

Generation of Electronic Nautical Chart Data for Assessment of Navigational Safety in Harbour and Waterway Design

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ABSTRACT: Navigational simulator is widely applied in the assessment of Navigational Safety in the harbour and waterway design. According to the needs of ENC(Electronic Nautical Chart) data in the navigational assessment, this paper analyzes the source of ENC data, such as S-57 data, MVCF(Military Vector Chart Format) data and CAD(Computer Aided Design) data. An effective method of ENC data generation has been developed. Special techniques are investigated for generating ENC data, such as ENC data structure designing, chart data conversion, digitization method of raster images of CAD design drawing, optimization approaches and data integration methods. Software has been developed to edit the chart data with good performance. The technologies developed in this paper have been applied to more than 100 practical projects and successful results have been obtained.

1 INSTRUCTION

With the fast development of water transportation in recent years, significant projects of harbour and waterway increase constantly, and the traffic density in water areas also increases unceasingly. Usually the investments of many harbour projects are enormous and it was costly if some design mistakes could not be identified. Once the accident happens, the direct and indirect losses are inestimable. Hence, it is important to carry out the assessment of Navigational Safety in harbour and waterway design to ensure safety of navigation when the projects are implemented (Guan et al. 2005).

To assess the navigational safety of designing projects of harbour and waterway, ship-handling simulator is employed to carry out simulated tests in real time. Results retrieved from analysis of the test data are benefit not only for the navigational safety of the vessel, but also harbour and waterway facilities. The tests help reduce the expenses of the engineering experiment, and optimize the design of the project. The shiphandling simulator assessment can improve the economic benefits and competitiveness of the port. It can check out the potential capacity of the port and berths, and provide approaches to make fully use of the berthing ability of the port.

Usually the fast simulation of navigation is adopted, using the simulation system of two-dimensional (2D) display. The system is composed of the Electronic Chart Display and Information System (ECDIS) and the navigational Simulation Controlling System. The operator, who is shown a 2D chart display, use the keyboard to control the engine and the rudder. Multiple PC systems can be used carry out simulation tests of different operation mode at the same time to accelerate the assessment procedure.

In order to perform the simulation test described above, it is a very important step to generate the ENC data for the planning harbour and waterways. In this paper, approaches are studied to use various existing chart data sources and design data of harbour and waterway projects. A rational and fast method is developed for the generation of ENC data specifically for the assessment of navigational safety of harbour and waterways.

2 THE NEEDS OF ENC DATA IN NAVIGATIONAL ASSESSMENT

The work of the assessment of navigational safety in the harbour and waterway design include mainly:

- 1 Assessing the efficiency of navigation in the channel. The data, such as the channel width, water depth, navigational marks, etc. of the design waterway, are checked whether the requirements could be met for the navigational safety of the

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vessel with design tonnage under certain hydrological and meteorological conditions. This step is performed mainly through simulator operations, obtaining the width of the vessels' paths and the tracks of vessels out of control or drifting.

- 2 Assessing the capacity of berthing in the port. The data to be assessed include the size and water depth of manoeuvring area of the design quay. Simulator checks are carried out to make sure the requirements are met for safe berthing operations of the vessel with design tonnage under certain hydrology meteorological conditions. (Qian 2003).

In order to meet the needs of the navigational assessment, the ship-handling simulator should provide the ENC data with large scales. Those data should be organized with a rational structure. The general precision of the ENC data is required to be within the range of meter. And it is required that ENC data must include the following details,

- 1 Lands and islands;
- 2 Quays, docks, bridges and inshore facilities;
- 3 Beaches, depths of water, depth contours and bottom characteristics;
- 4 Channels, anchorage, security area and sea floor pipelines;
- 5 Obstacles;
- 6 Aids to navigation;
- 7 For the ENC database used in the assessment, the following demands should also be considered,
- 8 Good compatibility and expansibility,
- 9 Adapting of the standard electronic chart data structure,
- 10 Adapting of the data of the design drawings of the project,
- 11 Efficiency and costs,
- 12 Maintainability and portability.

Meanwhile, it must be easy to search and revise, and in a hierarchical structure to raise the speed of data processing.

3 ANALYSIS OF THE SOURCES OF ENC DATA

The assessment of navigational safety in the harbour and waterway design usually assesses the project that is going to be implemented, or in progress of the design phase. There is, therefore, no ready-made nautical chart to be used. We can only combine the design drawings of the project and the existing nautical chart of water areas to set up specific ENC specific database to meet the needs. The sources of the ENC data can include the existing paper nautical chart, S-57 electronic nautical chart data, MVCF electronic nautical chart data, CAD project design drawings and satellite remote sensing image, etc. As to the existing electronic nautical chart data, corre-

sponding format change is necessary, changing the standard S-57 format data into the system defined format data. Special processes are needed for other sources such as paper nautical chart, satellite images and CAD design drawings, etc.

