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COMPUTER ASSISTED CARTOGRAPHY IN NAUTICAL CHARTING — AN APPRAISAL

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Abstract

Computer Assisted Cartography (CAC) is the application of modern computer technology in the fields of data capturing, processing and production. CAC has played a prominent role in *i)* acquisition of data through Automatic Data Logging Systems (ADLS), *ii)* creation of Data Bases of map/chart files using manual/automatic digitizers, *iii)* editing of data by Interactive Graphic Terminals (GRT), *iv)* precise plotting and projection of data using sophisticated plotters, *v)* scribing of lineal details/symbols, *vi)* photoflashing and photo plotting of alphanumeric details/symbols on film, *vii)* preparation of colour separation/ribbon originals. Thus CAC has taken over almost all roles of the time consuming conventional/manual cartography of hand print, stick up of phototyped alphanumeric details/symbols, hand scribe and manual colour separation. CAC has radically reduced the time span of chart making and provides fast, accurate and uniform results.

A computer assisted, cartographic plotting system consisting of an on-line system for data base generation and an off-line precision plotting system for preparation of fair drawing originals was installed in the Naval Hydrographic Office (NHO), Dehra Dun in 1981.

The paper outlines the process of chart production by CAC and discusses the functions of different units of the system such as the digitizer, verification plotter, graphic terminal, precision plotter, etc.

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The authors have made an appraisal of the functioning of CAC in nautical charting in NHO during the past 5 years and have explained various problems/setbacks that were encountered by cartographic programmers and draughtsmen in running the auto chart system and how these were overcome by continued Research and Development (R&D) efforts.

The paper reveals that initially compilations were not computer compatible, which resulted in positional errors/shift in plots, misinterpretation and misrepresentation. Standards for preparing computer compatible compilations have now been laid down. The 'cartographic rigidity' based on technical principles initially provoked resistance from certain cartographers and draughtsmen in accepting the CAC product. However, CAC products are now being accepted with minor reservations as these are drawn in a clear, sharper, uniform, accurate and faster manner.

The authors are of the opinion that nautical cartographers and draughtsmen who have the knowledge of charting practices and navigational requirements are better suited for working on the system than those persons without this specialized knowledge.

The paper outlines the R&D efforts and discusses various modifications made in original software and how certain new software was developed for projection, lattices, etc.

The CAC in NHO is being maintained in-house by qualified electronic engineers. However, due to non availability of certain spares indigeneously the system at times becomes non-operational.

The authors have pointed out the limitation of new technology and have outlined the compromises that have been made. There are still certain unsolved problems in text depiction, positioning of finely curved details, overlapping of details at sharp turns, plotting breakers, rotation of specific symbols, etc. However, it is felt that despite certain reservations CAC will continue to function as a useful tool for data storage, chart revision and production. It will also play a significant role in development of the new technique of the 'electronic chart'.

INTRODUCTION

Charting and mapping are very ancient practices. Cartographers have evolved meticulous standards and practices based upon scientific, artistic and aesthetic principles. The cartographic traditions of the national agencies within one country differ in reflection of discipline and history. With the advent of computers several aspects of chart making and cartographic techniques have been revolutionized. The first successful attempts to use computers in producing graphics were reported in the early 1960's. Since then, the growth of computer graphics has been rapid and cartography has vastly improved with the development of electronic gadgets in use for production of cartographic products such as nautical charts, maps, architectural designs and machine drawings. Considerable research has been oriented towards the conceptual or technical

problems of creating maps/charts using computers. Hydrographic Departments throughout the world have been using computers for the past two and half decades for various activities in accelerating the tasks in nautical chart production. Initially, various mathematical computations required for projections, co-ordinate conversion, azimuth and distance computations were solved by developing suitable computer programs. Then attempts were made to generate graphics by using plotters.

HISTORICAL RESUME OF DEVELOPMENT OF COMPUTER ASSISTED CARTOGRAPHY (CAC)

The US Defence Mapping Agency Hydrographic Centre (DMAHC) has been using an Automated Cartographic Production System (ACPS) since the mid-seventies. The development of this system has been carried out in a phased manner. ACPS consists of several sub-systems which are used for data capture, processing, editing and production of the nautical chart. These sub-systems are called: (*i*) Digital Edit and Compilation Sub-system; (*ii*) Hydrographic Cartographic Data Base System; (*iii*) Lineal Input System; (*iv*) Graphic Finishing Sub-system. Besides these, there are a few more sub-systems which provide other facilities for the DMAHC.

