. The anti-grounding system mentioned above will provide a strong entry point to further work in this area.

3.4.1 Quadtrees

3.4.1.1 Definition and Principles

The term quadtree is used to describe a class of hierarchical data structures whose common property is that they are based on the principle of recursive decomposition of space. Currently they are used for point data, areas, curves, surfaces and volumes. The present work was concerned with deriving representations and interaction techniques for producing information useful to marine navigation.

Quadtrees(47) were initially pioneered in the field of computer graphics. They use a storage principle based on the encoding of areas of homogeneous characteristics and are therefore also well suited to application in the field of GIS where they have been used with some success. A number of applications are described in the literature. Generally they are based on pointered representations(48), list representations (49) or a combination (50) (Example references are given). Three principal sources were used in the course of this work to provide the foundation upon which a maritime application of the quadtree could be based. Samet(51,52) gives a comprehensive introduction to quadtrees, their conceptual background and a number of known applications. Gargantini(53) outlines the linear quadtree technique used in the current work and Kingslake(54) was the source from which the recursive encoding and line searching routines were developed.

3.4.1.2. Pointered and Linear Quadtrees

See Figure 3.16 which shows the construction principle and addressing mechanisms of pointered and linear quadtrees.

The tree structure corresponds to a partitioning of space where:

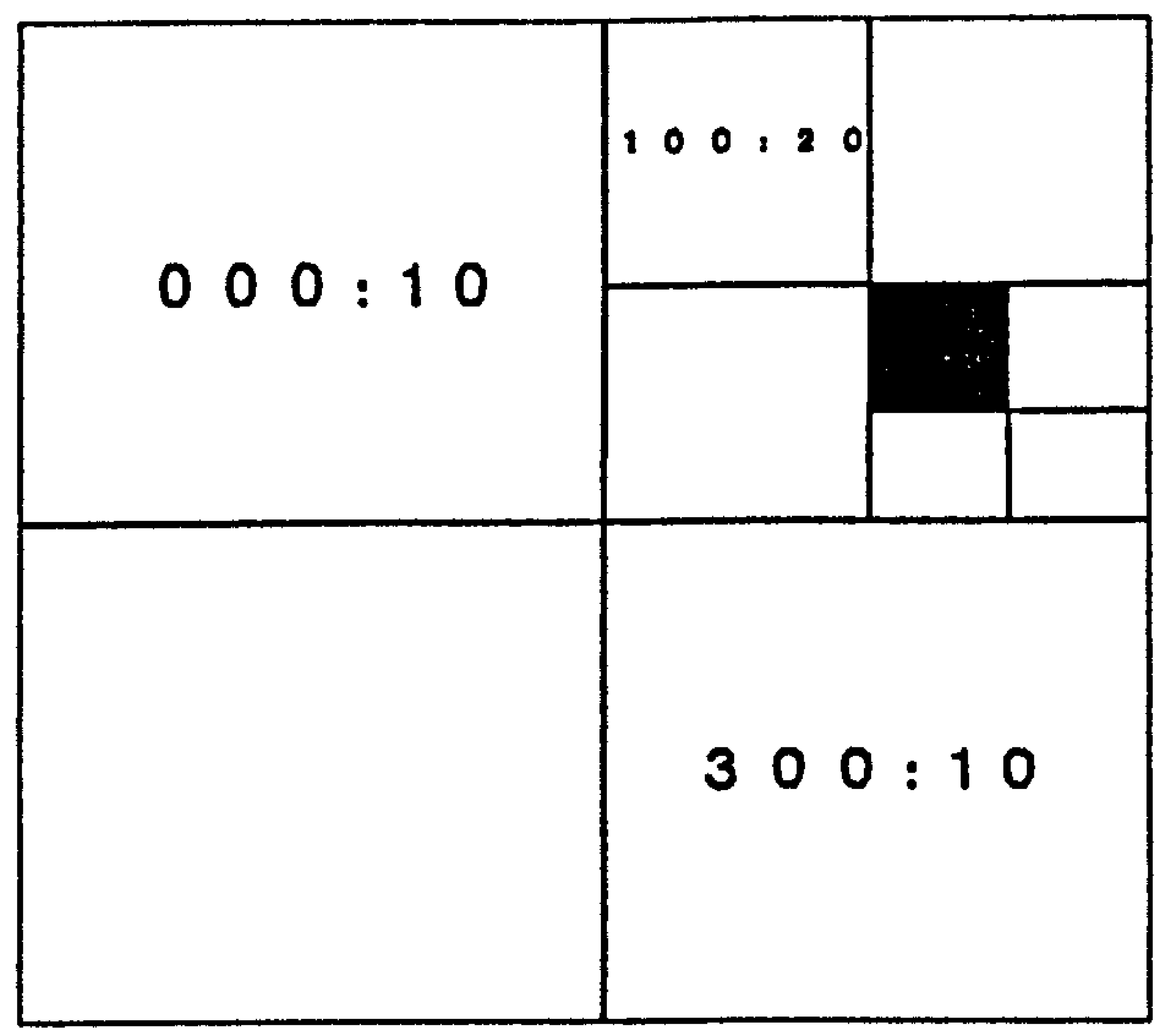
(a) each tree node represents an area;

(b) a terminal node represents an area having a unique attribute (eg a colour);

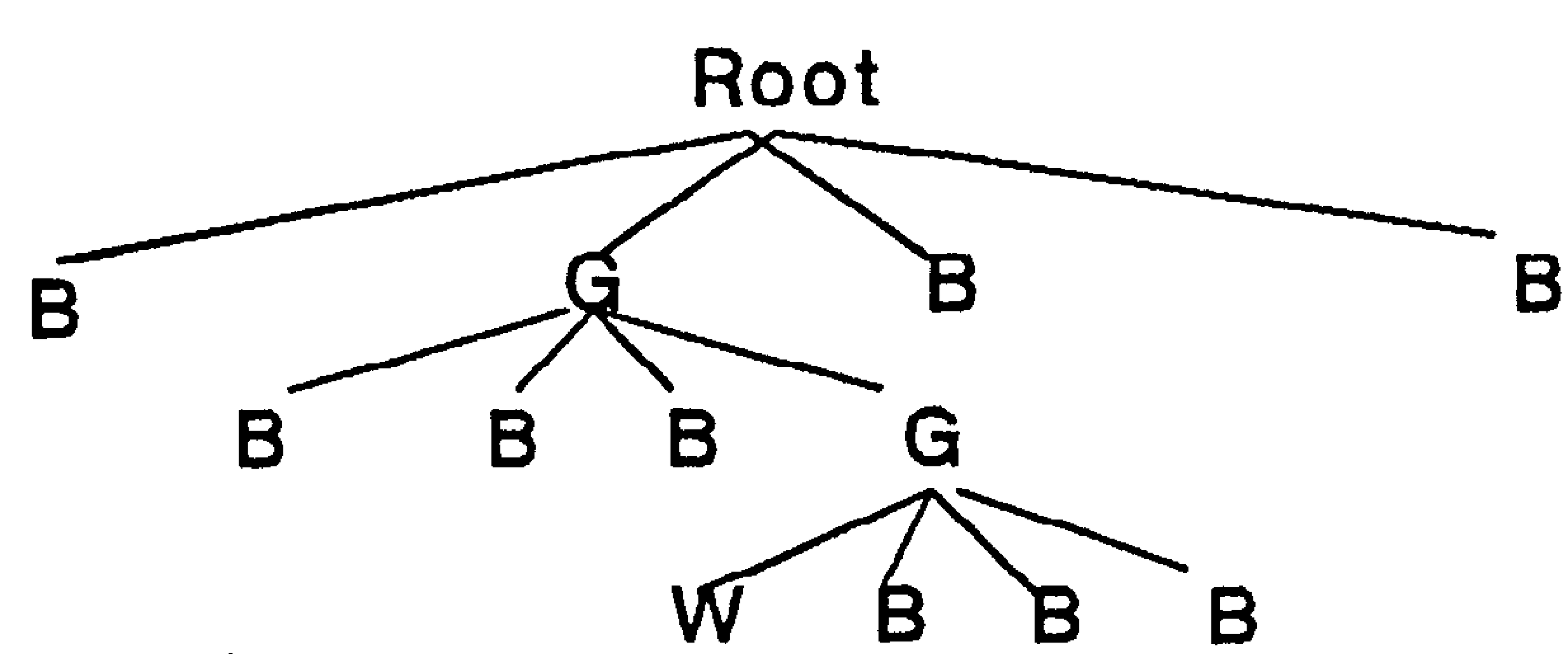
(c) the deeper the node in the tree, the smaller the area it represents.

The quadtree concept can be applied according to two fundamental schemas. The first, that of an ordered rooted tree uses pointers to

The Quadtree Addressing Schema



In this case, the shaded square in the diagram would be encoded and stored after the third call to encode()
It is a level 3 node with the quaternary address
1 3 0 : 3 1
The quaternary is composed of the following information:
1 3 0 is the Morton address of the quadtree node
The 3 after the semicolon is the level at which the node was encoded and the final 1 is the colour attribute of the node. The equivalent pointer based quadtree is shown below.



Where B, G and W represent the Black, Grey and White nodes .

Fig. 3.16

direct construction, search and manipulation algorithms across the data. The second is based upon the use of an ordered list of codes, each of which corresponds to a tree node and whose ordering implies a depth first traversal of the tree.

Each approach offers certain advantages and disadvantages to the software developer. For instance, set operations (range searching, and merging) are relatively easier on a pointered quadtree structure whereas aspatial searching is faster using a list structure.

The list structure was used in this project. It uses quaternaries(53) generated in accordance with the schema in figure 3.16 to store spatial attribute information about the quadtree nodes and is based upon a representation which assumes that a square image of side 2^n pixels is being operated on. A quaternary is simply a sequence of numbers which represent both the location and size of a homogeneous part of the image. The homogeneous attribute can also be represented. For example:

The quaternary 0 1 3 2 1 0 2 0 0 : 7 BLUE

is a level seven code representing a small blue part of an image. If as the example above implies, the whole representation was 2^9 x 2^9 pixels in size, (256 x 256) this code would represent a square of side 4 pixels coloured blue. The entire image can be defined as a list of such codes and, if ordered as integers - analogous to a depth first traversal of the quadtree - the list can be interrogated using a binary search.

Quaternaries are formed directly from the x,y coordinates marking the top left corner of the square they represent. This is done by interleaving the coordinate's integer bit representation. The technique is attributed to Morton(55).

Since the numeric representation of the quaternary codes consists only of integers from 0 to 3, a compact representation is achieved by encoding the quaternaries in binary data form. 4 bytes (32 bits) are thus sufficient to store each quaternary, its level in the tree and a 4 bit colour attribute for codes representing an image of up to 2^{12} x 2^{12} (2048 x 2048) pixels in resolution - sufficient for any maritime application using current technology.

3.4.1.3 Quadtree Application

See plates 15, 16 and 17 showing a chart image being redrawn from vector data, the quadtree scan being carried out, and a courseline being tested for safety from grounding.

Speed of processing in searching over courselines (and potentially other geometric primitives) was achieved by applying the same algorithm to generate search objects as was used to construct the original quadtree. A full account is given.

The implementation of the quadtree encoding algorithm makes use of a recursive procedure to decompose and store a coloured image of a subset of the spatial features on the chart. Land, the intertidal zone and depth regions taken at 5 metre intervals up to a 20m maximum were first drawn out and colour filled on a VGA computer screen as

Plate 15 Redraw of Vector Chart Data

Plate 16 Raster to Quadtree Encoding

described in a later section . The image was then scanned using a C implementation of the following algorithm:

3.4.1.3.1 The Kingslake(54) Algorithm

This is a generic quadtree construction algorithm which, when implemented in C, is used to scan and store raster images as linear quadtrees. The algorithm is presented in figure 3.17.

The algorithm is recursive - ie calls itself at the points underlined. This property allows the algorithm to subdivide the area of interest into successively smaller blocks until a resolution of 1 pixel is reached. The Liverpool implementation allows 9 levels of recursive calls to be made before the algorithm is forced to start returning. This restricts the ultimate resolution of the quadtrees used in anti-grounding to $2^9 \times 2^9$.

3.4.1.3.2 Quadtree preparation

The quadtree preparation process consists of the following stages:

1. Hand digitisation of the chart topography including colour fill.
2. Redraw of the digitised data on a VGA screen
3. Encoding of the VGA raster using the quadtree construction algorithm described above.

3.4.1.3.3 Vector Digitisation

The digitising software consists of a simple derivative of the

'The Kingslake Algorithm'

```
encode(quadtree)
{
  If onecolour (topleft)           //If top left square is one
                                   //colour
       note(colour)                //note   colour
  else encode(topleft)             //Otherwise encode this square.
                                   //The call increases resolution
                                   //at which scanning is being
                                   //done and restarts the encode
                                   //algorithm top left
  If onecolour (topright)
       note(colour)
  else encode(topright)            //NB the scan algorithm goes
                                   //back to top left
  If onecolour (bottomleft)
       note(colour)
  else encode(bottomleft)

  If onecolour (bottomright)
       note(colour)
  else encode(bottomright)
}
```

Fig. 3.17

waypoint editor used to draw outlines. The left mouse button defines lat/lon positions in the contour, the right button defines the fill point of the digitised polygon and terminates the contour drawing.

Five of the keyboard function keys are assigned depth values which are given to the contour and its fill point after the right mouse button is pressed. Data was added to a file one contour at a time and checked using the redraw program.

3.4.1.3.4 Raster to Quadtree Conversion

see Figure 3.18

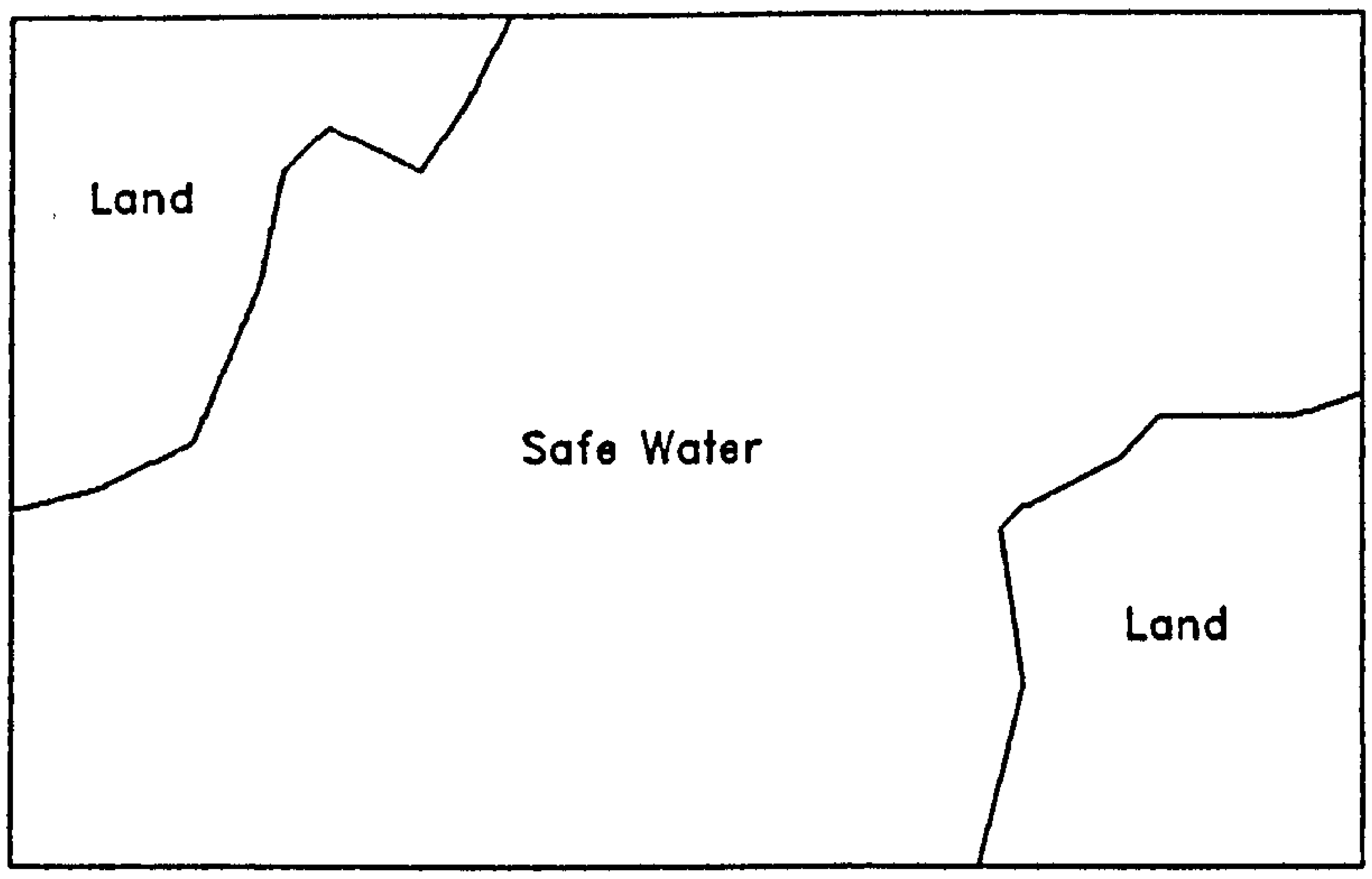
The code fragment in Figure 3.19 is the C implementation of Kingslake's algorithm. It is used to scan the redrawn chart data and place the resulting quaternary list in a data file.

This routine, is in combination with the bit interleave procedure, yields quadtree data in a compressed binary storage format and writes it directly to a storage file. Quaternaries with 'coloured' attributes are used to encode the land, drying zone, 5 metre and 10 metre contours; white is used to define safe water. After encoding, the data is ready for immediate use by the electronic chart's anti-grounding applications described later.

3.4.2 Grounding Avoidance

Three functions were developed giving progressively more rigorous and useful interaction with the depth quadtrees: a point interrogation

Quadtree Preparation from Vector Data



Vector data representing the chart topography is prepared using the interactive video and graphics
This is projected into a 256x256 square window on the VGA screen and scanned by the quadtree encoding algorithm.
The resulting data is used by the Anti-grounding and Track Validation algorithms directly.

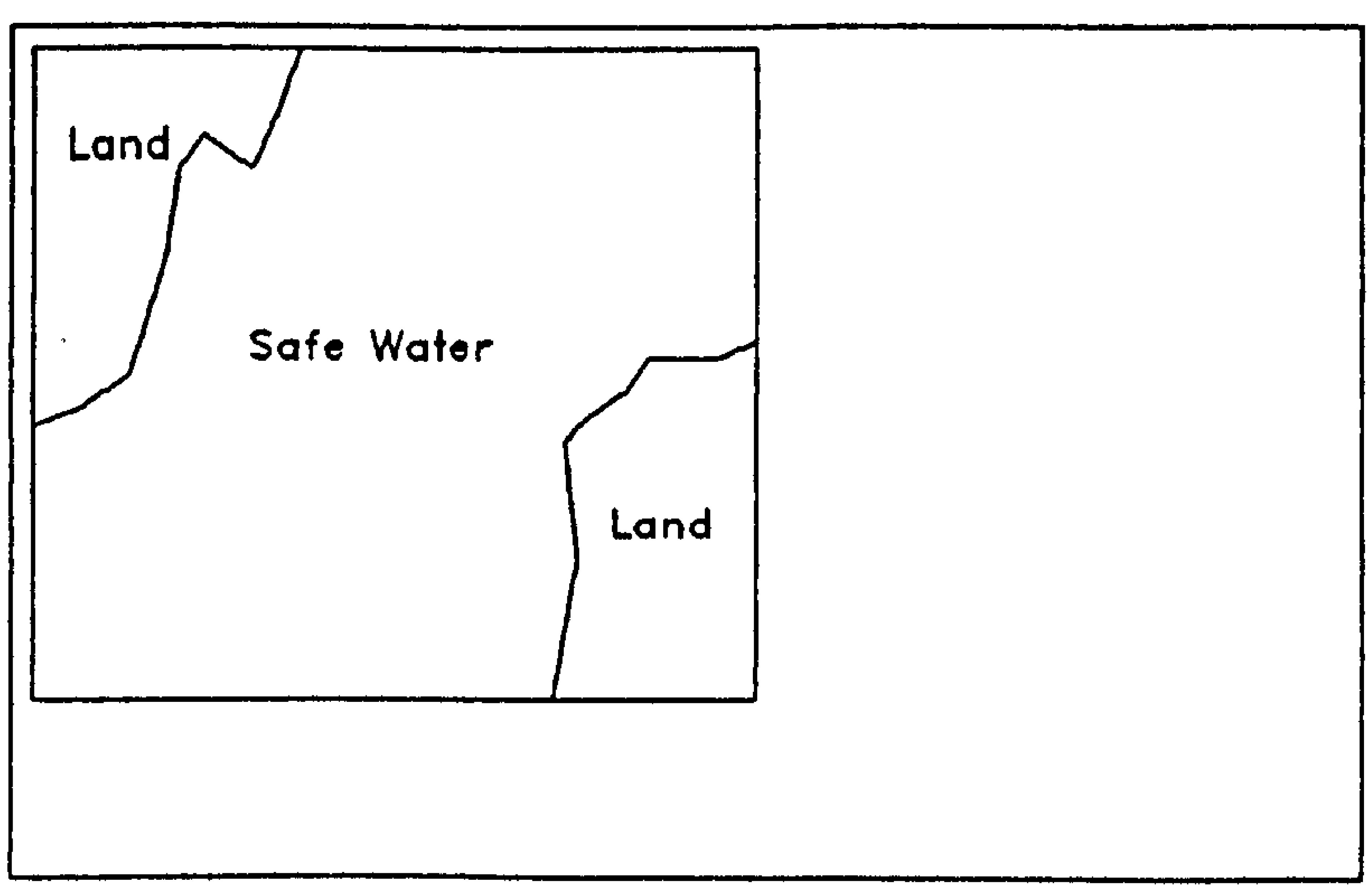


Fig. 3.18

Quadtree encoding using 'C'

```
encode_image(start_x,start_y,level,max_levels)
{
//start_x and start_y are the square origin
//level is the current resolution
//max_levels is the maximum permitted number of levels
int col;
int size;
int xmax;

level ++;           // increases the level at which to scan by
                    // 1

xmax = (int)pow(2.0,(double)max_levels);              //allows variable
                                                      //resolution
size = xmax/(int)pow(2.0,(double)level);              //calculate
                                                      //square size
if(!onecolour(start_x, start_y, level, &col, max_levels))
   //scan the square and see if it is all one colour.
   //if not, increase the resolution and try again
      {
      encode_image(start_x, start_y, level, max_levels);
      start_x += size; //move to the top right square
      }
else  { //form quaternary and store it
        quater(col, level, start_x, start_y, max_levels);
        start_x += size;//move to the top right square
      }

if(!onecolour(start_x, start_y, level, &col, max_levels))
      {
      encode_image(start_x, start_y, level, max_levels);
      start_x -= size;
      start_y += size;          //move to the bottomleft
      }
else  {
        quater(col, level, start_x, start_y, max_levels);
        start_x -= size;
        start_y += size;
      }

   etc.....

           //the two remaining blocks are scanned using
           //identical code.
```

Fig. 3.19

routine; a 'look ahead' function; and a swath validation / track analysis function.