3.1 S-57 data

The Standard IHO (International Hydrographic Organization) S-57 is the most popular ENC data worldwide. It is designed to permit the exchange of data describing the real world. The data produced is organised into named structures. Usually, more than one object is involved in an exchange. Therefore, since an object is structured into a record, an exchange is comprised of more than one record. To facilitate this, records are grouped into files. The set of information which is finally exchanged is called an exchange set (IHO. 2000).

This standard defines a set of records from which an exchange set can be built.

These records fall into five categories:

- 1 Data Set Descriptive Record : Containing information about the coordinate system, the projection, the horizontal and vertical datum used, the source scale and the units of height and depth measurement, and information about the origins of the data set.
- 2 Catalogue Record: Containing the information required to allow the decoder to locate and reference files within the entire exchange set. This part can be compared with a table of contents. It also contains information about special relationships between individual records within the exchange set.
- 3 Data Dictionary Record: Containing the description of objects, attribute and attribute values used in an exchange set.
- 4 Feature Record: Containing the non-locational real-world data.
- 5 Spatial Record: Containing the locational data. They may be of types of vector, raster or matrix. An exchange set may contain a mixture of the different spatial record types. Among them, vector records include the information about the coordinate geometry related to the feature records, including spatial attributes, topological relationships and update instructions. Vector records may be of types node, edge or area.

S-57 data can be obtained from the nautical chart publishing department.

3.2 MVCF Data

MVCF is an abbreviation of the Military Vector Chart Format, which is the digital nautical chart in-

terchange standard of China. It possesses the characteristics of the following:

- 1 It is a kind of geographical datum model without the topological relation, supporting the fast display and easy editing of the data;
- 2 It supports the index file. The structure of the data is succinct;
- 3 It supports point, line, polygon and annotation notes. Therefore it supports the exchange of the whole nautical chart data elements;
- 4 Attribute is supported. The attribute of the vector is stored in dBASE format file, and the attribute record is the one-to-one correspondence with vector record.

MVCF data file is organized by the sheet of paper chart. It adopts the catalogue structure. The catalogue name is the same as the serial number of digital nautical chart. MVCF data compose of four files: basic file, shape file, index file and attribute file. Among them, the shape file is a variable length record file of direct access. It contains the coordinate position data of the nautical chart. Index file contains describe the offset of the beginning record corresponding shape file record. The attribute file is in dBASE format structure. It contains the attribute of the vector data. The shape file record is one-to-one correspondence with the attribute file record.

MVCF data can be obtained from the Navigation Support Department of the Navy Headquarters. The nautical charts published cover the whole coast area of China.

3.3 CAD engineering design drawing

Usually, software of AutoCAD is employed in making the drawings of design projects of harbour and waterway. These drawings include data of water areas and land-based areas, especially the newly-built objects, such as quays, docks, bridges, channels and navigation marks, etc. These designs are the target of the safety assessment. The data may also include harbour building, shipyard workshop and coastline, etc., which are not as critical in safety assessment. Hence, the data that we care about are only part of the engineering drawings for the relating water areas, and it is unnecessary to change the whole CAD file directly. By retrieving part of the data from the drawings, information redundant can be avoided.

In China, the domestic coordinate system, BJ-1954, is generally used in the design drawings. Additional conversions should be made to ensure compatibility with the coordinate system, WGS-84, that ECDIS adopts. In our research an approach is developed for the processing of the drawings. The CAD data file is printed to a JPG image. Then, with digitization technology, vectorization operation of the parts we need is performed. In order to improve the

processing efficiency, we only concern the newly-built relevant objects, such as quays, docks, manoeuvring areas, channels and navigation marks, etc.

3.4 The satellite remote sensing image

The satellite remote sensing is the new technology to obtain the information such as resource, environment and calamity in the coastal areas. It has some conspicuous advantages, such as large-scale, high efficiency, synchronization, high frequency of dynamic observation and so on. With the fast development of the remote sensing and computer technology, the satellite remote sensing can replace the survey artificially with a great extent. It becomes a important data source of the digital chart. It is a kind of very economical and practical method to use the satellite remote sensing image of high-resolution. By digitization, Data of coastlines, quays, berths and buildings can be obtained from satellite images.