The British Hydrographic Department introduced computers in 1964 for various jobs and since the early seventies has been using computers in cartographic activities. It has an ICL computer as a host computer with peripherals and plotters interfaced to them for the processing of data for chart border and hyperbolic and circular lattices for navigational survey purposes. It has offline digitizers for data capture and voice recognition devices for digitizing depth values. For precision plotting, AEG and Kongsberg plotters are used.

The Canadian Hydrographic Service (CHS) has been using computers in the chart production since the late seventies. The data capture is done by a PDP computer interfaced to a digitizer and is called a digitizing system. Graphical Online Manipulation and Display System (GOMADS) with a PDP 11/34 computer and Tektronix graphic terminal are used for interactive editing of the digitized data. The plotting system with a Gerber plotter is used for drawing precision plots.

The Australian Hydrographic Department has also acquired a computer assisted cartographic plotting system called Auto Chart, with a HP 2000 series computer as host computer with Gradicon digitizer, Gerber plotter, etc., interfaced to it.

Similarly, West Germany, France, USSR and Japan have introduced computer assisted cartography in their nautical chart production.

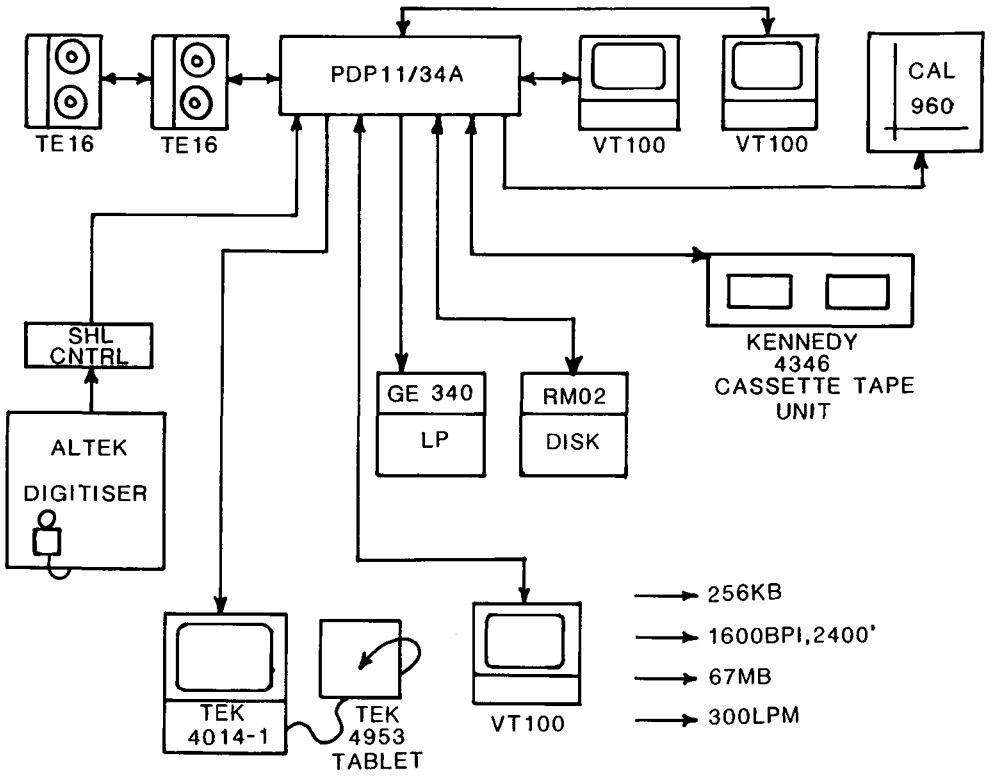

FIG. 1A. — Cartographic Plotting System. On line-system.