3.4.2.1 Point Interrogation

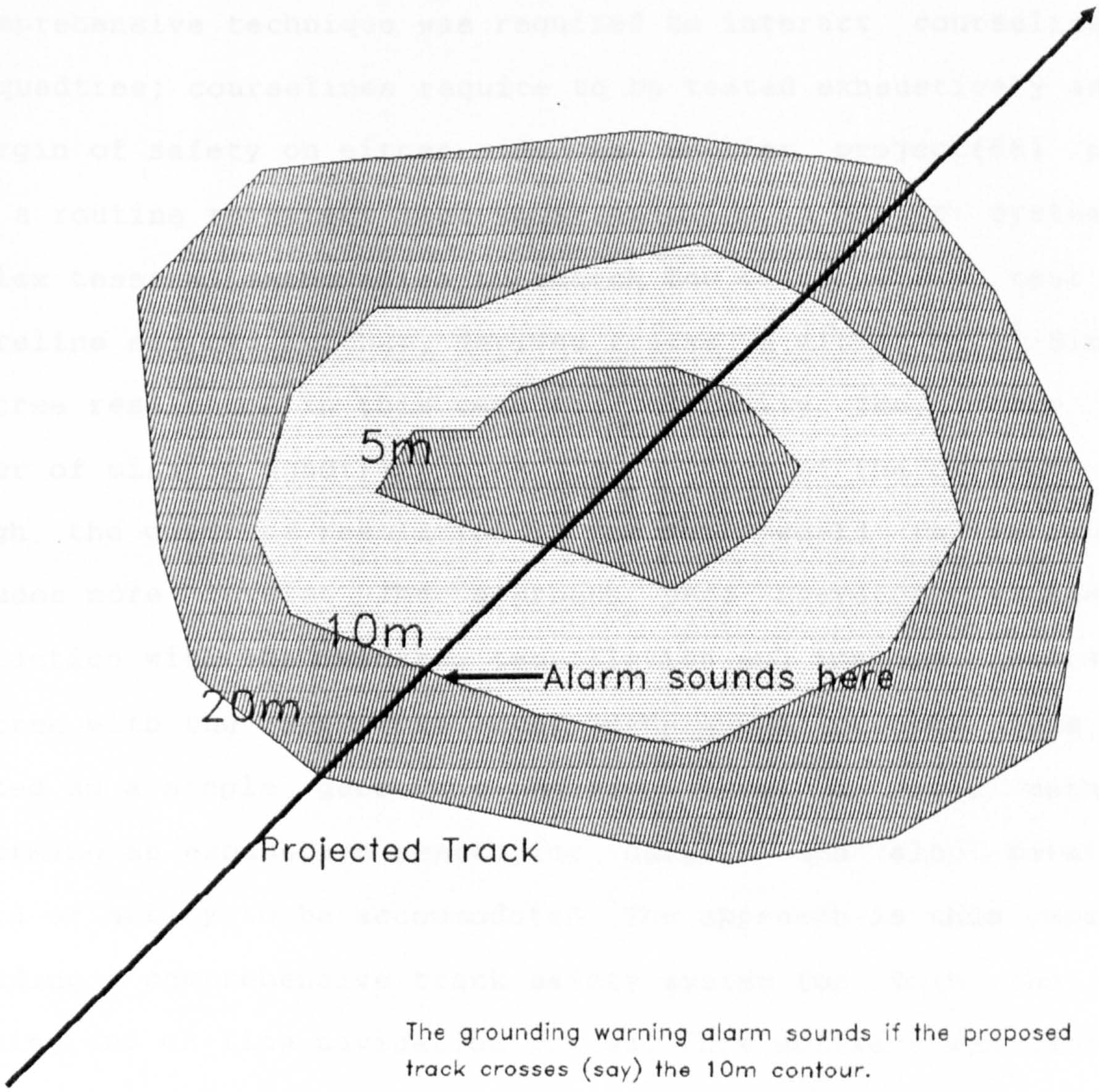
Point interrogation of the quadtree is used to display the charted depth at own-ship's position. It operates by calculating the x, y coordinate in the quadtree image of a geographical position, forms the appropriate quaternary and searches for it in the list. If found, the quaternary attribute is decoded and its value in metres of depth at own ship's position is displayed on the text screen. Navigation is assumed to be taking place at 'chart datum'; no tidal heights are included.

3.4.2.2 Look Ahead

See figure 3.20

The look ahead system is active in the chart's navigation mode when the 'Alarm' function is operational, it projects the intended Dead Reckoning track ahead of own-ship for approximately 15 minutes and samples 100 positions spanning the line - produced at equal intervals - for the local depth attribute. The look ahead line remains green if the DR is found safe; otherwise it is displayed in red. This method is somewhat crude and susceptible to missing small point dangers. A more sophisticated form of the track validation function was developed which will check the intended track and a safe distance swath specified by the user in an exhaustive and efficient manner. This is described in the next section

Operation of 'Look Ahead' System



The grounding warning alarm sounds if the proposed track crosses (say) the 10m contour.

'Look Ahead' uses 100 points sampled at equal intervals along the line in order to detect dangers

The Grounding Aviodance system – 'Swath Analysis' – is more rigorous and can detect dangers away from the line.

Fig 3.20

3.4.2.3 Swath Validation / Track Analysis

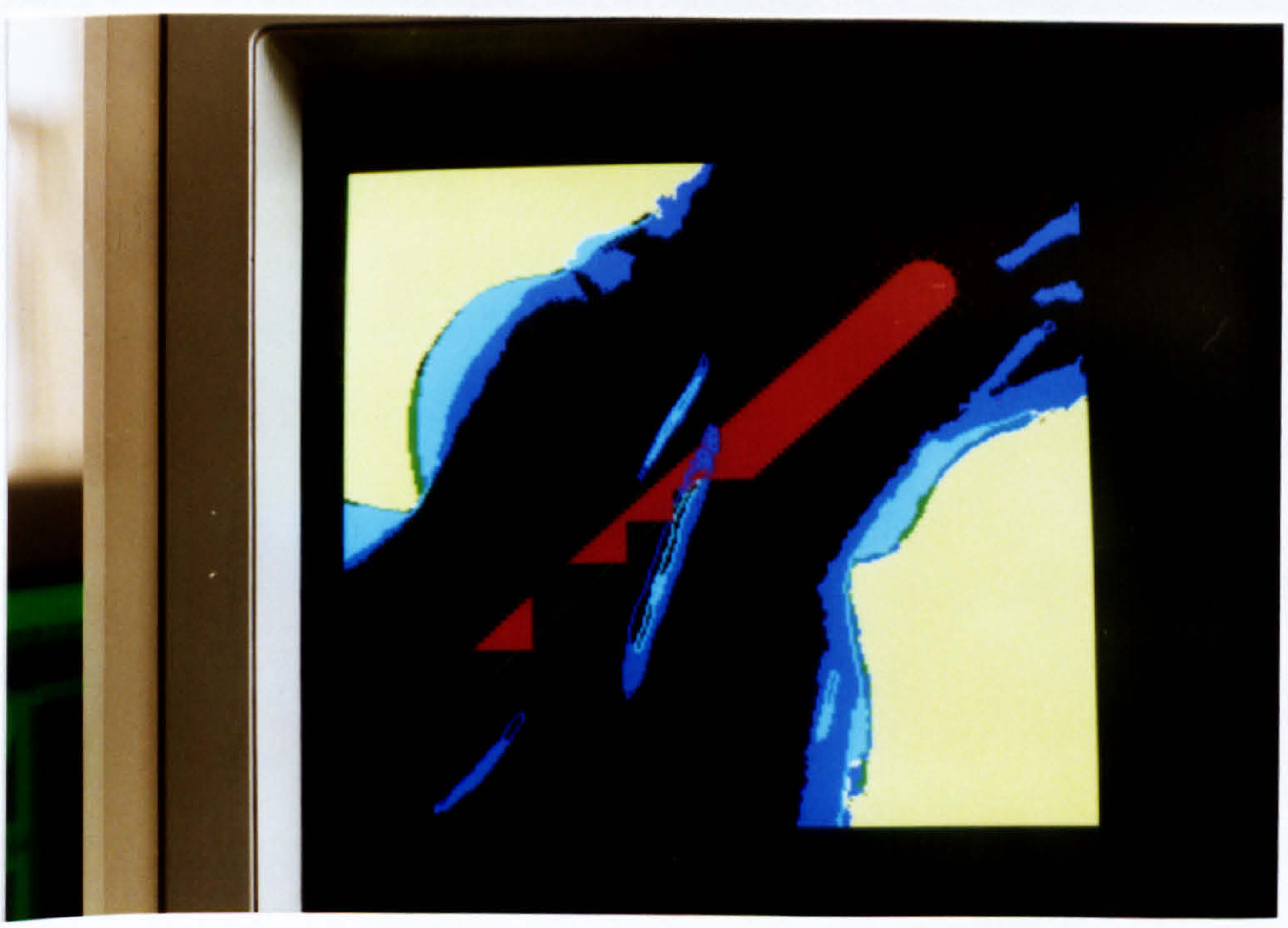
See Plate 17

A comprehensive technique was required to interact courselines with the quadtree; courselines require to be tested exhaustively and with a margin of safety on either side. An earlier project(56) produced such a routine to detect land constraints in an expert system using complex tesseral mathematics to search for quaternaries, test a track centreline and two further, derived tracks on either side. Since the quadtree resolution in this case was maximally 2km, there was no danger of missing quadtree nodes. In the case of the current project though, the quadtree resolution in the real world is variable and includes more levels. The approach used therefore avoided line interaction with the quadtree tessellation and instead, interacts the quadtree with the line. This novel technique allows the line to be treated as a single geometric entity, gives a rapid method for performing an exhaustive search for dangers and also permits any margin of safety to be accommodated. The approach is thus capable of providing a comprehensive track safety system for both the passage planning and on-line navigation phases. This software was implemented in demonstration prototype form, but not incorporated into the main ECDIS system due to time limitations.

3.4.2.3.1 Quadtree line inspection.

The routines used to perform swath validation of courselines are described in detail below.

Plate 17 Track Validation Algorithm in Operation



"The test line routine"

This function again uses a recursive algorithm similar to that given in Kingslake 'An Introductory course in Computer Graphics'

The routine proceeds as follows:

The top left quadrant at level 0 is tested against the line. ie the distance from the node centre to the line is checked against the node's size. If the node's centre is further from the line than the 'radius of influence' of the node, then the node is determined to be safe (too far away to have an effect).
Alternatively, if the node is sufficiently close to contain a hazardous object/attribute then the node's address is formed and searched for in the quaternary list. The quaternary list contains a complete coloured + white quadtree of the whole image. If the node is found in the list, its colour attribute is checked. White signifies safe water.
If it is safe, the test proceeds to the top right quadrant. If it is unknown whether the node is safe or dangerous, (ie the relevant quaternary has not been found in the list) the test drops a level and calls test_line, again searching the top left sub-quadrant first.
If any node found is known to be dangerous, the track is failed and the algorithm starts returning to clear the stack.

Note the similarity between this code and that described in the encoding section above, the function "prox_test" is substituted for "onecolour".

The line itself is defined by 4 global variables - x1,y1,x2,y2 which are referenced in the procedure "prox_test" through the subsidiary function "check_distance".

See figures 3.21 and 3.22. which show the principal functions from the line testing program in pseudocode.

"The prox test function"

This function tests the proximity of a quaternary node centre to the line being tested. If the distance of the node's centre is more than 5 pixels than the node radius (defined as the radius of the node's enclosing circle) the function returns safe. Otherwise, the node's attribute is checked by forming the appropriate quaternary, searching for it in the stored quaternary array, and returning the attribute.

3.4.2.3.2 Quadtree based Track Commentary.

In the examples discussed so far, quadtree line interaction has been based on depth information only. Further applications of the technique are possible involving other types of spatial objects such as traffic separation schemes, precautionary areas, anchorages etc or any other data distributed in a spatial (and possibly hierarchical) manner - for example The Sailing Directions. Potential thus exists for producing software giving a pilotage commentary of the route under consideration by inserting descriptions of areas, features and other objects in a list corresponding to the order in which they will be encountered.

Quadtree track validation

```
test_line(int start_x, int start_y, int level, int
max_levels)
{
int size;
int xmax;

level ++; //increases level each time the function is
            //called
if(level==9) return;

xmax =   (int)(pow(2.0,(double)max_levels));
size = xmax / (int)(pow(2.0,(double)level));

//TOP LEFT QUADRANT
test_result=prox_test(start_x,start_y,level,max_levels);

        if(test_result==NOT_KNOWN)
          {
          test_line(start_x,start_y,level,max_levels);
          }

    else if(test_result==DANGER)
          {
          output("Track failed");
          return;
          }
    if(level == 0) return;

    start_x += size; //moves search origin to TOP RIGHT

    etc............................
}
```

Fig. 3.21

Line Proximity Testing

```
int prox_test(start_x,start_y,level,max_levels)
{
 int dist=0;
 int result=0;
 qcode quaternary;          // 32 bits
 char buff[200];
 float size;
 int node_x,node_y;

      dist = check_distance(start_x,start_y,level);

      if(dist>5) return(SAFE);          //using 5 pixels in any
                                        //256 x 256 quadtree
                                        //as margin of safety
      else{
            //work out node centre so we can see it

            size = 256 / (int)pow(2.0,(double)level);
            size = size/2;

            node_x = start_x + size;
            node_y = start_y + size;

            pset(node_x,node_y,4); //shows the node
                                   //centre in red

            result = report(start_x,start_y,level);

            /*The report() function forms the quaternary
            to search for and uses a binary search to
            find it in the quaternary array. Report()
            is the point inspection function.*/

         if(result==SAFE) return(SAFE); // node white
                                        // wrt danger
    else if(result==DANGER) return(DANGER);
                                        // node black
                                        // wrt danger
         else return(NOT_KNOWN);
            }
 }
```

Fig. 3.22

3.4.3 2-Dimensional (2D) trees

Whilst linear quadtrees provide a useful indexing mechanism to spatial data, they offer poor performance in set operations or range searching although pointer based representations are capable of rapidly resolving requests of these types.

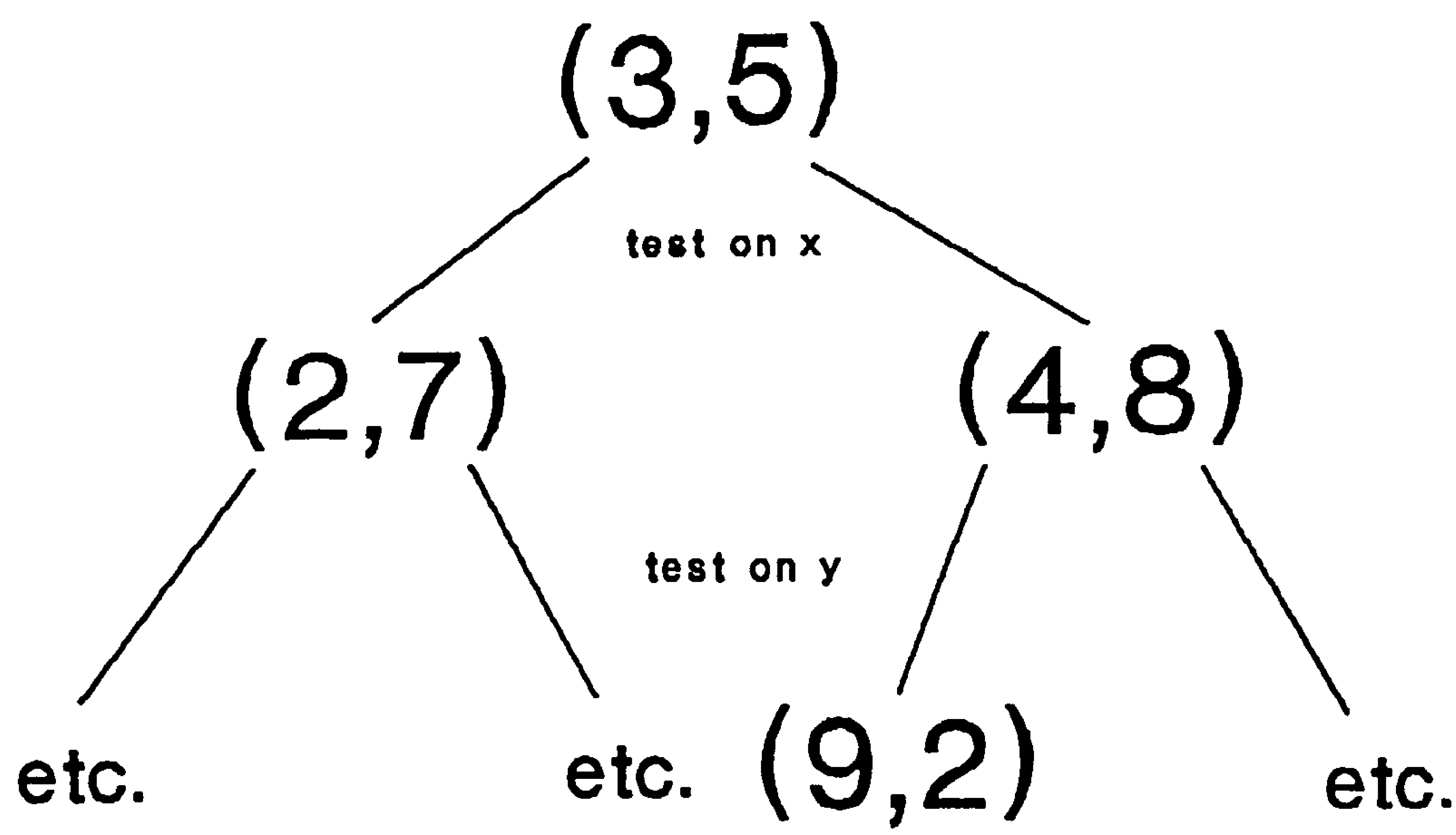
A method for indexing large datasets of point data was identified as a requirement early in the project, the method chosen needing to be capable of extracting a subset of a point database. Two - dimensional trees offer an elegant solution for establishing subsets of data within set limits of lat/long -ie within a geographic rectangle.

3.4.3.1 2D tree Principles

Two dimensional trees are a simple form of the generic k-dimensional tree structure attributed to Friedman and Bentley(57)

A two dimensional tree is a storage structure for point data comprising x and y coordinates plus the data fields. The tree itself is a binary tree, that is each parent node has two branches. The branch criterion at any level is either west/east or north/south depending on the magnitude of the x or y coordinate of the point to be stored compared with the parent node. The criteria for left/right branching in the tree is alternated between tests on the y coordinate and tests on the x coordinate at each successive level. 2-d trees are constructed and searched using recursive functions which toggle back and forth between x and y during tree traversal.

2-Dimensional tree construction



The above tree is formed from the points (3,5), (2,7), (4,8) and (9,2) inserted in sequence.
Within the electronic chart, latitude and longitude are used as the coordinate system and test criteria for storing an index to light list information.

Fig 3.23

As an example, the following points would build the tree in figure 3.23 on the previous page.