4 THE STRUCTURE OF ENC DATA

To meet the requirement of the navigational assessment, one structure of reasonable ENC data has been developed and named as HYENC (Electronic Nautical Chart Local Defined). Conciseness and memory saving are considered, and it is convenient for transformation, renewal and maintenance, as well as fast display.

HYENC data structure defines that each file represents one nautical chart. The file includes sheet data and figure data. The sheet data on the head of the file contain 600 bytes for the control information of each chart, and they are divided into 25 data items. The figure data are variable length records of direct access, recording the data of layers of each chart, and per layer of data includes the head data of 108 bytes and the records of variable length. The record counts and type are stored in the sheet data. The structure of HYENC data is shown as Figure 1.

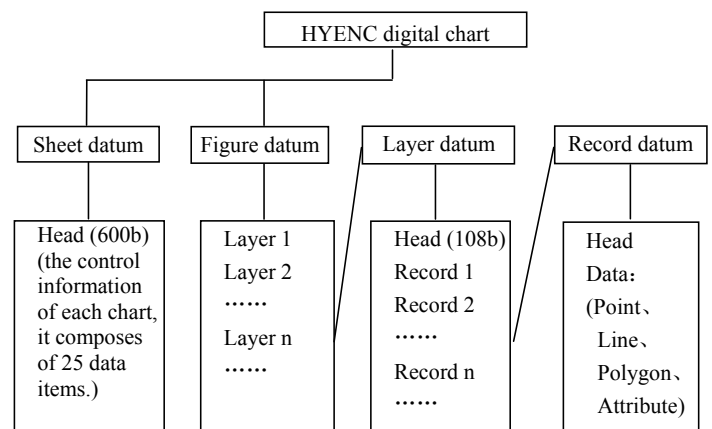


Figure 1. The structure of HYENC data

The sheet data includes information such as the name, range, scale, coordinate system of the nautical chart. By this information, chart search can be performed rapidly, and chart panning and seamless splicing can be realized. The figure data is such structured that it helps the hierarchical display of the chart, as well as convenience for combining, adding and deleting relative information.

5 THE METHOD OF ENC DATA GENERATION

5.1 ECDIS coordinate system and conversion

To display the chart on the computer screen, it needs converting Mercator projection coordinate into computer screen coordinate. When performing chart work on ECDIS, we need to convert computer screen coordinate into geographic coordinate. Conversion and calculation of all kinds of coordinate in real-time for the display and operation can influence system performance of ECDIS.

For fast display, the ENC stores the point assemble data in longitude and latitude coordinate. Longitude data is in the unit of minute, and latitude in meridional parts. When displaying the chart on the computer screen, the time for converting latitude into meridional parts can be saved, improving the speed of displaying.

In ECDIS, the point of left bottom is taken as the origin of coordinate with display format of north up. We establish coordinate system that the OY axis is upwards, OX axis rightwards. Suppose that a geographical coordinate point, $M_0(\varphi_0, \lambda_0)$, corresponds to screen coordinate point, $P_0(y_0, x_0)$, then any geographical coordinates and screen coordinates may be converted using equation (1) and (2):

Longitude λ converts into x :

$$x = x_0 + (\lambda - \lambda_0) \times f \quad (1)$$

Latitude φ converts into y :

$$y = y_0 - (\varphi - \varphi_0) \times f \quad (2)$$

where f is a scale, expressing the ratio of meridional parts of geographical coordinate to the display screen coordinate.

By the similar manner, it is easy to convert screen coordinates into geographical coordinates.

When performing zoom in, zoom out, drag and other operations, we can fast convert coordinates, and display ENC figure on the computer screen. Meanwhile, we use the screen clipping algorithm to filter the ENC data. It filters out the data beyond screen range, and improves the displaying speed of ECDIS.

In the ECDIS, the geographical position is expressed in longitude and latitude coordinates, i.e. degree, minute and second. Then the corresponding algorithm of mutual conversion between latitude and meridional parts may refer the paper (Zhang 2003).

5.2 The procedure of ENC data conversion

For the assessment of navigational safety in the harbour and waterway design, the design department supplies the project design drawing in CAD format. We must use another method to obtain other data such as the nearby coastline and channel. Through the analysis described above, these data can be obtained from sources such as paper chart, S-57 format data, MVCF format data, remote sensing satellite images and CAD project design drawings, etc. These data are mainly divided into two kinds, the digital ENC data and raster image. For ENC data, we need compile programs to apply converting of S-57 format data and MVCF format data, while a digitalization is need for paper charts, remote sensing images and CAD project design drawings. Then we integrate all data into one ENC data file which serves the simulation assessment. The converting procedures are illustrated in Figure 2.