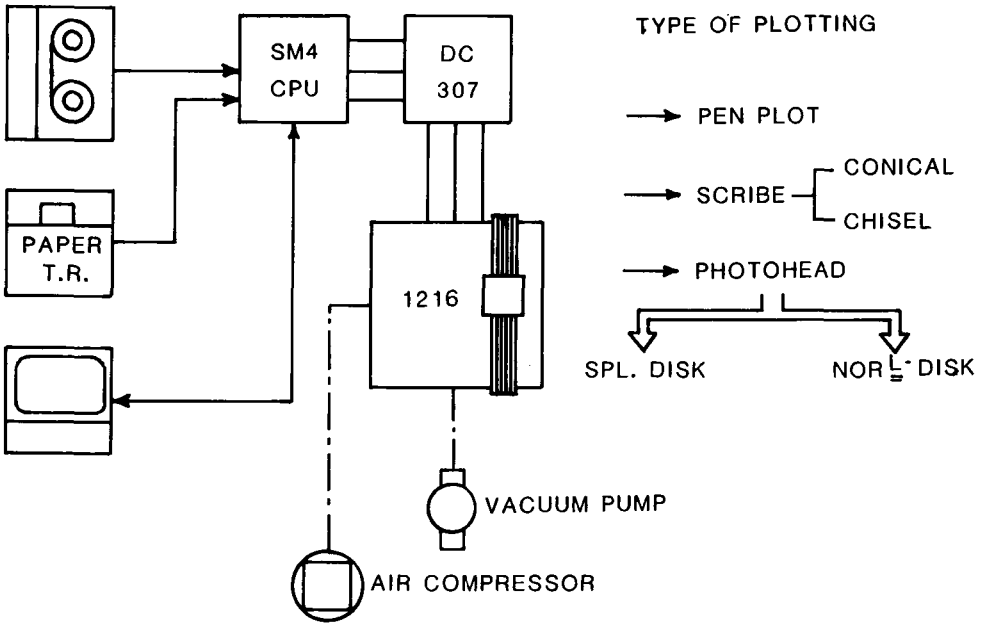

FIG. 1B. — Kongsberg Precision Plotting System. *Off-line system.*

NAVAL HYDROGRAPHIC OFFICE COMPUTER ASSISTED CARTOGRAPHIC PLOTTING SYSTEM

In order to increase the quality and quantity of chart production and to keep pace with the developments in computer assisted cartographic activity in other Hydrographic Offices of the world, the Indian Naval Hydrographic Office (NHO) acquired a cartographic plotting system (CPS) in 1981, which has been in operation since November 1981. The system consists of an on-line system with PDP 11/34A (Fig. 1-A) as a host computer for data capture, editing and processing and an off-line precision plotting system consisting of a Kongsberg flat bed precision plotter (Fig. 1-B), SM4 computer, Pertek tape drive and other peripherals. Verification plots are prepared on a Calcomp 960 plotter (on-line with PDP 11/34). The Kongsberg precision plotter has the facility of drawing originals on scribecoat using scribe tools, on draftex using pens or on film using a photohead.

Stages of processing

Chart production in the Naval Hydrographic Office (NHO) is divided into three stages: (*i*) Compilation; (*ii*) Fair drawing and (*iii*) Printing. The computer assisted cartographic plotting system (CPS) assists in all three stages. For compilation, a master grid with various control points plotted and graticule lines closely drawn on the required projection is prepared. The major contribution of CPS in NHO is the preparation of fair drawing originals which is explained schematically in figure 2.

Digitization

A compilation drawing is taken and linked to the system by creating a chart file, and physically linked to the digitizer by digitizing four corners of the compilation. This part of creating a chart file is called 'initialization' and is controlled by the System Manager (SM) Programme. Then the digitization is controlled by the Station Processor Program (SP). An Altek digitizer with a resolution of 0.02 mm and a digitizing area of 1050 × 1500 mm is used for digitization. It has a cursor with a key pad. The digitizing station consists of an Altek digitizing table, a Tektronix graphic terminal for interactive editing and monitoring and a video terminal for the operator's communication with the computer. The digitizing of features can be done either in point mode or stream (continuous) mode. The digitized position gives X, Y co-ordinates and the numerical figures on the keypad of the cursor can be used for the Z co-ordinates such as the depth value, or the height value. The textual features are digitized in a two point mode from where the start position of text and direction in which the text is to be placed is determined by the system. Actual text is keyed in from the video terminal.