3,5

2,7

4,8

9,2

The first point, (3,5) forms the tree root.
Point (2,7) is inserted in the left branch of the root since 2 is less than 3. (4,8) goes in the right branch. When (9,2) is inserted, the algorithm first goes right at the root (9>3) swaps to testing the y coordinates and goes left (2<8). A full treatment of the tree construction and range searching operations is given in Sedgewick(58).

3.4.3.2 2D tree Application

See Plate 18

An Admiralty chart is designed to give a visual representation of data distributed over a specific geographical area. Information relating to chart features such as lights and buoys is also reproduced in a non spatial manner in the mandatory books carried on board. The representation contained in these publications will typically be more detailed than that carried on the chart. A specific area of interest is therefore that of finding a means of 'cross referencing' the spatial index (chart) with this textual information.

Plate 18 The Interactive Video Chart Catalogue

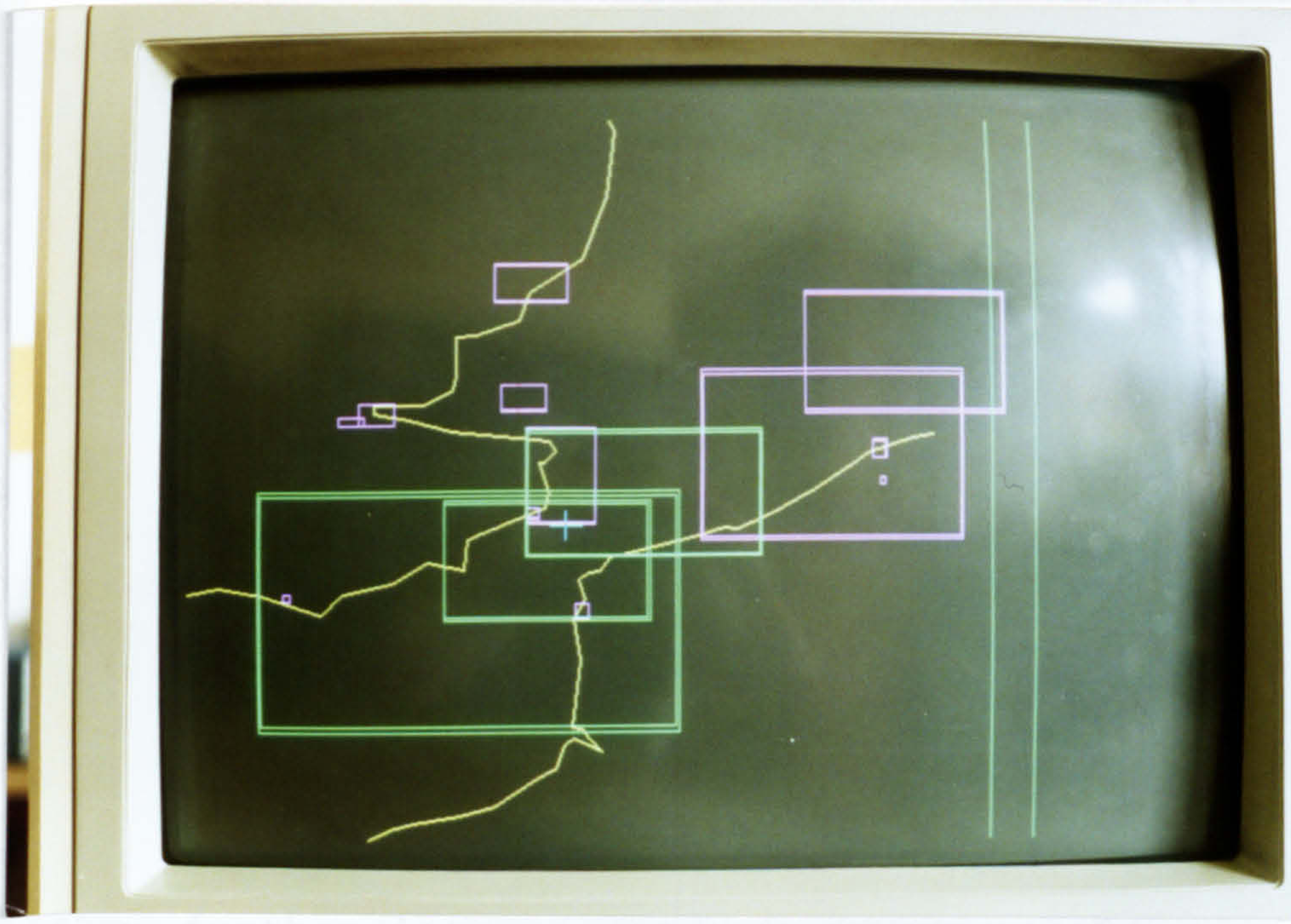


Plate 19 Light Selection Using Two Dimensional Trees

3.4.3.2.1 Lights

See Plate 19

A mechanism for searching for lights is demonstrated in the Electronic Chart. An open cursor activated by a single buttonpress on the trackerball is used to initiate the query, searching takes place over the area defined by the cursor and the text describing all the lights in this area are displayed. The same method is therefore able to yield groups of lights and single lights.

By using an appropriate algorithm, 2-d trees could also be used to yield temporary 'groupings' of points close to own-ship's track which can then be further interrogated. A useful example is taken from coastal navigation where an enquiry of the following form can be satisfied:

What lights are within 5 miles of my position?

or

Which is the nearest coastguard station?

3.4.3.2.2 Point data sets and chart scale

As chart scale decreases, the data displayed becomes a progressively sparser subset of the total data available. This is necessary since otherwise, the chart would be so densely packed with information that it would be impossible to read. Hence chart 2 of the British Isles shows only the major lights around the coast and omits all the smaller lights in ports etc. The problem of generalising this data truncation is widely recognised as being particularly difficult thus the proposed IHO data structure has avoided it by allowing duplication of information in different scale data-cells. In the case of a single and important type of data however it should be possible to perform this selection from the whole dataset. Lights therefore should include a minimum scale of presentation as one of their attributes, thus harbour lights might not be shown at scales of 1:100 000 or smaller. Alternatively, in this case, the display criterion could be based on the geographic range of the light.

3.4.3.2.3 Charts

See Plate 18

The 2D tree representation was also used to suggest a more effective chart selection algorithm. This resulted from a need to indicate the general availability of charts to the user due to the large number of charts in the Dover Strait area (a display of chart availability is also required by the IHO ECDIS specification). The 2D tree algorithm is able to form a subset of the total charts available based on those which overlap the cursor location. Thereafter, some might be eliminated as having their centres a long distance from the cursor to leave the four most appropriate charts available at the point of interest. ie a very small, a small, a medium and a large scale chart.

Section 3.5 The IHO DX90 Data Structure

3.5.1 DX90 data conversion

As stated earlier, the IHO has defined a data structure for the transfer of electronic chart data between the Hydrographic Offices and manufacturers. This is implemented in such a way that the full content of each chart cell can be transferred in a single file. The data itself is organised hierarchically with numerous linkages between data items. The DX90 structure is somewhat cumbersome to decode into a simpler display format and will therefore require that an appreciable software development effort is made by would-be suppliers. Nevertheless, the test graphic supplied with the DX90 specification was decoded into a simple vector file and a program developed to display it, in colour, on a graphics monitor. See Plate 20. It seems likely that the onward development of a full system for handling large quantities of DX90 data on a commercial basis will require a substantial effort, not least because of a requirement to maintain a Quality Assurance system alongside the data supply operation.

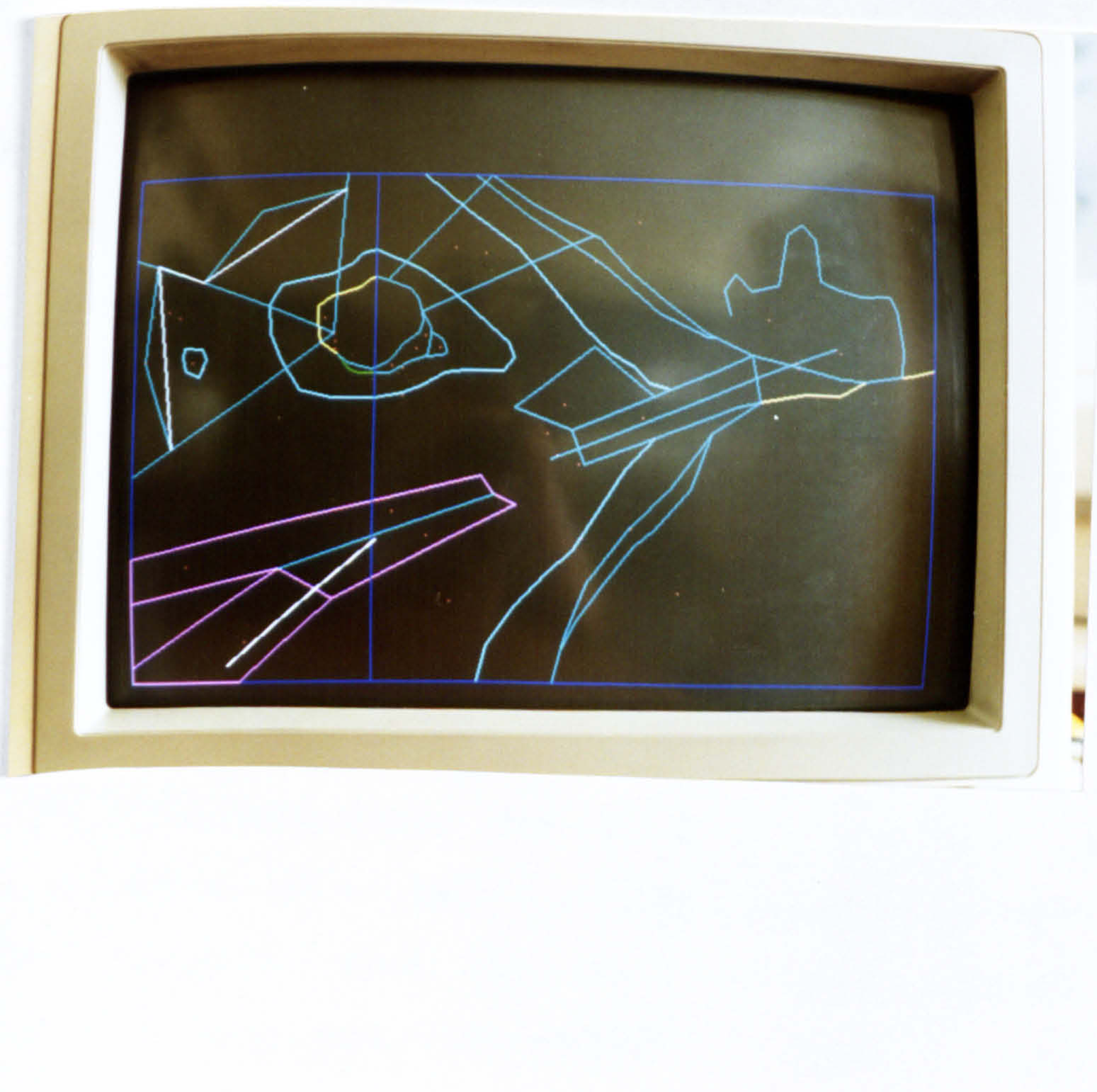
3.5.1.2 DX90 principles

DX-90 is the popular term used for the "IHO Transfer Standard for Digital Hydrographic Data". The standard is described in three main parts: Part A - the Object Catalogue; Part B - DX90 (The data format itself); Part C - the digitizing (Transfer Conventions).

DX90 is to be used for the exchange of New Data for ECDIS, Update data for ECDIS, Data for the production of paper charts and hydrographic survey data.

Understandably, as a result of these comprehensive requirements and the need to exchange data between nations in a "media independent"

Plate 20 The IHO DX-90 Test Graphic



manner, the standard is complex and, as stated earlier, will require some effort to use efficiently.

3.5.1.3 SP57 - Part A 'The Object Catalogue'

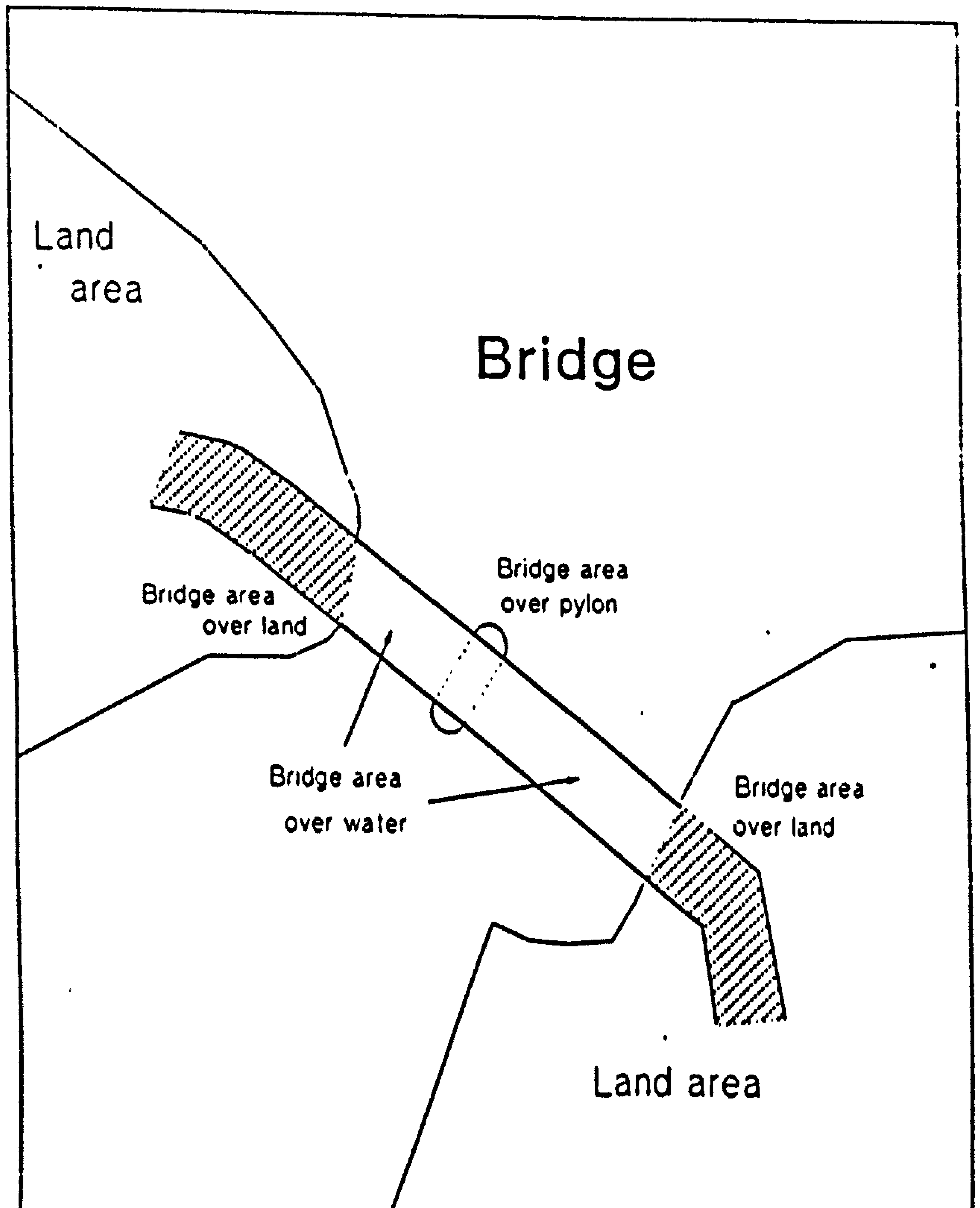
Formally, the Object Catalogue is based upon the model theory of modern cartography. This is the foundation for a 'Hydrographic Situation Model' and a 'Presentation Model' which together form the conceptual basis of the IHO data exchange specification. The Object Catalogue defines the data types that can be exchanged. It comprises a comprehensive catalogue of objects that are found on charts, defines a syntax in which they can be described and gives the symbols with which they should be presented to the user.

Some examples are given below

See figures 3.24 to 3.26:

Bridge (p A-2.19)
Coastline (p A - 2.43)
Traffic Separation Scheme (p A-2.170a)

Each object can also have certain attributes assigned to it; for example, the attribute-class 'characteristic of light' encodes the principle character of a light i.e. the rhythm. Care must be taken to ensure that confusion does not arise between objects and their attributes. e.g. Attribute code OBJNAM - 'name of object' is an attribute of the object.



Object-class 'Bridge'

IHO Object definition

'Bridge'

Object - Class:	Bridge

Code: BRIDGE

Reference INT 1: not specified

Chart Specification: not specified

Set Attribute_A: OBJNAM; CATBRG; CONDTN; NATCON; COLOUR; HORCLR; QUAVEM; VERCLR; VERCOP; VERCCL; CONVIS; CONRAD;

Set Attribute_B: SCAMIN; SCAMAX; INFORM; PICREP;

Set Attribute_C: SORIND; SORDAT; RECIND; RECDAT;

Geometric Primitive: Point; Line; Area;

Definition:

A structure erected over a depression, obstacle or water to carry traffic.

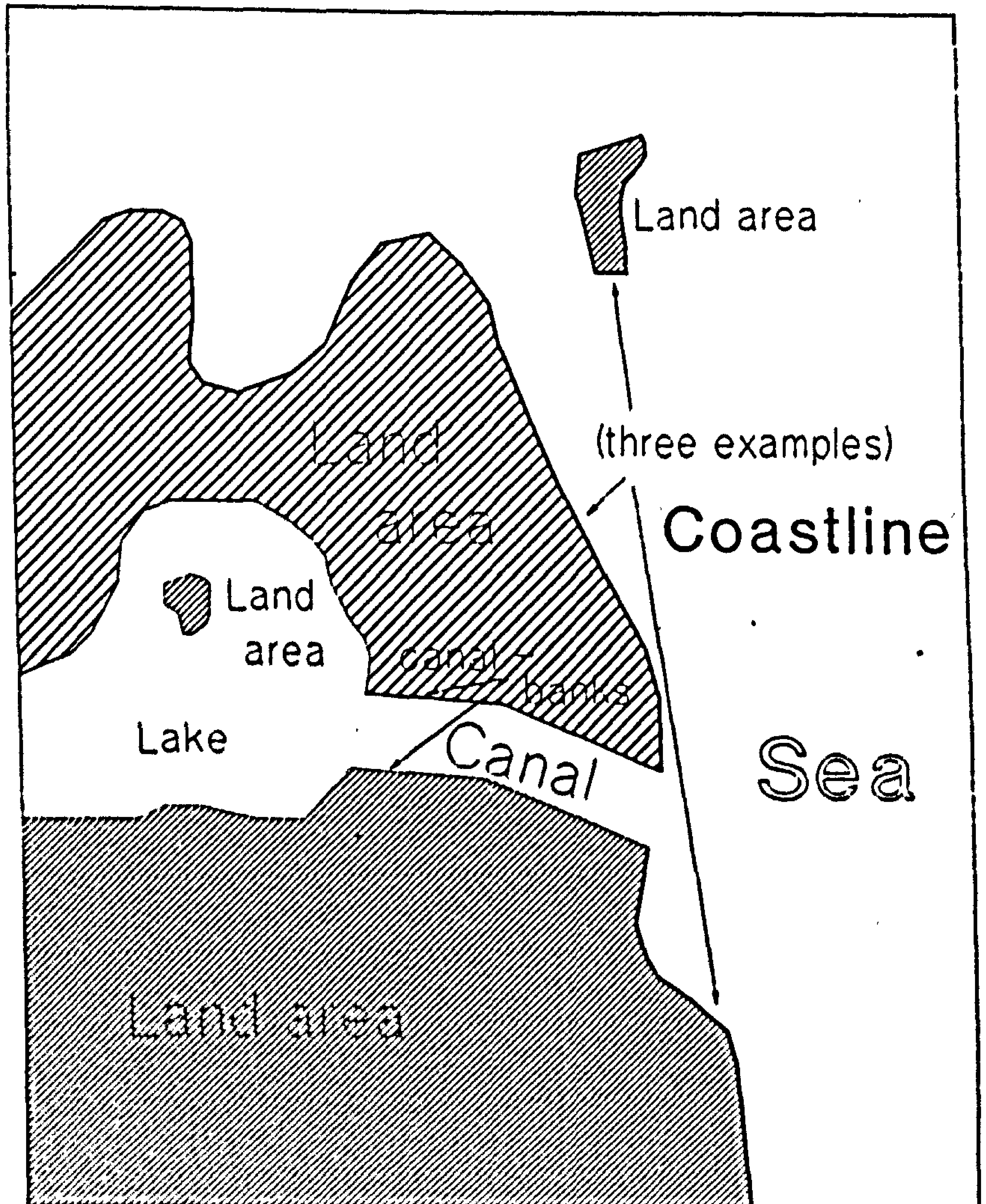
(USGS Jan.89)

Remarks:

A bridge may consist of the areas which cover the tract on land and on water underneath.