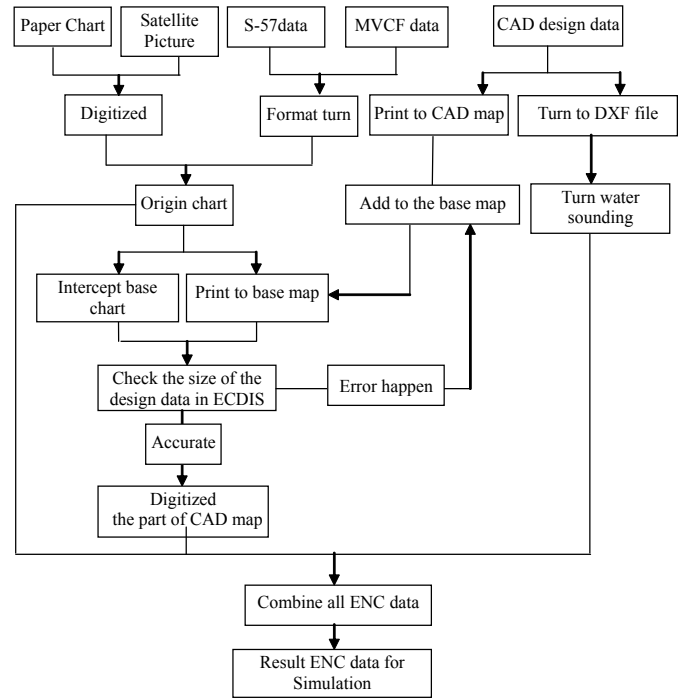


Figure 2. The procedure of data converting.

5.3 Digitization of raster images

Digitization is a very important step in the procedure described above, i.e. use certain apparatus and software to digitize raster image and convert them into vector data. Hu (1999) recommended a method of using digitizer to convert paper chart. This method utilizes digitizer and corresponding software of collecting ENC data together, which convert raster data

into vector data. The method which relies on circumscribed digitizer, a paper chart can only use on one machine at a time. It is kinds of complicated inefficient to convert the data, and inconvenient to modify latter data. The approach is kinds of inefficient and can hardly meet the requirement of project research in the time limit.

A PC-based ENC data editor system is developed to meet our needs. It uses the mouse and interface software to digitize raster images. Firstly, it is important to determine the key point position i.e. its longitude and latitude, the coordinates of the screen of southwest and northeast point. We can obtain the coordinates from the paper chart or the satellite remote sensing image. After determining the key point, we can display the raster image in PC-based ENC data editor's system, and then use the mouse to collect manually the point-line-face data of the chart. The system automatically converts a mouse position of the screen coordinate into geographical coordinate, and save the coordinate data into the data file.

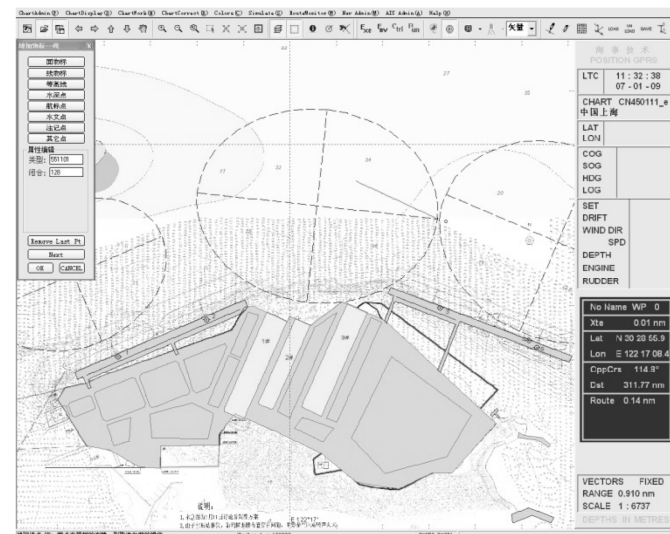
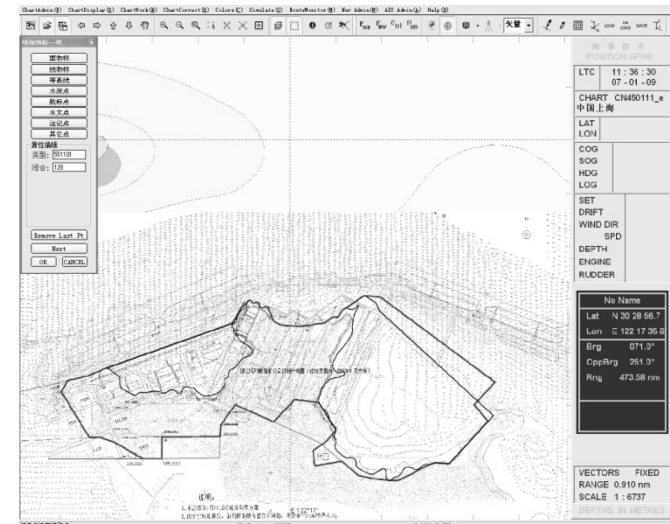