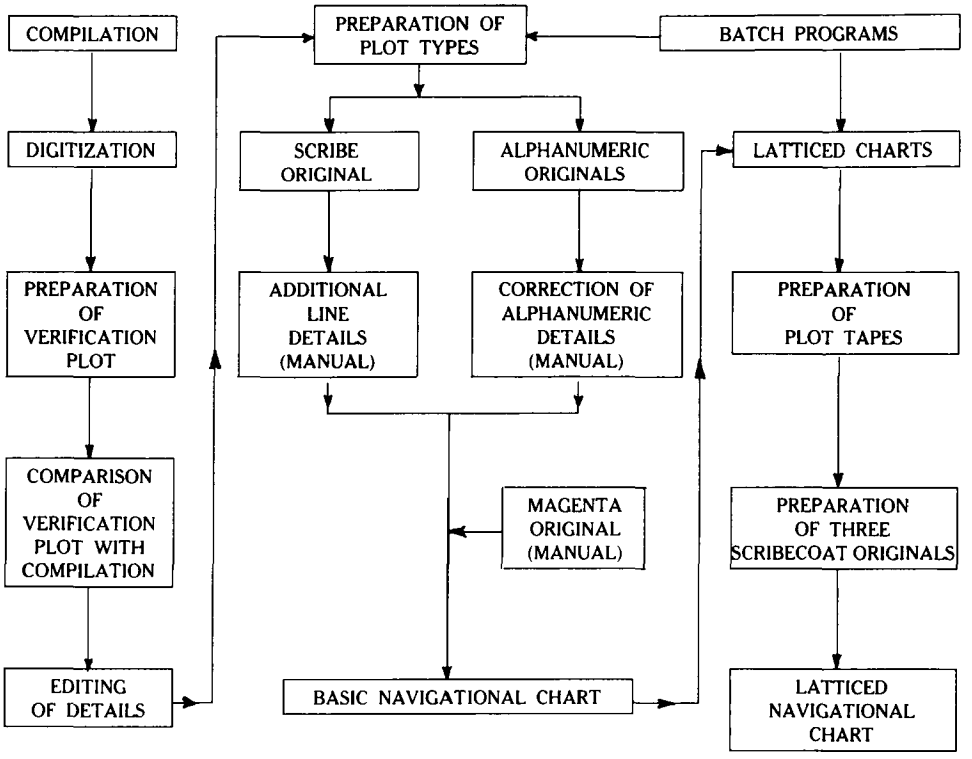

FIG. 2. — Role of the Cartographic Plotting System in the preparation of production originals of navigational charts in the Hydrographic Office.

Verification

The data captured from the table is then used to generate a verification plot on the Calcomp 960 (two pen plotter) on permatrace. This verification plot can also be made on the Kongsberg, but the Calcomp 960 gives a quick on-line plot.

Editing

The verification plot obtained from the Calcomp 960 is checked against the compilation to check whether any items have been left out while digitizing, or were erroneously digitized. These are included/rectified by using both Tektronix graphic terminal and digitizer.

Preparation of Plot Tapes and Plots

When the digitization and editing are completed, the data file is ready for use in the preparation of plots. The Kongsberg plotting system requires data in a

specific format, i.e. in EBCDIC code and on 800 BPI density magnetic tapes. In the NHO two originals are normally prepared, one for line work on scribe sheet in negative mode and one for alphanumeric details on film in positive mode. For some charts a third original, either on scribecoat or film, is also prepared in CPS if the 'magenta' details of the chart are numerous such as traffic separation zones, prohibited area limits, etc. The line details original also contains projection data such as the standard border and graticule lines, which are separately generated by a batch program.

Software Organization

The software of the CAC system in the CPS is divided into three parts viz. Data Input Sub-system, Data Manipulation System and Plotting Sub-system. A schematic diagram of software facilities supplied by the manufacturer is given in Figure 3. Besides the software supplied by manufacturers, cartographic programmers have developed batch programmes for generation of border graduation, hyperbolic lattices for survey vessels and Decca Lattice sheets for charts.

Input Sub-system

This sub-system consists of programmes called System Manager (SM), Station Processor (SP), Graphic Routines (GR), Station Graphics (SG) and Digitizer Polling. These are further supported by Subfile Access (SA), Subfile Interface (SI), Projection Routines (PJ) and several Utilities (UT). This part of the software is used for data capture and interactive editing.