(see sketch)

Fig. 3.24



Object-class 'Coastline'

IHO Object definition 'Coastline'

Object - Class:	Coastline

Code: COALNE
Reference INT 1: not specified

Chart Specification: not specified

Set Attribute_A: OBJNAM; VERDAT; QUAVEM; HEIGHT; CONRAD;

Set Attribute_B: SCAMIN; SCAMAX;
Set Attribute_C: SORIND; SORDAT; RECIND; RECDAT;

Geometric Primitive: Line;

Definition:

The coastline is the limit line between land area and the area permanently or temporarily covered by water (e.g. sea area, intertidal area).

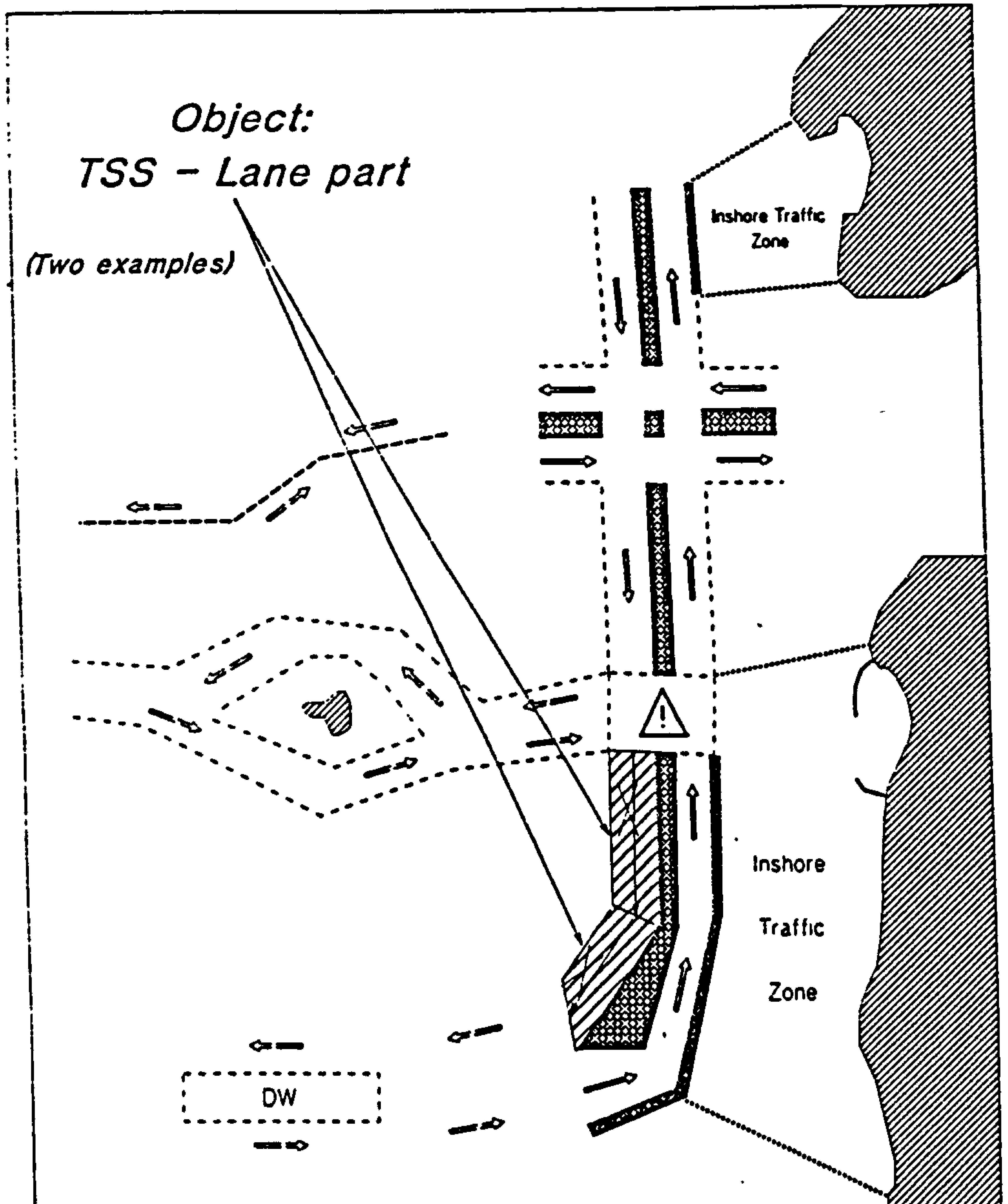
'Coast' is the term used with reference to the land, while 'shore' is the term used with reference to the sea.
(Int.Mar.Dictionary 2nd Ed.)

Remarks:

Distinction: river-bank; zero meter-contour; canal-bank; lake-shore; shoreline construction;

(see sketch)

Fig. 3.25



Object-class 'TSS – lane part'

IHO Object definition 'Traffic Separation Scheme'

Object – Class:	Traffic Separation Scheme – Lane part.

Code: TSSLPT

Reference INT 1: not specified

Chart Specification: not specified

Set Attribute_A: CATTSS; STATUS; ORIENT;

Set Attribute_B: SCAMIN; SCAMAX;

Set Attribute_C: SORIND; SORDAT; RECIND; RECDAT;

Geometric Primitive: Area;

Definition:

The TSS lane part is an area of a traffic lane with exactly one direction indicating the flow of traffic.

The complete traffic lane consists of one or more lane parts depending on the various shape of the lane.

Remarks:

The object 'Traffic Separation Scheme – Lane part' is defined to enable the presentation of the direction of the traffic flow (independend of the presented area on the screen).

The orientation of the lane part is defined by the 'middle-line' of the lane part – area relating to the general direction of the lane and is encoded by the attribute-class 'orientaion' (ORIENT). The orientation of the lane part replaces the 'arrows' under IM 10, 11. (see sketch)

Fig. 3.26

The Object Catalogue follows the usual rules of relational database theory; thus, for example, a light consisting of more than one light sector must be represented in terms of as many objects as there are light sectors.

Some objects are defined to be 'Composite Objects' - this relates to their association with other objects in a meaningful way - for example a buoy marking part of a traffic separation scheme. Others are solely cartographic in origin having no counterpart in the real world e.g. the compass rose.

The final part of the object catalogue defines the chart symbols that must be used in presenting data to a user on a paper chart. New symbols for ECDIS are still being defined by the IHO Colours and Symbols Working Group.

3.5.1.4 SP57 - Part B 'DX-90'

Part B is the definition of DX-90 itself covering both the semantics (meaning) and the syntax (structure) of files used to transfer information. The specification is based on ISO 8211 (59).

It should be noted that ISO 8211 states that the data format it describes is for exchange purposes only; it is not designed for general processing. A number of features of the standard make this obvious. For example it states

" ... if possible, all information necessary to successfully recreate the structure in the target system should be contained within the information transported on the medium"

Furthermore, the data is transferred using a minimum of four files (Data Set Description, Catalogue, Data Dictionary and Feature Files) which together, and including their internal structure, form a tree structure. Numerous links and cross references between records also inhibit direct processing of files transmitted in this form.

3.5.1.5 DX90 application

3.5.1.5.1 Conversion and Redraw

DX90 data was decoded and redrawn with some difficulty.
The approach taken was "a fudge" with respect to the DX90 structure as a whole, however it produced data capable of being redrawn on a VGA graphics screen. This is recognisable as the test graphic issued by IHO in 1991. (See Plate 20) Two programs were developed. One program converts the IHO data into 3 sequential files. These are simpler to read for the redraw program. A second simple program redraws the data.

The decoding software operates in the following manner:

See figure 3.27

1. The software provided by IHO is used to convert the original dx90 files into the .DAI format.

2. The .DAI file is then separated into two. The .DAI file is left

DX-90 Data Translation

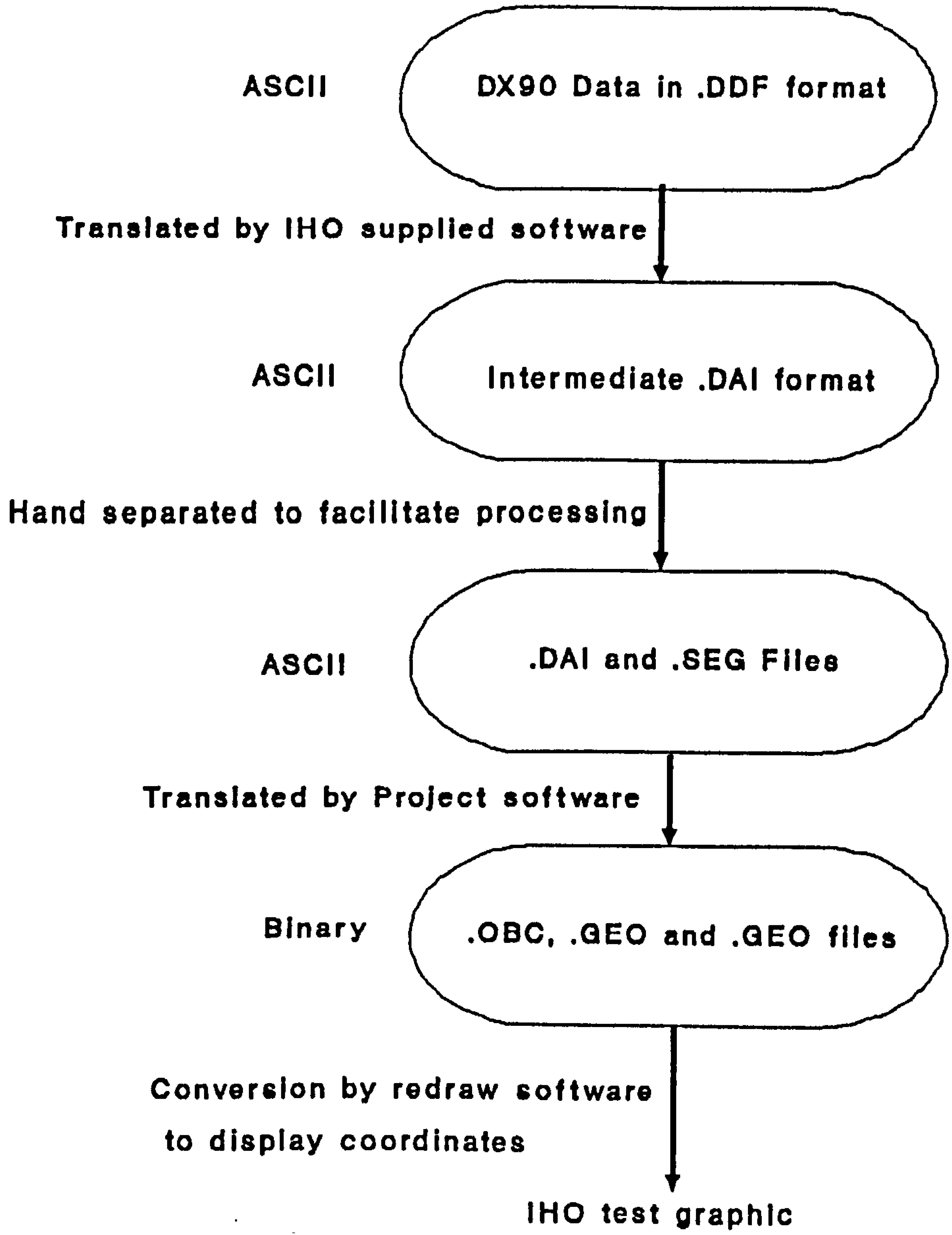


Fig. 3.27

containing the object codes, feature identifiers and segment numbers, a .SEG file (derived from the .DAI file) contains the segment information and coordinates. The data held in these files is in ASCII.

3. The translation software then operates on these two files to produce a further three files containing: (a) the object codes; (b) the number of cartographic line segments per object; (c) the geographic coordinates contained in each segment. These files are in binary (floating point) format.

4. The redraw program uses the three data files above to trace out the data on a VGA screen.

The program fragment in figure 3.28 is the function which actually draws out the cell and the colour setting function in figure 3.29 shows how the IHO object codes are equated to display colours in the redraw program. eg Traffic separation schemes are displayed in magenta.

Section 3.6 Comments on Chapter 3

3.6.1 Organisation of disc series

Two discs were produced for the project, one covering the Irish sea and the other the English Channel. Both provided adequate chart coverage of these areas for test purposes. However, the Channel disc was produced using an improved method of photography and was significantly easier to produce. The most substantial difference

The DX-90 Redraw Function

```
redraw_cell(char *string)
{
float lat,lon,lat1,lon1=190.0;
int points=0;
int object_code,number_of_points,i,j,num_segs;
int colour;

open_data_files(string);

  while(!feof(object_fp))
  {
  lon1=190.0;
  //get the object feature code
  fread(&object_code,sizeof(int),1,object_fp);
  //set the feature colour
  setcolour(object_code,&colour);
  //get the number of segments in the feature
  fread(&num_segs,sizeof(int),1,object_fp);

  for(j=0;j<num_segs;j++)
  {
  fread(&number_of_points,sizeof(int),1,coord_offsets);

     for(i=0;i<number_of_points;i++)
     {
        fread(&lat,sizeof(float),1,coord_fp);
        fread(&lon,sizeof(float),1,coord_fp);

         if(number_of_points>1)
           {
           if(lon1!=190.0)
           //draw the line
           LINE(lon,lat,lon1,lat1,colour,0);
           lon1=lon;lat1=lat;
           }
         //otherwise mark text location
         else pset(lon,lat,12);
     }
   lon1=190.0; //'pen up'
  }
}
 close_data_files(string);
```

Fig. 3.28

DX-90 Object Identification

```
setcolour(int object_code,int *colour)
{
switch(object_code)
     {
     case DEPARE: *colour=9;            //Depth area
               break;
     case DEPCNT: *colour=11;           //Depth Contour
               break;
     case LNDRGN: *colour= 14;          //Land Region
               break;
     case $CLOLN :*colour= 1;           //Cartographic closing line
               break;
     case $TEXTS :*colour= 15;          //Text Location
               break;
     case ITDARE :*colour= 2;           //Intertidal Area
               break;
     case TSS     :*colour= 13;         //Traffic Separation scheme
               break;

     default: *colour= 3;
      }
}
```

Fig. 3.29

between the two discs was the use of a larger Rostrum Camera capable of scanning a whole chart.

3.6.2 Chart Corrections

The provision of chart corrections was prototyped using graphical overlays. Each chart should have its own set of corrections which would be automatically loaded and displayed each time the chart is used. The DX90 data format supports chart corrections and they will be provided within ECDIS using this data format. It is anticipated that chart corrections will be sent to ships either on a floppy disc or via a satellite communication system in a manner similar to that prototyped successfully by the Norwegian 'Seatrans' project (11).

3.6.3 Selective display of chart features

It is not possible to add or remove chart features with interactive video. The prototype does however, allow certain classes of chart symbols to be highlighted and accessed using a cursor. Once the chart is fully supported by its database, there is no particular reason why symbols should need to be highlighted. Instead, the user should be confident that on selecting a chart symbol, the information relating to it will appear. The advantage of interactive video in this context is that the paper charts from which the electronic display is derived have been laid out carefully prior to printing and are thus less cluttered in appearance than electronic overlays.

3.6.4 Accuracy of Position Fixing

All position fixing systems have their limitations. Some such as Decca and Loran can vary in their accuracy according to the season, relative distance from land and distance from their transmitting stations. Others such as visual or radar methods are subject to quantifiable errors. It is a generally held principle in marine navigation that reliance should never be placed on a single system. Instead, the most accurate available is used, and cross checked with other methods. This means that any breakdown is found rapidly and the transition made to the secondary system smoothly.
ECDIS must reflect this practice.

3.6.5 Vector Representation of DX90 data in the Electronic chart

Owing to the use of interactive video, the various vector data structures commonly used in GIS were not investigated. It is nevertheless the case that they could yield useful results in an electronic chart because the IHO data exchange format is specifically a vector representation. A number of vector data structures providing advanced functionality are discussed in Mather(60).

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Electronic Chart'. Proceedings of Control Applications in Marine Systems 92 (CAMS '92) Genoa.

CHAPTER 4

Trials and Results

Chapter 4

Trials and Results

The first section of this chapter describes the early trials conducted on the Electronic Chart prototype in the simulator at Liverpool and the second section, the observations made at sea with both the research prototype and the first version of the Kelvin Hughes commercial electronic chart. The third section places the research work conducted at Liverpool in context, with a discussion based on a comparison of the results of this project with the results of two others.

The trials based in the radar training simulator were designed first to test the usability of the chart in terms of its basic concept and second, to test the navigational utility of the system. These trials used members of the Maritime Studies Department teaching staff, students attending professional courses and some completely independent practising mariners to test the system. In addition to the formal trials, the electronic chart was demonstrated on a regular basis to Pilots' refresher courses from which some useful discussion also emerged.

4.1 Simulator Trials

Plate 21 shows the system installed in the simulator at Liverpool Polytechnic.

Plate 21 The System Undergoing Simulator Testing

4.1.1 Test Design

The Simulator Trials had 3 principal purposes:

a) To establish whether the interactive video display method was acceptable to practising mariners as the basis for an electronic chart display. This assessment included testing the means of handling the chart using scrolling and zooming, basic colour perception, information collection and readability.

b) To test the usability of the navigational tools connected with the chart (Waypoint Editor, Electronic Bearing Markers, Information Outputs etc) under semi-realistic conditions.

c) To provide the opportunity for testers to suggest improvements to the system according to their own perceived requirements.

It was considered that attempts to measure the effectiveness of the system in terms of variables within a statistical model would impede the free exchange of views and ideas. It was also felt that the broadest possible range of feedback from different groups of mariners needed to be encouraged in order to provide a sufficiently critical sounding board. Therefore an interview / questionnaire / discussion technique was used, this having proved successful in earlier studies(32). It was also the approach, used independently, by the Netherland's ECDIS sea trials(13).

The first task set was the preparation of a passage plan crossing the Dover Strait between Dover and Calais. This introduced the people involved to the system and helped them to become familiarised with the display method, the navigation graphics and system controls. It had originally been the intention to introduce simulated collision avoidance targets and tidal streams as trials progressed, however time constraints prevented this. Nevertheless, realistic simulation conditions were achieved with respect to an accurate own-ship position and motion display. In general, the simulated radar images were compatible with the chart, although port development works at Calais had substantially modified the shape of the harbour entrance. Since nothing could be done to rectify this, it was decided in advance that subjects would not be notified of the discrepancy, but would be left to see if they discovered this incompatibility between the simulator radar data and chart for themselves. It was hoped that this would help to assess whether the presentation of a real time navigational display based on chart data tempted the user to use radar less as a position comparison method.

Own-ship was placed, stopped, at a point approximately 1.5 miles east of the Eastern Breakwater at Dover. The test subjects were shown how to operate the chart display and its navigation functions. They were then given a further 20 minutes to prepare a passage to Calais. Once they were satisfied that their plan was complete, they were asked to navigate own-ship along the tracks they had prepared. Once own-ship was making satisfactory progress, the subjects were asked to complete a questionnaire and invited to discuss their reaction to using the system. Where time permitted, some were able to enter harbour at Calais. The vessel type used was a cargo ferry. 10 subjects completed the trial.

4.1.2 Responses to the Questionnaire

The complete questionnaire is reproduced below with the responses given by testers.

Test Questionnaire

Thank you for completing the simulator exercise. This questionnaire provides an opportunity for us to find out how you reacted to the system as you used it and gives you the opportunity to record any feelings about how you think it may be improved for use at sea. Your answers will be used in combination with the those of other people only. Individual's responses will remain confidential.

Many questions provide tick boxes for answering. If you feel you wish to make any additional comments please write in the space below the question.

CHART

1. Does the area of the chart on display allow you to carry out chartwork to your satisfaction? Yes() No().

Responses: Yes: 7 No: 3

Some respondents felt that they lacked sufficient practical experience to comment definitely at this stage however most would have preferred a 'larger' area of readable chart to be displayed. (See question 4.)

---

2. Is the speed and flexibility associated with viewing different portions of the chart satisfactory? Yes() No().
Is it good(), adequate(), poor()?

Responses: Good: 1 Adequate: 8 Poor: 1

Again, a lack of experience was mentioned as a drawback in using the system. Many subjects found that the zoom operation as currently provided caused confusion since the sequence in which charts of progressively larger/smaller scale were presented could differ.

---

3. Could you find all the chart information you needed? Yes() No().

Responses: Yes: 7 No: 3

Two respondents mentioned the lack of tidal height and stream data

---

4. Should a larger readable area of chart be displayed?

Responses: Yes: 7 No: 1 Don't Know: 2

Some subjects found the question ambiguous, two mentioned a desire for a third intermediate level in the photography.

NAVIGATION AND CHARTWORK.

5. Did your chartwork and navigation techniques change substantially when using this Electronic Chart? Yes() No().

If so, in what way?

Responses: Yes: 3 No: 7

Continuous position update was mentioned as a positive consequence of having the system. Another subject felt that the system was focussed more towards reaching the overall navigational destination than an aid to situation monitoring. This may be have been partly due to the low situation monitoring requirement implied by an exercise without tidal stream or targets.

---

6. Did you pay more or less attention to the radar for positioning information than usual? Yes() No().

Responses: No response: 2 More: 0 Same: 3 Less 5

One subject emphasised that he checked the radar once on leaving harbour but did not bother otherwise.