Figure 3. ENC data editor's system.

We adopted layered storing and displaying technology of ENC data. We can digitally compile paper chart on several PC at the same time, and collect all the data into one file finally. Thus it can improve the speed of making ENC data, and shorten development period. Furthermore we may add, delete, edit the data randomly and maintain the data conveniently. Figure 3 illustrates the ENC data editor's system software interface.

If the image is the CAD design drawing, we need to convert the format of the CAD file into *.JPG image. Then The ENC data editor's system software interface is the image processing software such Photoshop is used to superimpose the image with the base map. The JPG format image needs to be zoomed in or out in the same proportion. Firstly we match the base map and the CAD design drawing. Then the length of the quay or size of turning circle area is measured by using the digitized system software. The size is compared with the dimension of CAD design drawing, and the difference proportion is calculated. Secondly, adjust the size of JPG image in the proportion until the two images are identical in size. At last the composite image can serve as digitized base map. When digitizing the image, we only need to choose useful information, for example, quay, dock, newly-increased coastline, turning area, channel line, designed anchorage, navigation mark, and depth of water and note information.

5.4 Generation of water depth data

Water depth is an important parameter in the assessment of navigational safety in the harbour and waterway design. The design water depth of channels or turning area should ensure enough Under Keel Clearance (UKC) for vessels. The designer supply CAD design drawings that includes survey data of depth of water. We can obtain water depth data according to the digitized method described in Section 5.3. But it is relatively heavy workload to input a large amount of depth of water manually. So we plan to obtain water depth data with data conversion method. Firstly export the CAD drawing format file (*.DWG) as Drawing Interchange Format file (*.DXF). Then extract water depth data from the file with certain algorithm, and keep a series of point, P (x, y, z), where the coordinate x and y express plane coordinate, and z express the depth of water, into a collection. Finally convert the point collection into ENC water depth data.

If there are no newly surveyed data, water depth can be obtained from the present paper chart. We can convert present S-57 format data or MVCF format data. Water depth data of S-57 format denote in SG3D record, while water depth data of MVCF format are specially stored in the sounding layer. In the ENC data editor's system, we can use the mouse to

add, delete, and edit water depth data. Based on present data of water depth, neural network technology is used to carry out difference calculation (Shi 2004). While navigating in the simulation area, water depth nearby the ship is detected in real-time, determining whether the water depth of the channel meets the demands or not.

5.5 Data combining and correction

In order to ensure the maintainability of ENC data, we adopt layered processing technology, which classifies point object, line object and area object based on different characteristic of ENC data. For example water depth, navigation mark, marks on the bank are inducted as point object; and coastline, depth contour and submarine cable, etc are inducted as line object; land, island and quay, etc. are inducted as area object. Because of data the layered structure, we can integrate pieces of ENC data easily. There are two kinds of situations. One adds data of additional map directly to base map data, at the same time adjust the sheet data of base map, thus additional map will overlay on the base map. Second method is to integrate the index number of layer data of additional map and layer data of base map corresponding to the index of layers.

In order to maintain ENC data and develop ENC editor system, when we edit point, line and area object, only the mouse is needed to finish adding, correcting, deleting of the point collection, and to edit attributes. Several computers can work simultaneously on one chart, and the generated data are put together finally, improving the efficiency of making ENC data.

6 CONCLUSIONS

Navigational simulator is widely applied to assessment of navigation safety in harbour and waterway design at present, but the ENC data are the fundamental element of the simulation. The ENC data produced by above described method can be applied to two-dimension ship handling simulation system. Meanwhile, it is the source of the simulation radar echo data and coastline, port building and topography of three-dimension visual system in large ship simulators. In this way, we can make all data totally identical, ensuring reliability of the simulation result. Software has been developed to edit the chart data with good performance. The technologies developed in this paper have been applied to more than 100 practical projects and successful results have been obtained.

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