Data Manipulation System

It consists of two programmes called Load/Dump (LD) and Chart Generation (CG). The Load Dump programme is used for the selective deletion or copying of the details or compressing the chart file. The Chart Generation programme is used for the merging of several chart files into a single chart file or vice versa or into transforming chart file from one scale to another scale or projection. These programmes are of great use, particularly when the existing chart files are to be updated or to be used for compilation.

Plotting Sub-system

This part consists of programmes Chart Plot (CP), Symbology (SY) and Plot Routine (PL). These three programmes with the input from the three basic tables: Matrix Definition (MD), Symbol Definition (SD), and Feature Definition (FD), generate the required chart plot processing the chart file obtained by digitization. These three tables constitute the main input for drafting various symbols used on the chart. They define the various aspects of features. The

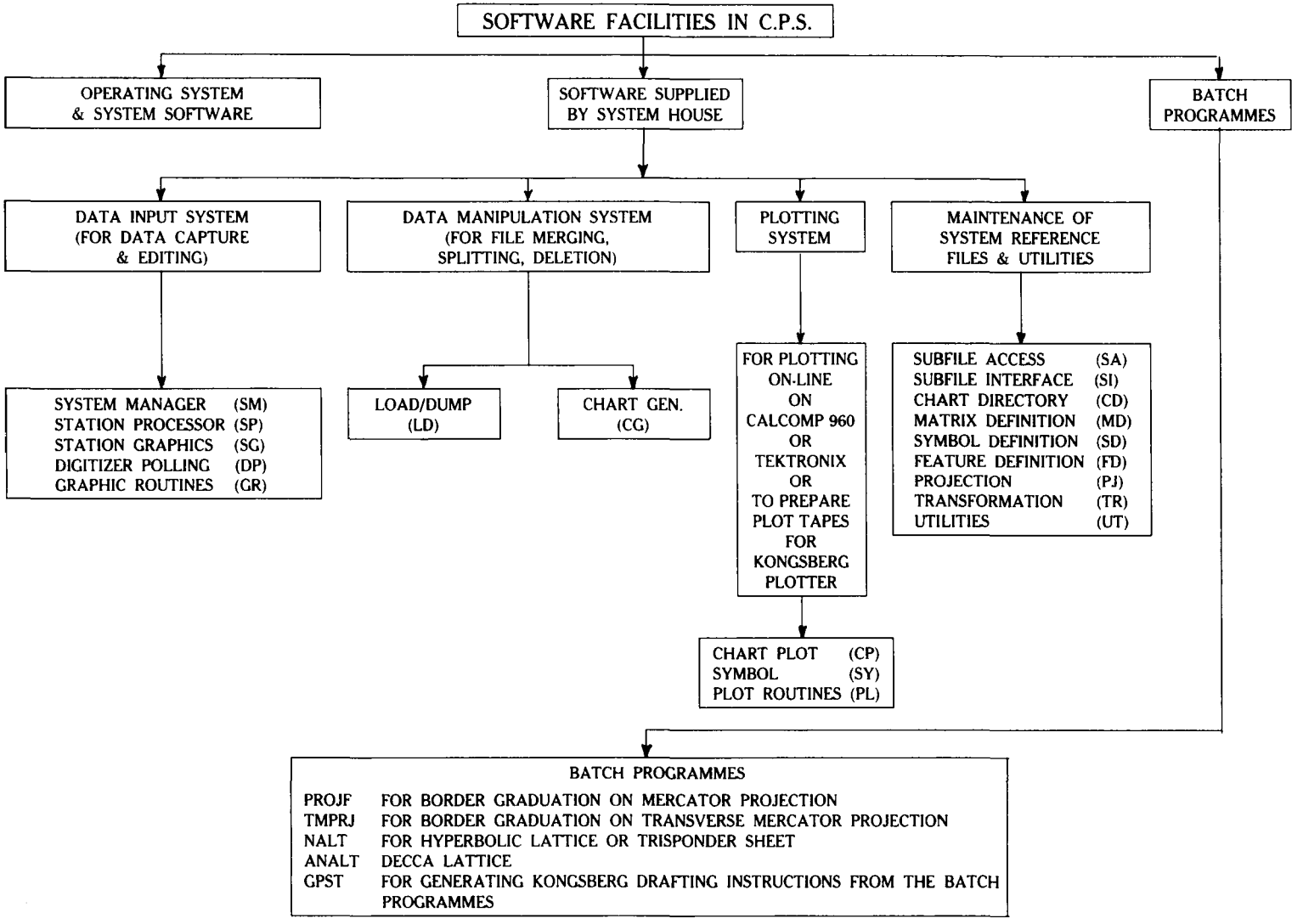
SOFTWARE FACILITIES IN C.P.S.
OPERATING SYSTEM & SYSTEM SOFTWARE
SOFTWARE SUPPLIED BY SYSTEM HOUSE
BATCH PROGRAMMES
DATA INPUT SYSTEM (FOR DATA CAPTURE & EDITING)
DATA MANIPULATION SYSTEM (FOR FILE MERGING, SPLITTING, DELETION)
PLOTTING SYSTEM
MAINTENANCE OF SYSTEM REFERENCE FILES & UTILITIES
SYSTEM MANAGER (SM)
STATION PROCESSOR (SP)
STATION GRAPHICS (SG)
DIGITIZER POLLING (DP)
GRAPHIC ROUTINES (GR)
LOAD/DUMP (LD)
CHART GEN. (CG)
FOR PLOTTING ON-LINE ON CALCOMP 960 OR TEKTRONIX OR TO PREPARE PLOT TAPES FOR KONGSBERG PLOTTER
SUBFILE ACCESS (SA)
SUBFILE INTERFACE (SI)
CHART DIRECTORY (CD)
MATRIX DEFINITION (MD)
SYMBOL DEFINITION (SD)
FEATURE DEFINITION (FD)
PROJECTION (PJ)
TRANSFORMATION (TR)
UTILITIES (UT)
CHART PLOT (CP)
SYMBOL (SY)
PLOT ROUTINES (PL)
BATCH PROGRAMMES
PROJF FOR BORDER GRADUATION ON MERCATOR PROJECTION
TMPRJ FOR BORDER GRADUATION ON TRANSVERSE MERCATOR PROJECTION
NALT FOR HYPERBOLIC LATTICE OR TRISPONDER SHEET
ANALT DECCA LATTICE
GPST FOR GENERATING KONGSBERG DRAFTING INSTRUCTIONS FROM THE BATCH PROGRAMMES