Comment: Most subjects were prepared to trust implicitly the 'GPS' positions given by the system. Subjects were not told that the harbour entrance at Calais was substantially different on the chart to that held in the simulator due to expansion works undertaken at the port in 1990. Not all subjects found this out for themselves.

---

7. Did you cross check the radar against the chart display for consistency of positioning?

Yes() No().

Responses: Yes: 6   No: 3   No response: 1

See comment on 6 above.

---

8. Roughly what relative amounts of time did you use 'close in' and 'wide angle' chart photographs?

Close in _____%, Wide angle_____%.

Responses:

Passage Planning	- Close in: 65%	Wide angle: 35%	(Arith. Mean)
On-Line	- Close in: 62%	Wide angle: 38%	(")

Comment: These estimates (albeit crude) suggest that the close up frames were used more than the wide angle frames but that the wide angle frames provide essential utility in navigation.

---

9. What scale charts did you use most?

Large scale (small area) ()

Small scale (large area)()

No real preference()

Responses: Large: 4   Small: 1   No preference: 5

(Some confusion arose in the use of the terms large and small scale)

---

10. At what intervals did you estimate cross track error? (Distance off track) ____________ minutes.

Responses: Continuously: 2 every 3 mins: 1 No response: 7

Most felt the question irrelevant due to lack of tidal stream input in the exercise.

MORE OR LESS INFORMATION?

11. In general, is the overall presentation of information acceptable to you? Yes(), No().

Responses: Yes: 8 No: 2

The two respondents who gave a negative response felt that tidal stream information was important. This may have been influenced by the previous question.

Questions 12, 13 and 14 ask what you think about the relative values of different types of information presented. Please read through questions 12,13 and 14 before answering them.

12. What additional information, do you feel would be essential?
13. What additional information, do you feel would be useful?
14. What information shown do you feel is confusing or not useful?

Responses:

The responses as given were not differentiable under the headings given by the question. However, all of the following were identified as necessary by some or all of the respondents:

Wheel over positions, Radio reporting points, Call Master and Standby positions. Tidal height and stream information, Course Made Good, Speed Made Good, Heading, Engine Speed. ETA at waypoint in time to run. Radar targets and target analysis, Own ship track history. Navigation Warnings, Sailing Directions.

Comment: Some of the above information was available but not found by the subjects. One subject noted that there were 3 different heading outputs being displayed to him in different places on the bridge during the exercise. Of particular interest to future work however is the need to clarify the presentation of the navigational situation as it relates to ground track versus water track. This is particularly important prior to any attempt to display radar targets. Furthermore, should target information be made available in future, there must be no doubt as to whether they are being displayed in true or relative modes. (This is the subject of extensive discussion later.)

SYMBOLS AND COLOURS.

15. Is the symbol used to show own ship satisfactory? Yes(), No().

Responses: Yes: 10 No: 0

One subject pointed out that own ship displayed as a 'mimic' symbol is only valid if positioning is extremely accurate (relative to the scale of the chart.)

---

16. Is the symbol used to show the trackball cursor satisfactory? Yes(), No().

Responses: Yes: 10 No: 0

The simplicity of the symbol used was appreciated by the participants.

---

17. Is the symbol used to show the Electronic Bearing Line satisfactory? Yes(), No().

Responses: Yes: 10 No: 0

One respondent appreciated its similarity to most ARPAS

---

18. How did you feel the colours used for the chart picture compared with those of a paper chart?

Same(), No Opinion(), Different()

Responses: Same: 9 No Opinion: 0 Different: 1

One respondent felt that the colour rendition was flat by comparison with the paper chart.

---

19. In general, were the lines you placed on the chart easily visible to you? Yes(), No().

Responses: Yes: 10 No: 0

One subject felt that the track line could obscure part of the own ship symbol.

---

20. Would you have preferred alternative colours or styles of line? (Please specify)

Responses: 7 were happy with the lines as given.

2 gave no response

1 expressed a desire for map-lines to mark danger areas and safety limits.

CONTINUOUSLY DISPLAYED INFORMATION.

21. Do you consider that the numerical display of Electronic Bearing Line (Range and Bearing) information was acceptable?

Yes(), No().

Responses: Yes: 9 No: 1

One respondent was unable to access the 'free' range and bearing marker.

---

22. Do you consider that the continuous display of the geographical position of the trackball cursor is necessary?

Yes(), No().

Responses: Yes: 7 No: 3

One subject would have preferred 'distance from nearest point of danger'. Another felt that it was necessary in passage planning only.

---

23. Do you consider that the continuous numerical display of own ship geographical position is necessary? Yes(), No().

Responses: Yes: 8 No: 2

One commented that this could be invaluable in search and rescue operations.

24. What is your opinion on the continuous display of chart information (ie Chart Name, scale, projection and publication date)? Useful(), No Opinion(), Not useful().

Responses: Useful: 6 No opinion: 2 Not useful: 2

One subject commented that it was not particularly relevant to the exercise but should still be there.

---

25. Is there any information you feel should be continuously displayed and isn't?

Responses: Currently satisfactory: 7

One subject felt that time to go to next waypoint should be displayed rather than time on arrival at the next waypoint.

---

26. Is there any information you feel should not be continuously displayed and is?

Responses: Currently satisfactory: 9

One respondent would have preferred time to next waypoint on the chart itself.

HISTORICAL OR OLD INFORMATION.

27. Did you find ownship's past track useful?

Yes(), No().

Why?

Responses: Yes: 7 No: 2 No opinion: 1

Two subjects commented that this helped them to assess the trend of own-ship's motion. Another commented that it led the eye to own-ship.

28. Would you find the presentation of any other historical information useful? Yes(), No().

What type of information are you considering?

Responses: Yes: 2 No: 8

One positively requested targets and their trails. Another requested 'course alterations'.

YOUR OPINION.

29. Has your opinion of the Electronic Chart changed as a consequence of participating in this trial ?

How?

Responses: Yes: 2 No response: 8

This question had assumed that a certain resistance to the introduction of Electronic Chart technology would exist prior to the trial. Most of the responses were, however, extremely enthusiastic.

30. Do you consider that the two screen presentation is suitable?

Yes(), No().

Responses: Yes: 8   No: 2

One would have preferred a 'larger' chart display. The intention of this comment is not clear. Another would have preferred a second screen showing chart sizes and 'area discrimination'. It is possible that this suggestion was given to assist in chart selection.

---

31. Would you prefer only one screen? Yes(), No().

Responses: Yes: 3 No: 6 Don't know 1

---

32. Where alarms are used, would you prefer them to be visual, audible, or a combination?

Audible(), Visual(), Combination(), No preference().

Responses: Combination: 9 Don't care: 1

Most responded that the sound element of a combination alarm should be cancellable.

---

33. Would you use this electronic chart at sea? Yes(), No().

Why?

Responses: Yes: 9   Not yet: 1

Some subjects added substantial positive comment. This is given later.

Please feel free to add any other points you wish to make that have not been covered by this questionnaire.

The Liverpool Polytechnic Electronic Charting Research Group would like to express their sincere thanks to you for your participation and cooperation in this study.

4.1.3 Comments by trials participants

In response to question 33 the following further comments were made:-

(I would use this chart at sea) "On the basis of checks against / with other systems."

(I would use this chart at sea) " but doubt if I would use it in pilotage and berthing phase yet. At this stage, I would use 1. Visual 2. Radar/Visual until absolutely confident in ECDIS from experience in clear weather and given assurances about the accuracy of own ship position and state of chart update."

"Obviously it is still in its early stages, and to replace the conventional chart is too much to ask presently, but with time and experience on the type of vessel I am used to (liner trade service) it could become a major part of the navigational equipment. It is ideal for getting an immediate assessment of the vessel's position in the case of a master being called to the bridge, however it should not be used instead of conventional position fixing and that is why I believe it will take time before it is accepted."

" (Due to) more accurate navigation the watch handover would be more safe and positive. In the event of an accident a more definite position is fixed. Fog situations would be alleviated ie entering port or in the Channel."

"I feel it will be an essential part of the bridge equipment allowing the Officer of the Watch more time for anti-collision work and less time correcting charts."

"I would find this AID to navigation extremely useful when navigating in waters in the Dover Strait area. Combined with ARPA, I would feel very comfortable when crossing over, knowing that I can monitor my progress from the screen and engage in anti-collision without having to lose any continuity by going backwards and forwards to the chart table / room. Any necessary alterations in course and speed for collision avoidance purposes would not present any navigational problems because I would always be aware of my orientation and position. A very useful and excellent tool."

Most of the mariners to whom the system was demonstrated appreciated the possibilities associated with electronic charting. They possessed a high degree of imagination and easily related to the idea of using such systems at sea themselves. Several had seen electronic chart plotters in operation at sea previously, though none had personal experience of using ECDIS.

Section 4.2 Sea Trials

4.2.1 M.V Shell Technician

M.V. Shell Technician is operated by Shell U.K. Ltd for the transport of refined products to depots around the British Isles. Her regular schedules frequently take her to Ireland and Western Scotland. The prototype system was installed for a demonstration trial on board, for one day in Spring 1992. The purpose of the exercise was to find a suitable location for the equipment on the bridge, develop an installation procedure and introduce the ship's crew to the possibilities offered by the equipment. Further, more ambitious trials involving a sea passage were to have been conducted in late Spring and early Summer however, the semi-permanent installation of a working commercial prototype of the system aboard a cross channel ferry pre-empted the situation.

The trial with 'Shell Technician' did provide useful insight.

1. It represented the first occasion that 'live' GPS positions had been placed on the chart. The first positions displayed were remarkably close to own-ship's visual position in the south west corner of Queen Elizabeth Dock - Eastham. (It should be noted that this was not attributed to any inherent accuracy of the system - further positions obtained from GPS displayed the characteristic errors caused by 'Selective Availability')

2. During a short passage from Eastham Lock to Stanlow Oil Dock, the comparison of visual position with the chart could be made directly,

since own ship's track was effectively contained by the channel width of the Manchester Ship Canal. The GPS track was observed to 'wander' in an unpredictable manner from bank to bank. This, above all else, emphasised the need to implement a more accurate positioning input before the system could be relied on for pilotage work.

3. It was the only occasion thus far that the equipment has been powered from ship's supplies. Given the addition of an Uninterruptable Power Supply (UPS) unit to the computer's power input, all the equipment operated satisfactorily from the vessel's 240v domestic system without further modification. This was reassuring.

4. The ship's crew considered that they would feel most benefit from a similar system in poor visibility during port entry. Again, a desire to see radar targets on the chart display was expressed.

In summary, the exercise demonstrated the feasibility of installing the system for test purposes and again elicited a positive response from professional mariners. Above all however, this was the first time that the electronic chart had been placed in the environment for which it had been designed; giving the opportunity for visual confirmation of the chart and positioning output.

4.2.2 'M.V. Stena Britannica'

Stena Britannica is a large Roll on - Roll off Ferry operated by Sealink Ltd on the Harwich - Hook of Holland route. A brief visit was made to this vessel to observe the commercial electronic chart prototype installed by Kelvin Hughes for trials and demonstration purposes. No formal programme was arranged for the visit.

The chart display unit was situated at the left hand end of a group of three consoles on the starboard side of the bridge. All the units faced forward. The centre console was a dedicated 'Nucleus' raster scan radar, the right hand unit was a 'Navigation Display' Computer. These three systems together form part of the full 'Integrated Bridge' discussed in the next chapter. During the visit, it was evident that radar target information was being automatically transferred from the 'Nucleus' radar to both of the other systems. In particular, targets and their vectors were being shown on the chart display. Both the navigation display and the chart were pre-programmed with route information and were tracking own-ship's position without the intervention of the ship's staff. Although the system was not being used for navigation, the Officer of the Watch was enthusiastic about the possibilities offered by by ECDIS and discussed the three displays at length. Again, this visit gave a valuable opportunity to see the electronic chart in its operational environment.

Section 4.3 Comparison with other ECDIS trials

Several ECDIS projects have published sea trials recently. Two important evaluations were made by the 'Seatrans'(11) project and the Netherlands Naval Academy. The sea areas concerned in each of these studies are dramatically different. The Netherlands project was concerned with the shallow shelf and estuaries of the eastern part of the southern North Sea in the vicinity of Europort; the Norwegian project dealt with the narrow and tortuous sounds between its off-lying islands and coastline. This made up a regular trading route for their trials vessel and covered a longer testing period.

Both trials were established for the purpose of testing the IMO ECDIS specification. The major findings of both projects are listed below.

4.3.1 The Seatrans Project(11)

This work (described in chapter 1) was initiated by the Norwegian Hydrographic Office and employed a fully digitised chart display. Provision was made for use of differential GPS and the receipt of chart corrections via Inmarsat C. The principal comments (relating to Liverpool) made by the navigators involved in the sea trials are outlined:.

1. The principal benefit was perceived to be the ability to see own-ship's position at a glance.

2. Positioning using Radar, Decca and Dead Reckoning was relatively unsuccessful compared with what was achieved with GPS (even in the non differential mode)

3. 'Track steering' was demonstrated, ie by output of track keeping instructions to the autopilot, the vessel could be made to automatically follow a pre-planned ECDIS route. Nevertheless, the navigators preferred to use manual control of steering in confined waters.

4. In some charts, the positional accuracy of the chart database was visibly less than that of GPS, ie the chart data itself fell short of the required accuracy standard.

5. The most useful hydrographic information in the opinion of the navigators operating the Seatrans ECDIS was the own-ship safety contour and light sectors. The safety contour provided anti-grounding information and the light sectors were used extensively for 'wheel overs' in the narrow sounds.

4.3.2 Netherlands ECDIS trials(13)

The Electronic chart used in this project was constructed on behalf of the Netherlands Hydrographic Office by outside contractors. The sea trials were conducted on board H.Nl.M.S. *Buyskes* , a hydrographic survey vessel belonging to the Royal Netherlands Navy.

The following comments made concerning this project have specific relevance to the work in Liverpool as follows:

1. The final production time for the preparation of digital data from a single paper chart was two weeks.

2. The charts used were digitised in the ED-50 datum and GPS positions placed on the chart were converted to ED-50 prior to display. The Netherlands has therefore requested that the obligatory use of WGS-84 for horizontal datum as mentioned in the IHO ECDIS performance standard should be amended to a specification that chart and position datum should be equal. This suggestion would benefit the

user only if the GPS receiver datum could be changed automatically by the ECDIS software. Potential exists within the Liverpool system to implement datum shifts directly such that no user intervention is required. (Few users of the Liverpool chart seemed to fully appreciate the significance of the horizontal datum used on the chart.)

3. Four merchant navy officers completed the navigational testing of the system. The normal Officer of the Watch of the vessel maintained a separate navigational record and executed the orders requested by the test subjects. No reference was made to simulator training / trials prior to the tests however, it was acknowledged that prior training would be required in future.

4. Spaans makes the following statement "An important complaint about the tested ECDIS was the lack of consistency in handling the system. The structure of the functions and the relation of these functions to keys on the keypad was not clear enough to the subjects and was difficult and time consuming to handle. A logical structure of functions with pull-down menus on the screen, handled with a roller ball, was suggested as a preferable solution." (This approach was used at Liverpool and by Kelvin Hughes Ltd throughout their Integrated Bridge products.)

5. On the subject of data layering -

"The capability of the system to present the 'standard display' and additionally several specified layers was highly appreciated by the subjects. The option was often used during both route planning and route monitoring. Preference was given to the presence of two displays for reasons of redundancy and for simultaneously planning and monitoring."

6. Finally,

"The subjects appreciated the north-up / true motion display of the ECDIS and would consider other display modes as confusing or even useless."

It should be emphasised that radar targets were not overlaid on the chart.

<u>Section 4.4 Conclusions drawn from Testing</u>

As a consequence of the results obtained from the work at Liverpool and by consideration of the results of others, the following conclusions may be drawn concerning ECDIS generally.

1. The most significant benefit arising from the use of ECDIS is the availability of a continuous, real-time position output referred to the local hydrography.

2. Owing to the use of GPS, the basic ECDIS display consists of an accurate ground-stabilised display of own ship in true-motion. The ability to present the ground track of own ship has, until now, only been available on sophisticated ARPA displays and has necessarily been subject to doubt owing to the lack of precise 'drift' data.

3. The display of Radar targets was the most frequently requested ECDIS feature, however the benefits of such an approach have not been satisfactorily tested yet.

4. The principal benefit arising from 'data layering' seems to be the ability to present the own-ship safety contour independently of other hydrographic information and the ability to reduce display 'clutter' on digital displays.

5. Prior training is essential before using ECDIS. If ECDIS were to be subject to the same training requirements as ARPA, then standardisation of the controls and functions between manufacturers would be required. Alternatively, this could be achieved using a 'training mode' on the equipment itself.

6. Under the current data standard and in the absence of fully automated digitisation, the data preparation time for vector based information is significant. The Netherlands stated 2 weeks per chart; Norway - 34 months for the Seatrans database. Even with the commitment of substantial resources, it is likely that it will be some years before an accurate, up-to date chart database is available for world-wide use. Given the need for co-operation between Hydrographic Offices and the establishment of the Regional Update centres, it will be (in the opinion of the author) at least another five years before such a database has become available.

7. An ECDIS 'track following mode' where control instructions are sent from the chart to the autopilot, is likely to be of benefit for open water navigation.

Summary

A simple testing programme yielded substantial evidence in favour of the Liverpool electronic chart as a navigational instrument. Some reservations expressed about the chart handling have been addressed, and software now exists to address the problem. The interactive video approach compares very favourably with conventional, digital ECDIS in terms of both data capture and the time taken to reproduce the chart on screen. It is evident from study of other work that the design of the Man-Machine Interface (MMI) is proceeding along appropriate lines and that the simplicity of use is appreciated by professional navigators. Notwithstanding the necessity of finding satisfactory solutions to a small number of remaining problems, the chart developed by this project appears to satisfy a substantial navigational need.

CHAPTER 5

The Electronic Chart and Integrated Navigation

Chapter 5

The Electronic Chart and Integrated Navigation

Section 5.1 A Definition of Integrated Navigation

An example Integrated Bridge, recently launched by Kelvin Hughes Ltd, is described in Appendix 1.

An Integrated Bridge System (IBS) can be defined as one where data connections have been established between the instruments comprising it, in order to enable enhanced functionality in a small number of primary displays. Recent systems of this type have employed computer technology for the presentation of information to the Officer of the Watch. A wide variety of on-board control activities have been treated in this way including, for example, engine room and cargo monitoring. At the core of an IBS though, is usually an Integrated Navigation System (INS) consisting of one or more displays linked to the principal navigation sensors and, in most cases, capable of controlling the steering of the ship via a track keeping autopilot. An outline history of the development of Integrated Navigation Systems was given in Chapter 1.

As the technology of hardware, software, external communications and computer networking became more sophisticated, it was progressively more feasible for the bridge to be a total ship control centre with a single individual monitoring almost all the onboard systems. Still some distance in the future lies the further possibility of introducing software to carry out parts of the overall bridge monitoring function. Such an approach would almost certainly require the application of Artificial Intelligence; possibly along the lines already demonstrated by the European KBSShip Project(22).

Of specific interest to this work was the contribution to Integrated Navigation that could be made by an Electronic Chart, both as a novel system operating in a 'stand-alone' manner and in combination with other sensors. The first avenue of investigation was prototyped at Liverpool, the second is being pursued by Kelvin Hughes Ltd.

Section 5.2 The Justification for Integration

There is both a 'technology push' and a 'market pull' forcing the development of new navigational equipment. The 'analogue' systems previously fitted on ships' bridges are giving way to a new generation of digital instruments which are capable of transmitting data messages onto a computer network. Some of these were described in Chapter 1. but include logs, gyros, chart tables, echo sounders, radars - and even barometers.

Integrated Navigation systems seek to collect this information and present it to the user in a form that is readily understood, on one or perhaps two displays. Naturally, manufacturers are keen to create and expand new markets for their products and have therefore been active in developing new systems. The market for Integrated Bridges and Integrated Navigation systems has also stemmed from the desire of shipowners to ensure that their vessels are as economical and safe in operation as possible. New legislation continues to be introduced concerning navigational safety - for example, covering one man bridge

operations, routing of vessels, and communications. This again creates a need for new systems. Integrated Bridges are now available from a number of European and Far Eastern manufacturers. Whilst some offer a 'modular' approach to allow more than one maker's equipment to be used, most see the integrated bridge as an opportunity to provide a complete fit of instrumentation and controls including not only navigation systems but also engine-room, other machinery space, communications and cargo management facilities. At the time of writing, integrated bridge systems are available from: Racal Decca (Mirans); Selesmar (Vector); Norcontrol (Bridge Line); Siemens; Kelvin Hughes; Raytheon Marine (SNA-91) and Sperry (VMS)(61).
It is evident that commercial competition in the integrated bridge market will be lively.

There follows a brief discussion of some of the more frequently quoted justifications for the introduction of Integrated Navigation systems.

5.2.1 Safety

Safety at sea is generally considered to be a high priority amongst both mariners and shipping operators. The cost of pollution claims or damages for loss of life etc can be extremely high. Most Integrated Navigation Systems therefore claim to enhance navigational safety by improving navigation control through the use of progress monitoring functions and alarms. The most significant contributions to safety are currently made by the existing, basic navigation monitoring functions of ARPA radars (guard zones, Closest Point of Approach (CPA), Trial Manoeuvre), improved communications (GMDSS) and (shortly) electronic charts with anti-grounding functions.