FIG. 3

definition and structure of each feature and symbol is obtained from these tables by the programmes SY and PL.

Other Uses of the System

Besides preparing the fair drawing originals, the CPS is used in the preparation of hyperbolic lattice sheets used by survey vessels for electronic position fixing on the survey grounds and Decca lattice overlays for basic navigational charts. Survey fair sheets wherein survey data is incorporated by ship's personnel are also prepared with the system.

Experiences

Even though the system has been utilized for various activities in the nautical chart production, the cartographic personnel operating the system have to face innumerable problems. Initially, due to a lack of understanding of the exact procedure for making the compilation compatible for this type of processing, several deficiencies were observed when plots were examined and were not accepted by the Drawing Office personnel.

a) Lineal Features

Lineal features such as foreshore rocks, corals and mangroves need a specific line of digitization to get the correct delineation required on the chart. Compilers used to show these features symbolically on the compilation for the benefit of fair drawing draughtsmen. When these features are digitized, either taking the outer fringe or the inner side of the feature, the final depiction on the plot showed shift in the delineation. To obtain an exact depiction of the feature, compilers were advised to depict feature by a line only. If there are several features, the colour code has been suggested for each feature. Besides this suggestion, the point of origin of a feature in the matrix defined for the feature was shifted to get the correct alignment of the feature. Similarly, roads which are required to be depicted on charts as a double line have a specific width. If the compilation shows a double line for a road, it would be impracticable for digitizing draughtsmen to run the cursor at the centre of the double line to obtain the specific depiction of road. To obviate this problem it was suggested to the cartographers that a line only be given for a road and the width of the road be defined at the time of entering the feature which will be taken care of at the fair drawing stage. In case of shoal soundings surrounded by ring contours, generally the sounding value overlaps the contour line; since these are given on two different originals, there is always a possibility of mismatch. To avoid this, cartographers were advised to depict the depth value to the size given on the chart and then mark the contours around the value. This facilitates better depiction of the shallow depth with ring contours on the printed chart.

b) Point Features

Symbols flashed from the symbol disk in the photohead initially were not positioned on the chart correctly. After several checks, it was found that digitized

positions of these symbols needed offsets while flashing. So matrices for all the flashing symbols were given required offset individually and in the digitization the symbols were precisely digitized. This has improved the positions obtained on final plots considerably.

c) Soundings

Soundings (depth values) given on the chart are required to be in a specific standard. Metre and decimetre values of the sounding are spaced in a standard gap. This gap between the two figures is atypical for these two figures. Initially, the data supplied by the manufacturer was not satisfactory. Cartographer programmers have modified the software and defined the spacing as per required standard. Soundings depicted on compilations written by draughtsmen are not uniform. Each draughtsman writes the depth value in his own way and no two depth values written by two different draughtsmen are alike. This has created a problem to position the cursor for digitization accurately. The position of the sounding would be the centre of the entire figure. If this position is not digitized properly, the position of the sounding is shifted. This problem of variation of the sounding position was looked into and the compiling cartographers were advised to indicate the position of the sounding by a dot while they are transferring the data from originals. This has resulted in better positioning of the charted depths.

d) Software and Hardware Modification

The positional inaccuracies in point features were minimized/eliminated by replacing the crosswire cursor by a more pronounced cursor with circle and dot at the center of the cursor. Software modifications were done to depict certain symbols by way of converting one point feature to two point features or two points to multipoint or by changing the scale of the matrix defined for the symbol or by changing the position of the symbol.

e) Computer Compatibility of Compilations

Stated concisely, the compilations hitherto which were not compatible for digitization have been made compatible and cartographers have also accepted the computer product. Initial reluctance to accept the computer product by comparing it against the manual output (drawn by draughtsmen) has now diminished. Many problems in which the Cartographic Plotting System is unable to help the cartographers as of now, are being looked into for obtaining some positive solutions.

f) Limitations of Computer Product Vis-a-Vis Manual Product

The basic difference in the product generated by the Cartographic Plotting System as against the manual one is that it cannot reproduce symbology in smaller areas whereas the draughtsman would squeeze in the details or by mosaicing the details to suit the area available. Since the computer product would be of uniform size and predefined, it always requires a space for which it is programmed. In this context, only scale changes for features can be applied or new features defined for them. This is done for features like steep coast, corals or foreshore rocks. The textual features are produced with a specific uniform spacing and this gap gets squeezed in case of curvilinear text if the curve is too sharp. In

such cases, manually the draughtsmen mosaic the text on the curve as required. Software modification is required to overcome this problem.

Other Applications

The Computer Assisted Cartographic System can also be used in the compilation stage by providing reductions/enlargements from already existing chart files. Chart files can be manipulated to merge several files into one and vice versa. Preparation of colour separation originals can also be undertaken for the printing stage by using some special tools.

R&D EFFORTS IN HAND

a) Coastline

This feature is drawn with 0.2 mm thickness either on film or scribecoat, causing some variation in the output, particularly when the coastline is undulating. In such cases, the coastline depiction is not satisfactory. The coastline is normally digitized in point mode and a curve fitting routine is applied to produce a smooth line at the time of fair drawing. If the line is digitized in continuous mode, the coastline so obtained is not satisfactory. To get a better output sampling rate for data capturing, resolution has been modified in the case of continuous digitization and tested. Now except in a very pronounced zigzag curves, coastline digitized appears to be satisfactory. But work is in hand to eliminate the problem permanently in all cases.

b) Breakers, Submarine Pipelines and Submarine Cables

These symbols are available on symbol disk for photoflashing. But if the line of digitization is other than East-West direction, these symbols are not flashed in the required direction, which implies that the rotation required for these symbols before flashing is not affected in the existing plotting software. This needs to be solved by introduction of rotation factor for the feature.

c) Textual Features

When combining textual features with numerical data the spacing required between the characters is not uniform. The spacing between characters in relation to certain numerical characters has to be modified. This is being attempted by changing the width of the matrix of the character or point of origin.

d) Labelling and Symbol Disk for Text

Labelling of the borders, lattice sheets and Hifix plotting sheets can be done by plotter by using batch programmes. A few subroutines are to be added to generate this labelling. Further, textual details are also being obtained on symbol disk to flash the textual characters instead of photoplotting. This new disk when obtained has to be integrated with the existing system with necessary software modifications and additions.

e) Software Maintenance and Development

All the software supplied by the manufacturer is maintained in-house and the required modifications are carried out by the cartographic programmers. All the batch processing software was developed in-house and attempts are being made to improve the software to overcome the difficulties encountered while processing. Software modifications and development are an ongoing process and experience has shown that the cartographers who have computer background are better suited for the software maintenance and development and the draughtsmen for the day to day operations on digitizer and plotter.