5.2.2 Navigational Efficiency

From a day to day perspective however, the ability to improve a vessel's navigational efficiency can generate significant cost savings. A few days extra freight carriage per year can amount to additional income to the vessel operator in the tens of thousands of dollars. Fuel and depreciation of the vessel together make up over 50% of the costs of a single voyage(62). The reduction of stress damage to the hull and fuel savings through accurate and economical adherence to delivery times can therefore produce substantial savings.

5.2.2.1 Speed

A faster vessel can carry more freight per year than a similar, slower ship. Improvements in engine efficiency have ensured that the average cruising speed of ships increased substantially over the last 50 years in the face of increasing vessel sizes. As ship speeds increase, the navigational requirements also change and Integrated Bridge layouts have therefore to be appropriate. For example, an increasing number of Hydrofoils, Hovercraft, Large Catamarans etc are coming into service on short ferry routes. The bridge layouts of these vessels tend more to resemble aircraft cockpits than 'traditional' bridges. A particular characteristic of these designs is that the watchkeeping officers are usually seated whilst the vessel is under way. High speed navigation demands a greater degree of pre-processing of navigational information during passage planning than conventionally since there is rarely sufficient time available to perform calculations, find information etc once the vessel is underway(19). A real time position reference is indispensable under these circumstances; a role hitherto fulfilled by radar and now also satisfied by the Electronic Chart.

5.2.2.2 Commercial Efficiency

The term 'Integrated Navigation' in it's broadest sense includes all aspects of a vessel's trading or operational activities that influence her movements in the long and short term. There is therefore a close relationship between a shipping operation's command and control organisation ashore and a vessel's capacity to respond rapidly to new instructions, with the outcome being visible in terms of ship movements. Necessarily, the process of running any shipping organisation is an 'information-intense' activity and effective communications play a vital part in maintaining a viable operation. For example, a vessel needs to be able to report a wide variety of data relating to commercial information, her onboard systems and navigation in a secure and efficient manner. The Integrated Bridge could thus also provide a means of automating some of the communications requirement.

5.2.3 Social Factors

Safety of navigation depends though, on many other factors including social considerations such as training and working practices, the motivation of the watchkeeper and his levels of fatigue and stress. It is therefore desirable that the design of the equipment he uses makes a contribution to ensuring that these 'human factors' are ameliorated. Two areas where new navigational practices are expected to have a social impact are briefly mentioned next.

5.2.3.1 Training and the Roles of Personnel

The training establishments will need to explore new methods of adequately preparing mariners for professional service on board the new generation of vessels. The dual-role or 'polyvalent' officer is one capable of both deck watchkeeping and the monitoring and control of machinery spaces. Training along these lines has already commenced at some U.K. institutions. It is likely that cross specialisation will also be required of ratings, since the overall number of personnel borne is falling noticeably in the newer vessels. The safe levels of manpower to cope with emergencies and other unforseen events have still to be properly established.

5.2.3.2 Reduced Manning

The Classification Societies are in the process of formulating precise regulations for operating ships with a reduced (one man) navigational watch. This is largely motivated by the efforts of Western nations to remain competitive against the low wage rates in vessels operated by third world countries. The application of technology in this area is being directed towards ensuring that sufficient automation of the routine processes of navigation is applied to ensure that a satisfactory lookout can be maintained by one man, whilst at the same time, he carries out the other responsibilities of the Officer of the Watch.

Section 5.3 The Electronic Chart as an Integrated Navigation System

The Electronic Chart, by its very nature is potentially capable of acting almost as a complete 'Integrated Navigation System' and should be able to provide information to the user in support of and beyond that already supplied by the paper chart. This would be achieved by the integration of a chart display, chartwork facilities, real-time vessel positioning and sophisticated data access methods within a single system. As stated earlier, there is also speculative interest in combining some part of the radar output with the electronic chart to assist in collision avoidance. An interest to this project has therefore been to evaluate the contribution the electronic chart might make in an 'integrated navigation environment' and to assess the validity of radar overlay. No practical work was undertaken owing to time constraints, however consultation with informed opinion during simulator and sea trials suggested that problems could arise in attempting to define the Electronic Chart as the sole place in which collision avoidance information is concentrated. These are discussed in the next section.

5.3.1 Current Practice and Problems in Navigation Integration

5.3.1.1 Existing Integrated Bridge Systems

In the case of the current work, the electronic chart display was implemented using radar-like navigation functions. However charted information is static rather than - as in real radar - dynamic. From the user's point of view, the positioning reference offered by the electronic chart (under coastal navigation conditions) is visually similar to that observable on radar (particularly in the vicinity of radar conspicuous coastlines) with the added advantages of a clear presentation of underwater depth contours and easy identification of charted objects. It was apparent during simulator trials that this led to a reduction in the amount of time spent by the user in monitoring radar positioning information. It is not fully clear whether the addition of collision avoidance targets would have changed this situation.

The electronic chart is likely to supersede radar as the prime positioning reference and the use of, for example, relative motion work in 'Blind Pilotage' will thus be made obsolete by the precise positioning offered by GPS. It should be noted though that in Blind Pilotage, radar targets and track-keeping data are presented on the same display, allowing a single individual to monitor the entire navigation situation as it develops. A drawback of Blind Pilotage done traditionally is that a substantial amount of chartwork is involved in it's preparation.

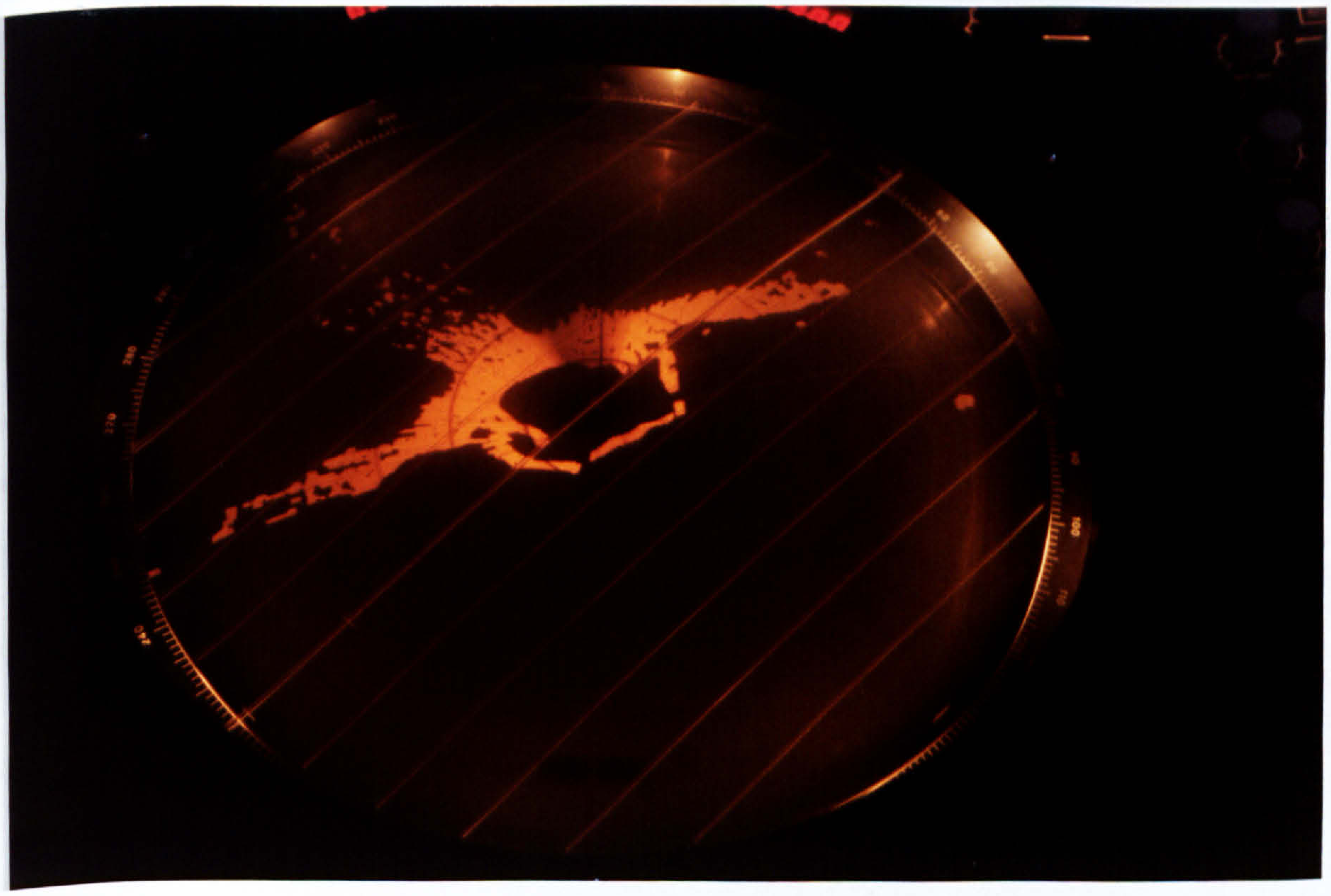
Radar is, primarily a navigation sensor showing an (almost) instantaneous display of above water contacts and land; the chart is a topographic reference based on static, historical information. It is possible that the overlay of ground stabilised target information on the chart will offer the navigator insight into the likely navigational intentions of other vessels, however radar has, until now, been best suited to target analysis and collision avoidance work. A serious question therefore arises as to whether (or how) a single display could be used as both the charting and collision avoidance reference and if this should be based on 'radar-on-chart' or 'chart-on-radar' information.

Although a degree of data transfer in both directions has proved beneficial in the past, it is suggested that reliance should not be placed solely on a single display for the following reasons:

(a) Radar and chart display information come from widely different sources. Direct overlay of a full radar image and the chart is difficult because of the different methods of plan presentation (The chart is projected mathematically whereas radar is generated in range and bearing form - giving, at best, a 'polar presentation'). Furthermore, radar images can only give an approximation of the real, above-water picture.

(b) The background reference of an electronic chart is the sea-bottom topography against which own ship is presented in ground stabilised true motion directly (14). A radar display may show own ship in relative motion, sea-stabilised true motion or ground stabilised true motion. A radar will generally give relative motion directly, sea-stabilised true motion based on log and heading inputs and ground stabilised true motion if a calculated 'drift' component has also been accounted for (although it is understood some very recent radar designs allow positions to be input to achieve ground stabilisation). It is suggested that targets' relative motion vectors, if displayed on the chart, should be displayed in addition to targets' true motion vectors and not on their own. This would help to prevent confusion during the introduction of radar overlay usage as a new navigational technique.

Plate 22 Radar Showing Relative Motion Vectors



(c). A significant degree of processing is required to generate radar true motion. By implication, 'ECDIS true motion' suggests that target vectors would be calculated using successive target positions generated using range and bearing information from own-ship. These two calculation techniques are substantially different and could yield very different data in the presence of log and heading errors, or differences in the environmental forces (tide, current, wind) being experienced by own-ship and the targets of interest. With the availability of differential GPS comes the possibility of very accurate true motion presentation at close quarters. The true motion of targets displayed on the radar should therefore be the same as that displayed on the chart to avoid uncertainty in the mind of the user caused by different calculation methods.

4. Given that both radar and chart were originally designed to fulfill different, though complementary purposes; if too much of the functionality of one is added to the other, the user may become overloaded with information.

5. A single display would not permit the user to look ahead on the chart without losing the current radar 'situation'.

6. A single display would probably be unacceptable to the Classification Societies due to the risk of breakdown.

In order therefore, to fully exploit the advantages the electronic chart offers in positioning, it is essential that it is operated <u>alongside</u> radar (which may send basic target data to the chart for display) to allow the fullest navigational 'picture' to be obtained. It is suggested that target data displayed on the chart should be used solely as an additional, informative feature of the chart and not as the primary means of collision avoidance.

The work at Liverpool in recent years has, however, been concerned with extending the functionality of both radar and electronic charts as tools for decision support. Beyond the transfer of basic data and functions between radar and chart, it may well be difficult to proceed further in developing an Integrated Navigation System which gives the full, potential functionality of both types of system (Target Analyses, Anti Grounding, Trial Manoeuvre, Chart data access, expert systems etc). It is for this reason that the approach to integrated navigation data usage in the next section is suggested.

Section 5.4 A Proposed Approach To Integrated Navigation

In anticipation of a conservative approach by the Maritime Legislature, it is difficult to foresee an Integrated Navigation System based on a combined radar/chart display. It is suggested, however, that a possible approach to giving a comprehensive integrated navigation output on one display may lie in having a third system linked to both the electronic chart and (ARPA) radar. This would offer an avenue for the eventual development of a sophisticated decision support system and would ensure that Radar and the Electronic Chart could be operated (and sold) separately as conventional units.

5.4.1 Outline Specification for a 'Tactical' Navigation System (TNS)

The objective in designing an Integrated Navigation system must be to provide a system that is entirely coherent with the mariner's existing skills and understanding. Secondly, it should be as simple as possible to use, requiring a minimum of additional operator intervention over traditional navigation methods, and third, it should offer substantial benefits in navigational control, safety and operational efficiency beyond those offered by a conventional system.

5.4.1.1 System Units

See figure 5.1

The following system units would make up the proposed TNS

i). A radar display with ARPA and mapping functionality.

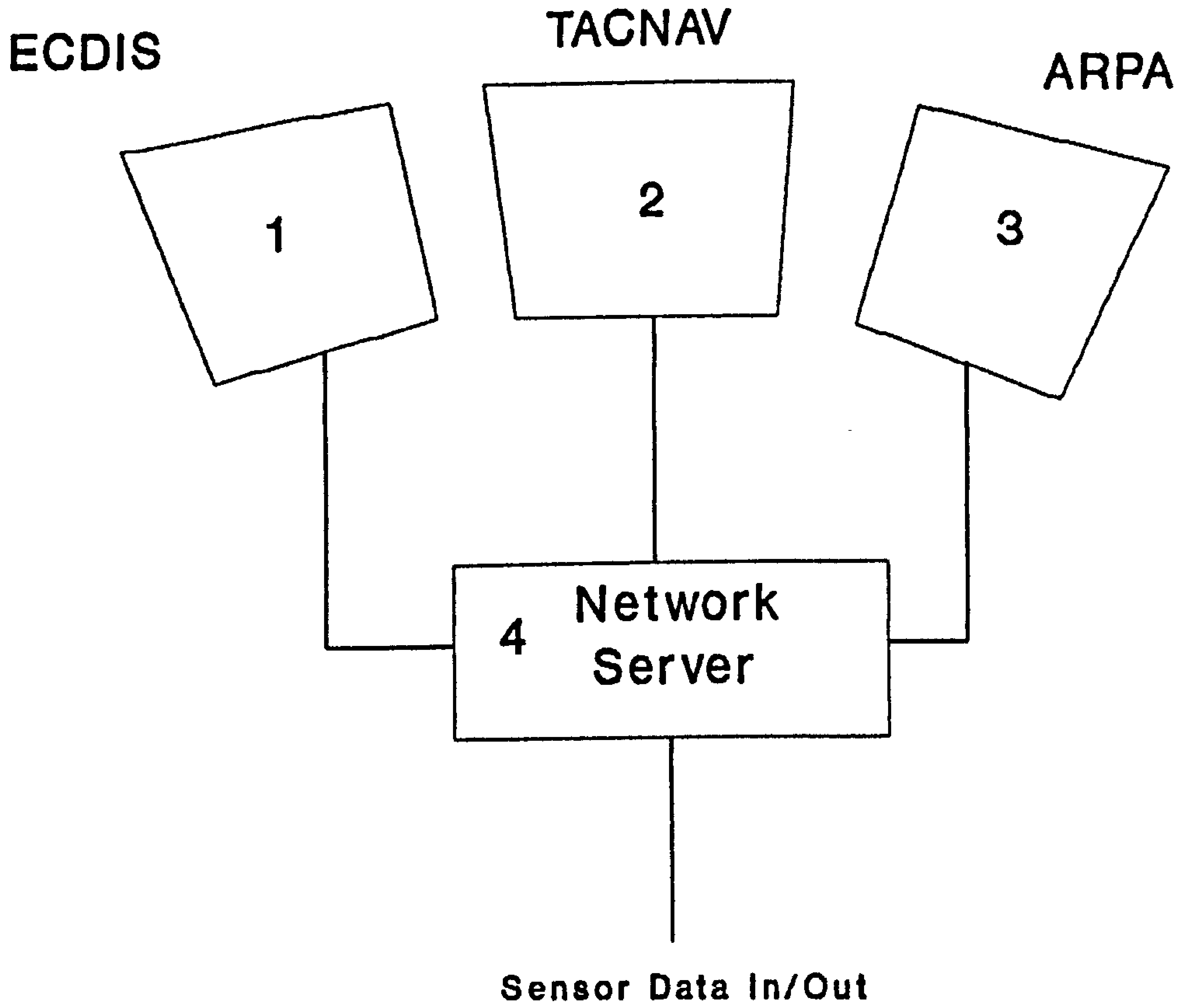
ii) An electronic chart system (paper based, ECDIS or CDU).

iii) An "(Intelligent) Tactical Navigation Display (TACNAV)"

iv) Mass storage and network functionality for distribution of digital overlays and data exchange between components eg (target data, DX90-derived chart data, anti-grounding information, database information, stored routes etc.)

The chart and radar should not differ significantly from the

A Proposed 'Intelligent' Integrated Navigation System



Data output by an Electronic Chart (1) and an ARPA radar (3) are interpreted by an 'Intelligent Tactical Navigation Display' (2).

File handling and distribution of sensor data is managed by a 'star' network.

Fig. 5.1

existing systems to which mariners are accustomed other than as follows.

i) The chart might be capable of displaying radar targets in ground stabilised true motion.

ii) The radar might be capable of displaying route information and user-entered map lines.

Further, more complex functions should be implemented away from the chart and radar which together are considered to be the primary navigation system for whose use the Officer of the Watch would be responsible. It should be emphasised that he would be at liberty to accept or reject the TNS system output, taking full responsibility for his own eventual decisions and actions.

5.4.1.2 The "(Intelligent) Tactical Navigation Display" (TACNAV)

This system would provide comprehensive decision support based on the output of a Passage-Planning and Situation Analysis Expert System.

The function of this unit would be twofold. First, it would take the passage plan as prepared on the chart and perform a sequence of checking and annotation using the 'track validation' schema described in Chapter 3. Once in the on-line, passage execution mode, the purpose of the system would be to provide live "situation analysis" information based on an abstract of key data taken from both the chart and the radar. For example, it could show: own-ship safety contour; buoyage; anti-grounding information; traffic routeing measures; target data derived by ARPA and the collision avoidance analysis. The display would consist of combined graphics and textual output and its operation would be governed by the activity being pursued by own-ship namely:

Berthing;

Anchoring;

Pilotage;

Coastal Navigation;

Ocean Navigation;

or Special Operations. (eg fishing, search and rescue, naval operations.)

The graphical part of the display would be presented in Relative motion, True motion (ground/sea stabilised) or 3-Dimensional simulation according to the user's choice.

The style of display presentation would be similar to a simplified ECDIS chart image but would exclude most of the interactive functions (which would be available anyway on the adjacent electronic chart). In order to minimise operator interaction to a reasonable level, the enhanced functionality of the system would be available through the application of situation tracking software loops designed to test for navigational safety automatically as follows:

(Note that the descriptions given closely parallel the recommendations of the Admiralty Manual of Navigation and use a schema close to that described in Chapter 2.)

First, during passage planning -

1. Does the planned track leave safe water ? (Accounting where necessary for vessel dimensions);

2. Does it approach any dangers too closely ?;

3. Does it leave sufficient sea room for collision avoidance ?;

4. Can the track be optimised with respect to distance without breaching 1-3 above ?;

Then the first amplification stage where the following are added to a list based track-commentary.

5. Safe maximum cross track error for each leg;

6. Safe / Economical speeds on each leg;

7. Estimated tidal streams and courses to steer;

8. Wheel over points and wheel required;

Then a further sequence of checking, where the answers to the following would be sought.

10. Are any environmental factors critical to the execution of any part of the plan and can they be accounted for? (tides, darkness, fog, anticipated sea-states etc)

11. Are any other regulations applicable to own-ship along the track

(Cargo type, one-man bridge operations, defects)

12. Are all timing requirements met with the current planned speeds?

At this point, further annotation may take place against which the track is again checked for safety.

13. Sea-marks passed and major visible shore marks.

14. Radio Reporting Points and other mandatory communications.

15. Pilotage regulations.

16. Cautions and warnings appropriate to the charts in use.

17. Local Notices to Mariners and Radio Navwarnings.

18. Weather forecast / likely.

Once all the above factors had been checked and resolved, the passage plan would be deemed to be 'valid for system use'. The track-commentary produced would then be printed out in hard copy and the information listing stored for further reference once the ship was underway.

In On-line Navigation, the requirement would then be to continuously check the real, moving situation against approximately the same goals as in passage planning.