Exchange of Digital Data and Role of CAC

The International Hydrographic Organization has constituted a committee to look into the aspects of digital data exchange for charts. Hitherto, national agencies under an agreement obtain charts of other countries in the form of repromats for printing. With the advent of computer assisted cartographic system, it is felt that the need has arisen to look into a better means of exchange of charts. The Indian Naval Hydrographic Department is represented on this committee. The format designed for exchange is a tape format, on which a chart file is formatted in a sequential manner, with chart information in first logical record, feature codes in second logical record and positional data in third logical record. This format is very flexible and user agencies can convert them to their formats with some computer programs written at their end. This format was considered at the XIIIth I.H. Conference in May 87 for adoption.

Electronic Chart

The concept of the electronic chart has developed from the fast growth of electronic systems used in hydrography and nautical cartography. We can say that it is in embryo stage as far as the navigational chart is concerned. Even though, certain commercial organizations have introduced these for limited use such as in fishing and yachting. To apply the same technique to navigational chart at this stage is too early. Most of the developed countries have expressed a cautious opinion about its utility. Conceptually, it is equivalent to a paper chart. The CAC would be contributing to the concept of the electronic chart by creating a comprehensive data base of digital charts.

ACHIEVEMENTS AND CONCLUSIONS

We can confidently point out that the introduction of computer assisted cartography in nautical charting has considerably improved the quality of the products, accelerated the production of charts with uniform, accurate and constant outputs. With the present situation in manpower constraints imposed by the Government and increasing demands for charts, the cartographic plotting system

TABLE

QUANTITATIVE ACHIEVEMENTS OF CARTOGRAPHIC PLOTTING SYSTEM

Sl No.	Nature of job	Quantity completed from Nov. 81 to date	Items accomplished	Percentage of job	Items to be accomplished	Percentage of job	
1	Electronic position fixing Plotting sheets, i.e. Hifix, Trisponder and Seafix	55	Hyperbolic/circular pattern Lines for each pattern (maximum of 3 patterns for a sheet)	90%	Labelling of lane numbers, title, and grid geographical intersection values	10%	These can be achieved once labelling options are implemented in batch programmes
2	Survey plotting sheet	76	Drawing standard border graduation with grid and geographical intersections	95%	Labelling of graticule values, grid intersection values	5%	"
3	Compilation master grid	142	Drawing of standard border graduation, graticule lines and plotting of control points in the chart	95%	Labelling of graticule values	5%	"
4	Navigational chart a) Line original (black)	115	Border graduation, graticules, radar, scales, coastline, contours (land & water), roads, railway line, building, river, characteristics of coast, various limits, different pecked lines, tables and boxes	95%	Minor cringing details, features of smaller, irregular shape	5%	This can also be improved by smoothing the details
	b) Alphanumeric original (black)	115	Sounding, spot heights, all point features and all text features up to font 9	75%	Title, graticule values, marginal details including text details above font 10	25%	
	c) Magenta original	12	Various magenta limits, flares, text up to font 9	40%	Compass rose, certain magenta limits with symbol in oblique direction (not possible on film)	60%	Some of the originals are obtained on scribecoat
5	Decca navigational chart	12	Decca lattices of all patterns	90%	Labelling of lanes, notes, cautions	10%	

contribution is significant. The quantitative output obtained from the cartographic plotting system in respect of various cartographic jobs undertaken in the NHO is outlined in the table.

Data can be easily converted into digital form through digitization and complex symbols are reproduced with consistent uniform sharpness and accuracy. The most time consuming job of generating pecked lines of different sizes of different types is fast produced on plotters with precision and uniform gaps. Complex computational requirements for projections, Hifix, Seafix, plotting sheets and co-ordinate conversions, etc., have been simplified and easily available for the users.

With the introduction of a new data acquisition system on the survey grounds, new techniques in electronic position fixing systems and plotting devices, there will be significant changes in the outlook of nautical cartographers. More and more computer aided techniques will be used in various spheres of cartographic activity in the near feature.

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