1. Is own-ship safe <u>here</u> ?

2. Is the Dead Reckoning / Ground track safe ?

3. What radar targets are there in the vicinity ?

4. Do any require action in accordance with The Rule of the Road

5. Will any require action in the future based on own-ship's plan or likely action by the other vessel.

6. What external regulations are in force

7. Is own-ship anywhere near the planned track?

8. If not does it matter? any action to regain required?

9. Other marks/features of safety interest around us?

10. Is own ship making satisfactory progress against the planned schedule

11. What likely future events do we need to start responding to now? eg securing for heavy weather, preparations for entering harbour.

Recording functions would allow reconstruction of past events, simulation functions would allow 'trial runs' through the navigation control of difficult passages etc.

Summary

An 'Integrated' approach to navigation systems' design is now used widely by manufacturers. Although this has produced benefits to navigation beyond that provided by traditional systems, care must be taken to ensure that information is presented in its proper context. The placing of collision avoidance information is a good example.
An 'Intelligent Tactical Navigation Display' could be capable of producing a useful degree of navigational safety analysis and decision support, following the recommendations of The Admiralty Manual of Navigation(40). The majority of the functions described are known to be feasible through:

i) the software built into existing equipment;

ii) Software recently prototyped at Liverpool;

iii) Work known to have taken place outside the group.

The notion of a 'Tactical Navigation System' (TNS) extends the 'Integrated Navigation System' (INS) concept in a novel manner. It applies the same 'Situation-Analysis' criteria as are applied by a human watchkeeper by use of a combination of Geographic Information System (GIS) and Artificial Intelligence (AI) techniques. In use, it is intended to:

(a) provide safety checking and amplification of passage plans.

(b) assist the watchkeeper in visual watchkeeping in a manner similar to having an additional human expert or 'Pilot' at his elbow. This would provide advice concerning the safety and efficiency

of the current navigational situation.

New References - Chapter 5

(61) Fairplay Magazine, Feature on Integrated Bridge Systems, 'A move towards an automated future'. 6 February 1992

(62) Alderton R.M. 'Sea Transport', Thomas Reed Publications ISBN - 0 900335 63 7

CHAPTER 6

Conclusion

Chapter 6

Conclusion

Section 6.1 Project Summary

The initial project proposal(34) submitted to SERC in 1989 gave its aims as follows:

"To develop a fully operational prototype Electronic Chart for marine navigation. The proposal is based on the novel use of interactive video for chart display, coupled with the overlay of normal chartwork facilities and associated navigational data using conventional software. Methods of providing overlay of selected radar data will also be investigated. A longer term aim of the study will be to evaluate and test modern data structures for the storage and processing of chart data. The objective is to progress the Electronic Chart concept towards a Marine Geographic Information System."

The project has, over the last three years, built a prototype electronic chart system capable of being used for simulator testing and navigation trials at sea. The system developed at Liverpool was adopted by Kelvin Hughes Ltd as the basis from which their Chart Display Unit (CDU) was developed. This is now in service as a trials unit on board a cross channel ferry; sales of further units on a fully commercial basis are expected to start in the near future.

The chart was developed broadly in line with the current requirements specified by IMO for the presentation of an Electronic Chart Display and Information System (ECDIS). Notwithstanding the novel approach taken in using interactive video - which differs substantially from the approach assumed by the official bodies - the chart was found to comply closely with the essential IHO requirements. Testing of the chart display has demonstrated conclusively that the 'window on the chart' offered by interactive video gives an adequately clear and usable presentation for its use in navigation. The present status of the Liverpool System with respect to the IHO standard is given in Chapter 2.

The way in which the chart presentation, chartwork facilities and data access functions were implemented is described in detail in Chapter 3, as is the use of modern GIS data structures for storage and processing of chart data. Measuring the proximity of danger was of substantial interest to the project with considerable time being spent on developing the data structures for an ECDIS system to respond appropriately. The most important piece of software to be prototyped in this area was the grounding avoidance routine which interacts with a quadtree data structure to validate a vessel's intended track.

As a result of testing with experienced mariners under a variety of circumstances including: Radar Simulation exercises; the Manchester Ship Canal; in the Southern North Sea; and in discussion in the laboratory, the chart was subject to the comments and constructive criticism presented in Chapter 4.

In addition to the objectives outlined in the initial project proposal, the chart was developed with the broad aim of supplying a prototype for the chart display component of a fully integrated ship's bridge. Attention was therefore paid to ensuring that the Man-Machine Interface (MMI) of the chart followed the scheme designed by Kelvin Hughes Ltd, whilst remaining consistent with the patterns of chart usage familiar to practising mariners. The intended relationship of the chart with radar gives rise to the description of methods by which radar data may be overlaid on it in Chapter 5. This chapter also contains a discussion of how a broader based approach to navigation decision support could be presented in a 'Tactical Navigation System'

Section 6.2 The role of the Interactive Video Electronic Chart

ECDIS looks set to have a central role in navigation in the future. Indeed, the principal stated objectives of bridge integration are capable of being fulfilled almost entirely by an ECDIS meeting the current IHO specification. The value to the watch-keeping officer of the electronic chart described in this thesis lies in two principal areas: the prevention of grounding and the improvement of navigational efficiency; its potential value as an aid to collision avoidance remains to be explored. It is suggested that the most comfortable conceptual position for the current work is to describe it as an 'Electronic Paper Chart', by which is meant that further work should aim to duplicate the functionality of the paper chart as closely as possible. This should give a navigational instrument as flexible and convenient in use as the traditional system and represent a consolidation of traditional practice. For example, it should include a magnetic compass interface, visual fixing facilities, gyro check functions etc. Mariners will thereafter decide for themselves which functions are most useful in the longer term. In any event, an approach of this type would not leave the chart open to criticism for any failure to accommodate tried and tested traditional practice. Nevertheless, the IMO specification has determined that GPS will be the primary fixing system for fully compliant ECDIS systems and as a result, the traditional techniques of visual fixing, dead reckoning and navigational astronomy may reduce in importance over a period of time. A thoughtful implementation of these techniques in an ECDIS would, however provide a backup in case of severe GPS errors or other sensor failure, and also retain elements of conventional practice in the system to give enhanced user confidence.

6.2.1 The Principal Benefits of the Electronic Chart.

The following are the principal benefits associated with using the Liverpool electronic chart for navigation:

(a) in common with other electronic chart systems, the main benefit obtained was a continuous display of own-ship position upon the chart;

(b) the interactive video display gave a familiar chart presentation that was immediately usable by all the mariners who used the system;

(c) the implementation of the chartwork functions allowed inexperienced users to use the chart for navigation after minimal instruction (20 - 30 minutes);

(d) the prototype anti-grounding function demonstrates a novel and useful safety feature and has generated interest outside the immediate project group.

6.2.2 Issues concerning Electronic Chart Usage

Some topics frequently recurred in discussion about the use of electronic charts for navigation as follows:

(a) track keeping in pilotage waters demands high accuracy in navigation, only differential GPS and some survey systems are able to meet this need;

(b) cross track error may be monitored relatively simply. Some autopilots are able to respond 'intelligently' to cross track errors by steering back towards the track. Care should be taken to ensure that this does not happen when the ship is deliberately off track eg during a collision avoidance manoeuvre;

(c) the distance to wheel over (not generally the same as distance to waypoint) should be computed in a straightforward manner as should the time likely to be taken in getting there;

(d) The monitoring of tidal streams and depths against predicted values requires both a substantial database of tidal and depth information and interfaces to depth measuring and position fixing equipment from which the true values can be computed. It is not expected that uncertainty in measuring the real tide from a moving vessel (owing to meteorological effects) would materially affect navigational accuracy.

(e) It does not seem likely that interactive video will allow the presentation of the chart in a 'ship's head up' orientation. Because of the reasons stated in the previous section, the chart symbology is fixed. The main requirement for a head-up chart presentation is in pilotage. It is suggested that a pilotage system of the type described earlier would better fill this need.

(f) The combined use of electronic chart and radar data is currently the subject of considerable discussion. In essence this relates to the use of a ground stabilised chart presentation as the topographic reference against which targets' relative and true motion might be presented. The principal questions in this field relate to the cognitive perception of such a display by a user and the physical validity of the presentation. In any event, the findings of such a study would have a substantial bearing on the training requirements for mariners in the use of such equipment. No substantial experience exists in this area as yet.

Section 6.3 Suggested Further Work on The Electronic chart.

6.3.1 Error monitoring between navigational sensors

In order to provide navigational functionality in the electronic chart to an acceptable, quality assured level, it will be necessary to quantify the navigational errors inherent in the calculations performed by the system. For example this should include the errors to which the primary and secondary electronic position fixing systems are subject and any errors in radar target presentation relative to the chart projection. Where errors are found to be significant, it will be necessary to take steps to reduce them.

6.3.2 Improvement of frame handling

The frame handling algorithm as presently implemented in the Liverpool system is occasionally prone to confuse users particularly where a large number of charts are potentially available at the cursor location. It is suggested that the chart series would be better handled by an implementation of the 2-D tree algorithm prototyped during the current project.

6.3.3 Improvements to scaling software

The scaling and chart software should be extended to allow projections other than Mercator to be correctly handled and to reduce the residual errors generated during the scaling operation.

6.3.4 The use of charts containing plans and insets

Charts containing plans and insets constitute a valuable part of the Admiralty Chart series and are largely used in pilotage and river navigation. Unfortunately at present, the alignment, size, shape and presentation of plans and insets is subject to a somewhat ad-hoc scheme of arrangement which causes difficulty in preparing them for use in interactive video. An investigation of means by which this might be overcome would be valuable.

A number of issues can be identified as having significance in the commercial supply of an interactive video chart system.

6.3.5 Chart Correction

The existing system of data provision and update in the paper chart is substantially flawed, with many publications (particularly the sailing directions) remaining out of date for several years. This is in no way attributable to negligence but simply reflects the very high cost of data collection and publication in the real world. The traditional correction system relies on both formally commissioned surveys and 'Hydrographic Notes' sent in by mariners to provide new and updated material. In general, the data which is most safety critical tends to receive most attention according to a priority system. Therefore, the light and radio signals lists are updated weekly and re-published each year, regularly used charts are re-drawn every two to three years and the sailing directions may take ten years or more before they are re-published in a new edition. (A system of supplements is used to used to assist in maintaining the sailing directions). The light and radio lists contain the most frequently updated information and are considered authoritative over charts which are generally more up to date than sailing directions. Temporary and Preliminary Notices to Mariners (Ts and Ps) help to warn of temporary amendments to the database and provide information about intended works and modifications. The system of radio-navwarnings (WZ and Navarea) messages give notice of rig movements, buoys that are unlit or off station, wrecks etc that are sufficiently important to navigation to be broadcast but which may only affect the mariner temporarily or have not been in effect sufficiently long to have been published as a Notice to Mariners.

The Admiralty Chart series is thus subject to a continuous programme of update. Viewed simply from a database point of view, chart corrections and navigation warnings can be considered as deletions, additions, or modifications to the data on a temporary or permanent basis. The individual charts (which provide a convenient method of sub-dividing the data) are also considered to be data entities and are subject to the same rules. A chart correction schema appropriate to interactive video has to take account of the near impossibility of modifying 'analogue' video data directly and must focus instead on the use of digitally overlaid graphics and disc reissue to maintain the chart database. It is understood that this is being developed as a matter of priority by Kelvin Hughes Ltd.

6.3.6 Software Quality Assurance

The provision of a fully usable electronic chart demands that a substantial quantity of data is available to the system for both display to the user and to ensure correct operation of the system. All will need to be subject to rigorous quality control. Recognising the safety critical nature of the electronic chart, a formally recognised scheme of software quality assurance needs to be applied to the software. Minimally, this would have to be ISO 9001(63). Quadtrees are not supported as a recognised data structure within the formal definition of the IHO. For this reason, two possible avenues offer themselves to a manufacturer inclined to make use of them within a commercial system. First, they could be prepared using DX90 data ashore, and transmitted to vessels using a proprietary data format based loosely on DX90; Alternatively they might be prepared on board as a part of the general chart update procedure. Given the comments made earlier, a sophisticated application of quadtrees to navigation would probably be better made in a 'Tactical Navigation Display' rather than directly within an interactive video system.

6.3.7 Cataloguing, Handling and Distribution.

Current practice dictates that each ship of any size must carry the subset of the charts available internationally which she requires to:

a) meet her operational needs;

b) comply with the SOLAS convention(2) and;

c) comply with the local requirements of the territories she visits.

Therefore, in order to provide an electronic chart supply service equivalent to any existing paper based system, the above requirements must be taken into account. Each vessel's needs are clearly unique to some extent. Given the massive extent of the total chart series available, it would be difficult to supply a single product capable of fully meeting a number of different vessels' chart requirements particularly where they are engaged in different trades in different parts of the world. Given that interactive video using pressed videodiscs is a relatively inflexible storage medium (from the point of view of analogue data modification), several options offer themselves at present.

1. To supply a 'world' videodisc based on a subset of the charts currently valid, and to continue to supply paper charts 'to fill in

the gaps'. This would provide a useful short term objective.

2. In the longer term, to supply a complete videodisc series subdivided into ocean regions with users choosing the discs they require.

A large scale commercial system capable of use in world-wide navigation is likely to span more than one disc. The organisation of the discs used would need to reflect the most frequent types of user interaction with the system. The trials with the prototype at Liverpool suggested that the existing techniques of passage planning should continue to be supported, namely that the drawing of courselines and their adjustment (fine tuning) should proceed in succession from the smaller to larger scale charts. Therefore the videodisc arrangement might be by Geographic region using the existing folio system or by chart type; that is Ocean charts, Coastal Charts and Pilotage charts being on separate discs. Should a subset of the Admiralty chart series be provided, it is essential that expert advice on the choice of charts is taken.

For the time being at least, it seems likely that ships will need to carry paper charts in addition to electronic charts (unless they are participants in special programmes of research). However, the future possibility of supplying ships with a database of charts tailored to their individual needs should not be ignored.

Section 6.4 Further Application of Spatial Data Structures and Artificial Intelligence to Navigation

6.4.1 Passage Planning

The passage planning objective is to find the safest and most efficient means of achieving the vessel's navigational aim. During this work, the necessity for track validation, particularly with reference to water depth was recognised and prototyped in a sub-system. This piece of software points towards a future capability of the system to generate a commentary on the vessel's intended track. As the work has proceeded, it has become clear that it is particularly necessary to distinguish between the planning of coastal passages, pilotage, and ocean navigation. Work has concentrated on the coastal and pilotage aspects since these would provide the greatest improvements in safety in practice (The optimisation of long distance ocean navigation is known to produce the greatest fuel savings).

6.4.1.2 Sailing Directions

The techniques and examples dealing with the representation of spatial data are concerned with explicit data representation. However, they might also be used to provide keying information into some of the less structured data associated with navigation. A good example is the 'Sailing Directions'. These can be thought of as loosely hierarchical, each volume providing information related to a particular area. The chapters normally proceed in geographic sequence and a variety of specific port data, port entry and coastal navigation information is listed within them in increasing detail. By using some of the spatial data access methods described elsewhere, a coherent framework for the presentation of a selection of this information could be created.

6.4.1.3 Report Generation

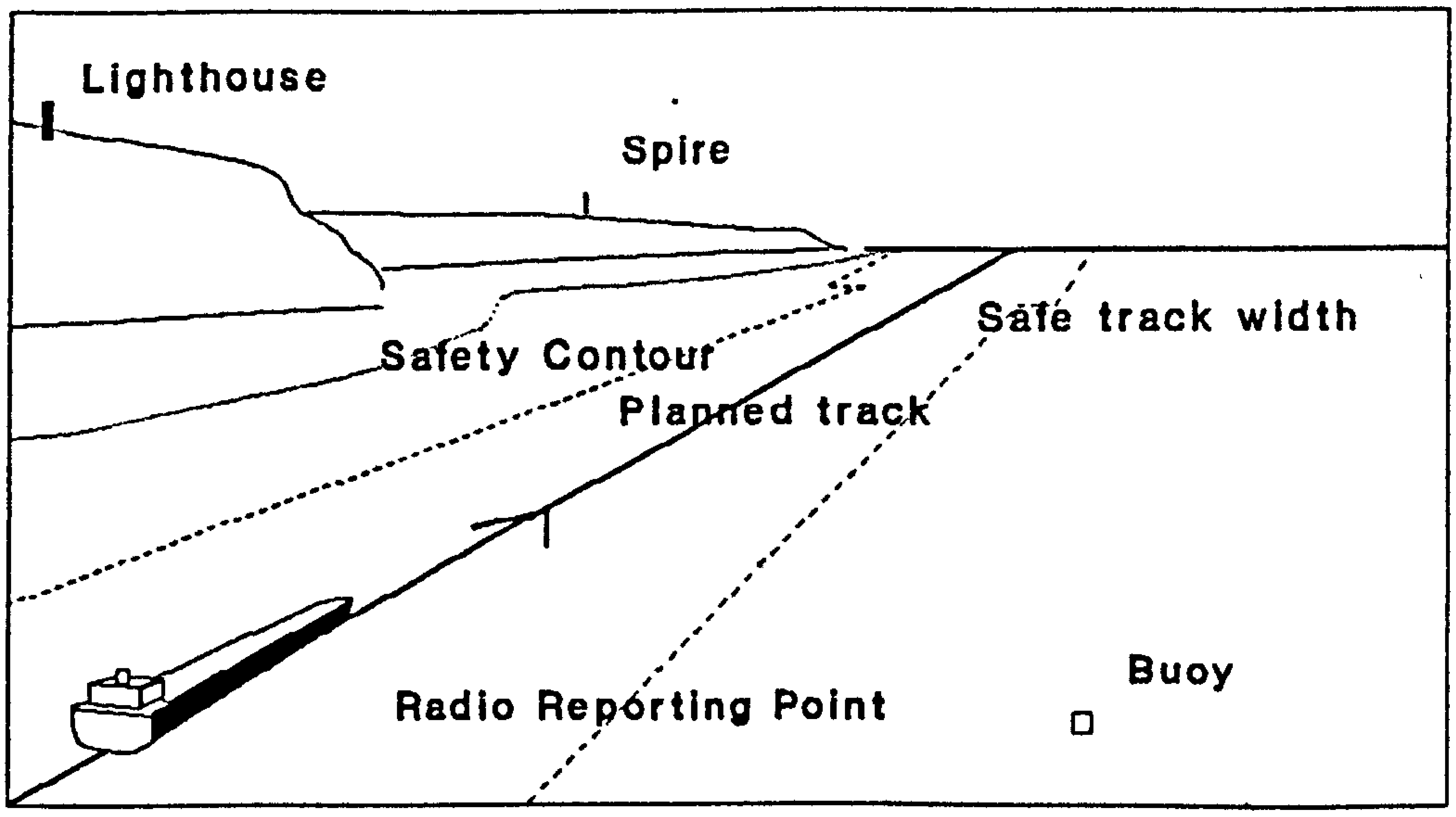
Quadtree procedures may be applied with generality to any spatial subset of the chart which completely and exclusively describes the whole chart area. An example is man-made restrictions to navigation such as traffic separation schemes, anchorages, submarine exercise areas etc. which, in combination with a 'free navigation' descriptor, are again mutually exclusive. Two or more of these files could be used in combination to report multiple spatial attributes eg

Charted depth is > 10m;	From contours file
Explosives Dumping ground;	From man made restrictions file
NorthTown Port Authority.	Authority for survey

A system of automatic report generation was devised which can be expanded or contracted in scope according the user's requirements.A diagrammatic illustration of the system principles and output is given in figure 6.1. The technique closely parallels the 'Navigators Notebook' approach favoured by the UK Royal Navy and described in detail in the Admiralty Manual of Navigation(40). The naval method is specifically devised to be used in pilotage but is equally applicable in other navigational contexts. The technique uses a tabular layout of specific information relating to each leg of the intended track and a diagrammatic representation of the salient features of the

Track Commentary Model

Navigational Scenario



System Output

Leg	Features (Abeam)	Comments	SAFETY
WP 3 to 4 045 CTS 043	A1 buoy to Cod Bank	Start Auto pilot	M.E.D 9m Tide 090 0.5kn
0.5 mile	Radio R.P Buoy	Call 'HarbourNav' on VHF Ch 12 Fl(3)R 6 sec	Safe Track width 0.75nm
1 mile	Cape Nonsuch (Lt)	Fl(4) 15sec 24M	Min exp Depth Now › 20m
1.5 miles	--------	--------	Safe Track width 2nm
2 miles	Spire		
	Etc.		

Fig. 6.1

relevant chart portion including the navigational plan is then drawn alongside. Together they are used by the navigating officer to 'con' the ship.

6.4.2 Pilotage

Pilotage is used here as a generic term describing fine control of a vessel's navigation. An important function of the integrated bridge is to enable this to be carried out at all times rather than simply during port entry and exit. Nevertheless, the most significant improvements to navigational safety will be seen during the port entry/exit and coastal phases of a voyage. Vessels often have to be navigated in crowded waters which may in fact be unfamiliar to the Officer of the Watch. Automation and Decision support should be used to ease both the bridge workload in terms of its mechanical tasks and to assist in dealing with the moment to moment decision making processes. Provided that navigation is seen as more than the control of the vessel's motion and covers the whole of its interaction with other ships and the environment, potential exists for assisting the mariner in making a safe and efficient passage. As described in a previous chapter, this may cover anything from collision avoidance advice to ensuring that the ship complies with local and international regulations.

6.4.2.1 Grounding avoidance

The work on grounding avoidance using quadtrees described earlier has special significance to navigation. It represents a novel set of techniques by which safety monitoring can be carried out on a ships

Plate 23 The Chart Showing a 'Safe' Anti-Grounding Vector

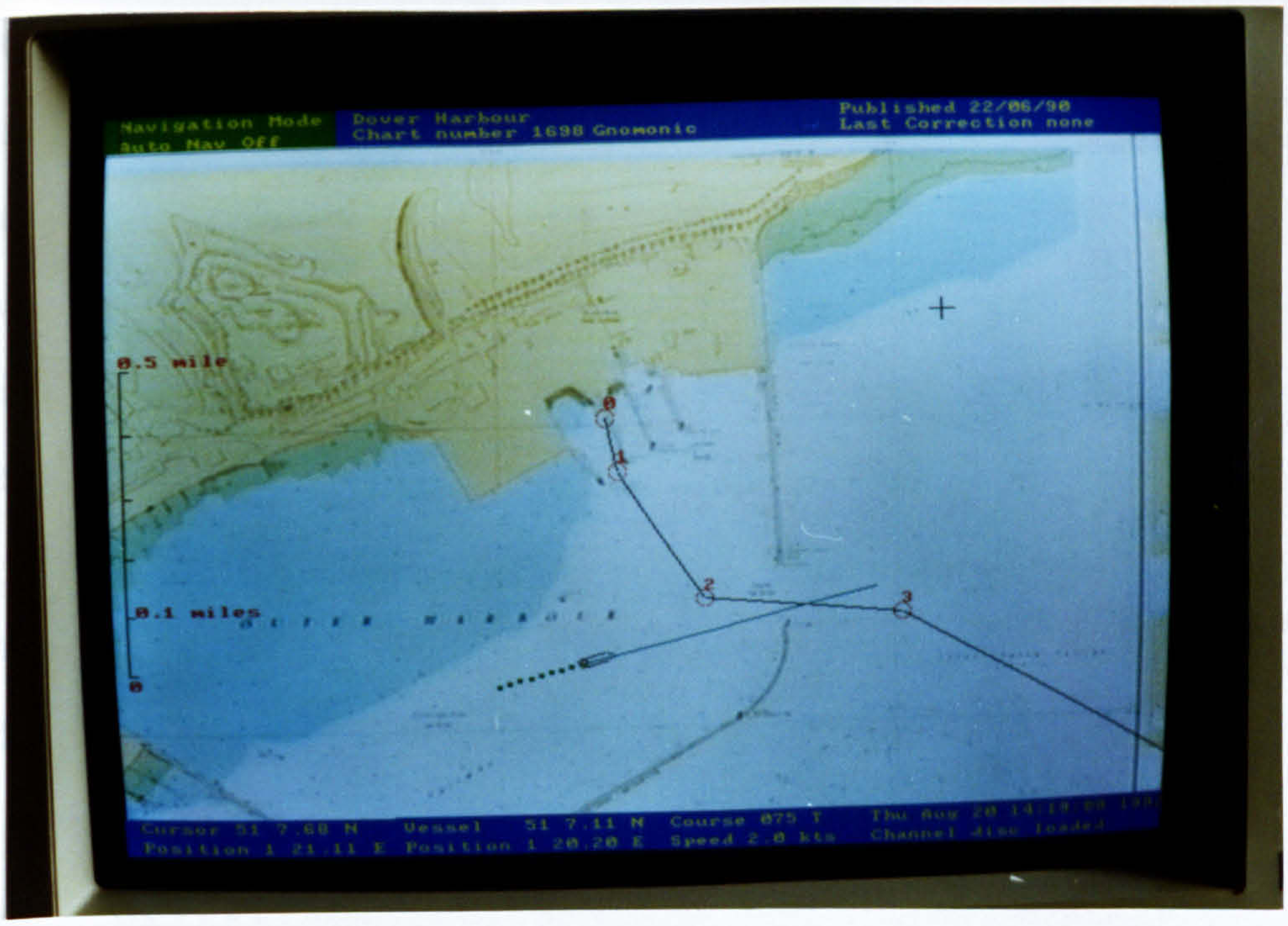


Plate 24 The Chart Showing an 'Alarm' Anti-Grounding Vector

progress regardless of the stage in the voyage or the chart being used. Furthermore, the anti-grounding alarm system developed in Liverpool implies no requirement for a pre-planned track to be in the present vicinity of own ship. This is because a minimum distance from land/submerged dangers could be set by the operator when on passage and checked automatically using own-ship's ground track. This would be valuable in the safe execution of collision avoidance manoeuvres or during operational exercises such as fishing, naval exercises etc. where there may not be a specific passage plan. The benefit of having a variable safe-distance function owes much to the fact that it is not the vessel's primary navigational objective to follow the planned track; staying safe is.

6.4.3 Artificial Intelligence

Whilst no prototyping of Artificial Intelligence techniques took place during this project, earlier work(32) suggests that strong possibilities exist for the introduction of AI into a system of this type. Specific mechanisms for instantiating spatial variables have been developed which are capable of describing a vessel's navigational environment. These may prove to be of value in future AI work.

6.4.3.1 Goal definition

Prior to any attempt to use Artificial Intelligence in a navigation system, it is essential to clearly define the goal states the software is to be designed to achieve.

Two possible areas of AI application are immediately recognisable. First, to use an expert system to determine the chart output under varying navigational circumstances, and second to apply expert system technology to the navigational processes eg collision avoidance. The goal of the first approach would be to ensure that the system output was tailored specifically to the activity and navigational context of the ship. The second approach would aim to provide assistance in navigational decision making to the user. Two examples are given.

6.4.3.2 Operation of the Electronic Chart Software

An example rule is given relating to the reporting range of lights. A simple formalisation is used.

If Nav_mode = Ocean
  then: display lights with range > 20 miles
If Nav_mode = Coastal
  then: display lights with range > 10 miles
If Nav_mode = Pilotage
  then: display lights with range > 2 miles

6.4.3.3 Potential in Navigation

An example is given relating to safe passing distances from dangers. This might relate to the generation of advice and/or the conditions governing an automatic change of navigational context eg Coastal to Pilotage. A less formal description is used than above.

In Ocean navigation hazardous fixed objects should not be passed

closer than 10 miles.
In coastal navigation hazardous fixed objects should not be passed closer than 2 miles.
In pilotage hazardous fixed objects should not be passed closer than 100 metres.

It is possible, even within a relatively simple framework to imagine a very large number of such rules. The true number of navigational contexts is also made greater by special cases such as traffic separation schemes, rivers, poor visibility etc.

Both the Passage planning and Navigation modes thus show potential for encoding as Expert Systems. For example Passage Planning is a situation where route validation could take the form of an expert system with a principal goal of safety and a sub-goal of efficiency. The expert system applying to live navigation would apply similar reasoning in a continuous manner throughout the voyage, collision avoidance being included as of necessity. This is the scheme of usage upon which the 'Tactical Navigation Display' described in Chapter 5 is based.

6.4.4 Tactical Navigation Display

The continuing work at Liverpool Polytechnic has covered various areas including electronic charts, radar presentation, navigation integration and expert systems. The application of all these technologies in a single navigation system would, however, present a particularly intractable set of problems in its design and implementation. The usefulness of each of these areas of study to navigation is without dispute and it is therefore suggested that a simplifying approach should be sought. The 'Tactical Navigation Display' using essential data extracted from chart and radar and subject to Intelligent control may offer such a development route (described in Chapter 5).

6.4.5 An Expert system 'overlay' for the Integrated Bridge

A fully integrated ship's bridge such as the one described in the appendix to this thesis allows the exchange of digital data between its system units. Given the potential number of messages that might usefully be defined for exchange, it is important that the context of usage of the information content is controlled. The work developed by the KBSShip project(22) illustrated the way in which data from a variety of systems including engines, cargo management and navigation systems could be processed so as to aid the navigational decision maker in his pursuit of the overall navigational objective. The system made substantial use of Knowledge Based Systems (KBS) techniques to achieve this. A similar implementation tailored, to some extent, to a ship's operational requirements would make a valuable contribution to the usefulness of a commercial Integrated Bridge.

Section 6.5 Chapter Summary and Conclusion

This project, based on interactive video, has given a useful opportunity for developing both 'traditional' navigation functions suitable for direct use on the chart display, and other, more innovative functions related to chart content and real navigational needs. The development of 'Intelligent interaction' between own-ship and the chart held considerable speculative interest at the commencement of the project. The work on spatial data structures has met this aim and now represents a set of techniques by which the electronic chart can be extended. The importance of 'navigational context' has also been emphasised because this should determine the system response under various circumstances.

The process of navigation is much more complex than simple reference to and use of chart data. A vessel must also interact safely with other shipping and the environment. The development of the sensors and instruments used to do this has taken many years and in the traditional context, each would have been used to add data to an overall 'picture' in the mind of the navigator against which he would make decisions according to his training and experience. Both the electronic chart and the Integrated Bridge exploit our ability to use technology in the first level of the decision making process - namely that of collecting information and establishing simple relationships and a primary level of safety monitoring can also be applied both within the ship and to its navigational conduct. The human navigator can be relieved of much of the drudgery of conventional methods, and the precision and quality of navigation can be improved. By redefining the role of the Watchkeeping Officer and introducing appropriate technology, the need for personnel to continuously monitor systems physically remote from one another is removed and leads to a lower manpower requirement on board. A natural consequence is an improvement of the commercial efficiency of the vessel. The mariner's professional training is likely to change: it must include some non-trivial understanding of onboard computer systems; a broader understanding of other shipboard systems in particular, propulsion and power generation; but, at the same time, should not be done at the expense of developing the traditional knowledge required of a professional navigator.

Much excitement has been generated throughout the shipping industry at the advent of the electronic chart. Phrases such as 'The most important breakthrough since radar(64)' are being used. The results of the evaluative work conducted at Liverpool suggest that this is probably true. What should also be recognised though is that it should not be seen as a navigational panacea. Experience with radar has shown that users need to acquire fresh skills and understanding for such a system to be used to its full effect. Nevertheless, particularly favourable comment was made by testers concerning the ease of chart usage, the good implementation of navigation functions, the availability of charted depth information and the very useful continuous display of own-ship position. Together these features move the chart conceptually from its usual 'dusty corner' to a central position at the front of the bridge where it forms a primary, active display used by the Officer of the Watch.

New References - Chapter 6

(63) Department of Trade and Industry (DTI), (1990) 'Tickit - A guide to software QMS and certification using ISO 9001/EN29001/BS5750 Part 1 (1987) Issue 1.1' pub. DTI.

(64) Slettevoll I. (Capt) 'The View from the Bridge'. Navigation News (July/August 1991) pp 12 - 13. The Royal Institute of Navigation.

APPENDIX

The Kelvin Hughes

Integrated Bridge

Appendix 1

Integrated Bridge Specification

(See Figure A_1)

The Kelvin Hughes Integrated Bridge uses a token ring network as the main communications channel between the displays, processing units and sensors. Devices accessing this use a message structure based on the NMEA 0183 format. This allows equipment from a variety of sources to be used and gives the purchaser the opportunity to configure a system according to his own requirements. Much of the conventional equipment is managed by software, in particular for communications and ship control. (An example is the steering model).

The principal integrated bridge components are:

ARPA radar
Electronic Chart Display Unit
Navigation Workstation (NAVDIS)
Navigation Monitor (NAVMON)
Ship Control Station (SHIPCON)
Vessel Monitoring Workstation (MONDIS)
Communication Station Workstation (COMDIS)
Electronic Chart Table (ECTAB) and bar-coded chart initialisation subsystem
GPS Receiver (built into NAVDIS)
Data Logging Printer
A3 Plotter
Data Logger Backup unit (tape streamer)

The Principal displays are effectively dedicated P.C. computer terminals designed as workstations and using a networked architecture. The functions of each are described below.

NAVDIS - Navigation Display Workstation

This is a graphics and text mode display, it provides the main operator interface for the Integrated Bridge System. The following functionality is provided:

System Configuration - Sensor selection.
Vessel Parameters
Data Logger setup
Tape Backup Control
Master Yeoman Interface
Plotter Setup
Alarms Configuration
Navtex interfacing
Weather Data
Paper Chart Selection
Barcode interface for paper chart Initialisation
Database Information for lights, Communications frequencies and Gazetteer within the charted areas.
Route Planning - Safe depth, tides, weather etc
Event and emergency handler
Paper and electronic chart correction interface.

Kelvin Hughes' Integrated Bridge

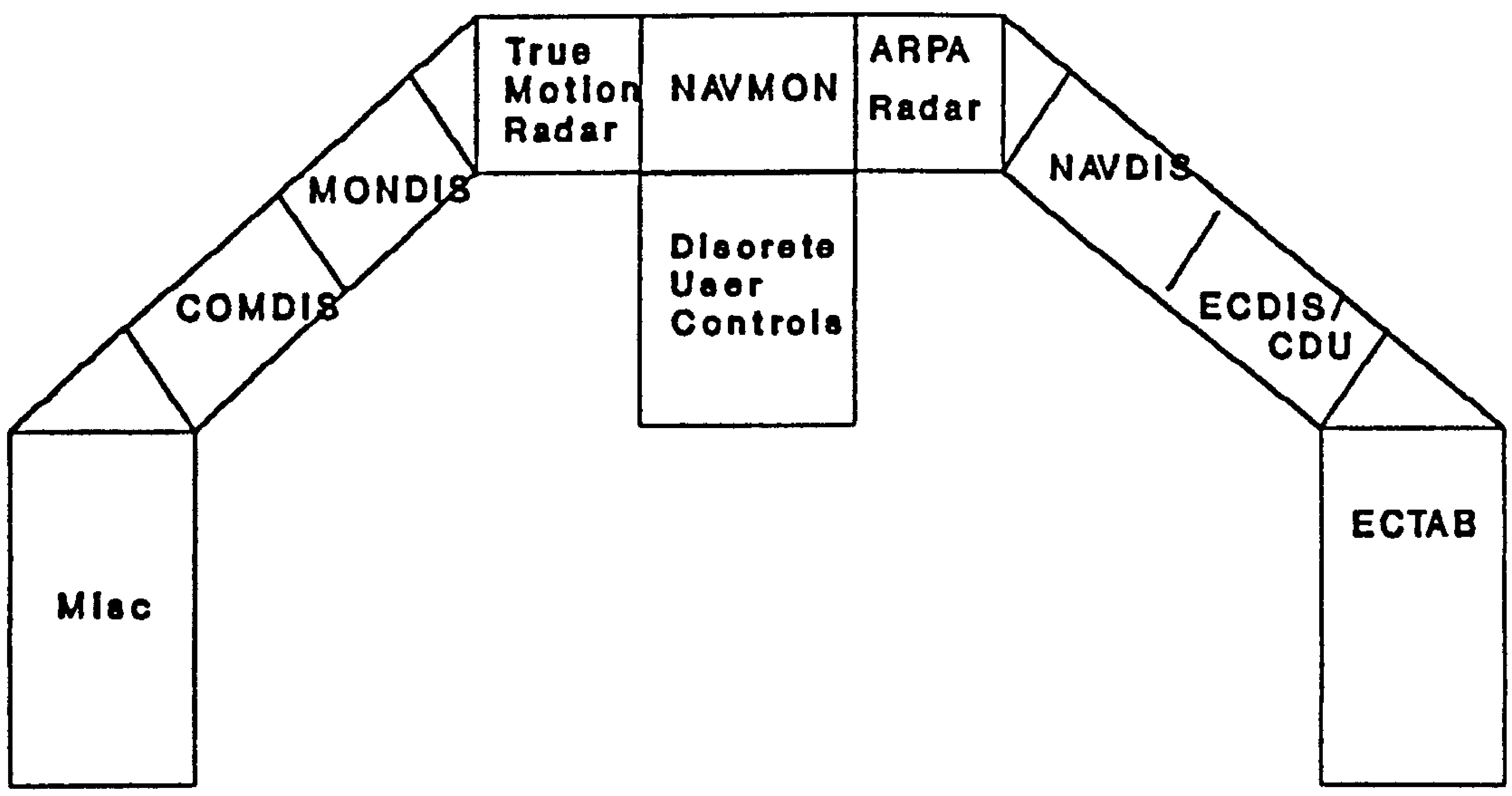


Fig. A_1

The Navdis workstation contains all the navigational algorithm software within the system and the interfaces to the ship's sensors. The interface may be battery powered to provide functional continuity in the event of a power or NAV system failure. It reads all the sensor data and retransmits it to the NAVDIS computer through the ARC-NET / NMEA 0183 interface.

Two NAVDIS workstations can be used in an IBS to maintain 100% functionality in the event of a workstation failure. Both workstations can be supplied with data from one interface unit or parallel connected to two interface units.

NAVMON - Navigation Monitor Workstation

This display provides a continuous real time display of the following ship's parameters

Time (UTC)
O/S Speed
Gyro Heading
Rate of turn
Course made good
Log speed and status
Speed made good (ahead/astern)
Rudder angle
Rate of turn/turn radius (from autopilot)
Revolutions / pitch Port/Stbd
Depth under keel/depth alarms
Barometric pressure trend indicator
Waypoint / Cross track error alarms
Autopilot Steering mode & status (Manual Track Off Auto)
Wind Speed and direction

Additionally whilst in 'On Route' mode.

Waypoint Alarm on/off
CTS to next waypoint
Dist. to next waypoint
Drift Set and Rate
Navaid status (in use / availability)

During Berthing Mode

Doppler Speed Indicator (Ahead / Astern / Athwartships)
Bow thruster status
Actual rate of turn
Wind direction and speed

SHIPCON - Ship Control Workstation

This unit forms the centre limb of the Integrated Bridge and houses the following electronic units:-

Autopilot
Auxiliary steering tiller
Hydraulic steering pump controls and indicators
Ships helm
Steering mode switches

Ships Audio Control
Man overboard button
Analog Gyro tape repeater
Ship's Helm
Bow Thruster Controls and Indicators
Main Engine Controls and Indicators
VHF Radio
Group alarm Panel (Fire?)
Intercom telephone system
Housing for Binoculars, Coffee cups, pens, pencil
etc

MONDIS - Ship monitoring Workstation

This display provides the bridge with a remote monitoring workstation for sensors located at critical areas of of the ship's system. A token passing network is employed between the outstations and the central display. Regulations require the fitting of group alarms on the bridge but the MONDIS provides the bridge officer with greater diagnostic capabilities. The following types of monitoring are supported:-

Main Engines
Propulsion
Generators
Electrical Switchboard
Fuel Consumption / levels
Tanks and bilges
Fire control
Hotel Services
Sea water inlet temperature
Video windows - Car deck, Bow doors etc
Data Log output to Satcom
Off line loading calculation package

COMDIS - Communication display workstation

This workstation provides the operator with a graphical operational interface to the HF Radio, The Satcom system and the VHF. It provides automatic call routing and data upload / download to shore. All features displayed on the workstation are repeated (due to legislation) in the Radio room.

ECTAB - Electronic Chart table Unit

The electronic chart table consists of a grid positioning tablet and 'puck'. Paper charts are positioned on the table surface and their corner coordinates loaded into the ECTAB interface computer using a bar-code light pen. Subsequent movement of the 'puck' over the chart result in the readout of true lat / long coordinates on a display built into the puck. Further functions supported through interfacing are:-

Indication of own ship position
Indication of Range / Bearing or lat / long of positions
Indication of position from system
Transmission of 'puck' position to CDU and Radar

Transmission of chart number to system
Transmission of route plan / waypoints to system
Construction of steering sequences and route plans
Construction of maps for the radar mapping system
Entry of chart corrections from database / satellite downlink
Bar code chart initialisation
Plotting of tracked targets from the Radar system

Data Logging Printer

The printer attached to the NAV computer can be set to print the following data at intervals of between 30 seconds and 10 minutes.

Time (UTC) and date
System Status
Ownship Data:-
- Gyro Heading
- Log Speed
- Course made good
- Speed made good
- Lat and long (sensor)
- Lat and Long (computed)
- Cross track error
- Shaft Revolutions and Pitch
- Rudder angle
- Steering Mode
- Engine Monitoring Data
- Navtex / Satcom Notices to Mariners
- Sound signals log
- Light signals log
- Event data
- Position Plot (ECTAB)
- Deck and Machinery Log

GPS Receiver

The GPS receiver used in the system is mounted on a PC expansion card. Other types may be used via the NMEA input adapter (SLAB).

A3 Plotter

The plotter may be used to provide the following:-

Projection Grid
Position Plot - track line and backtrack
Radar Map plot (Coastlines / Boundaries etc)
Radar tracked target plot (with labels)

Data Backup Unit (Tape Streamer)

The NAV workstation incorporates a 40mb tape streamer which will store the same data as is printed on the data logger during the voyage. Tapes thus created may only be modified or reformatted under password control

Barcode System

The barcode system enables labels to be created for the chart initialisation data. These are read when a new chart is initialised on the system. In addition operator entered data on routes and passage plans can be printed in bar code format to provide hard copy storage of data.

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