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Progress and Prospects of Hydrographic Surveying Technology in China

By Huang Motao, Zhai Guojun, Ouyang Yongzhong, Liu Yanchun and Lu Xiuping, Tianjin Institute of Hydrographic Surveying and Charting, P.R. of China, China

During the last decade, significant advances have been made in the study of hydrographic surveying technology in China. This paper gives an outline of recent progress in the fields of survey equipment, information acquisition, data processing, data management, basic survey theory and their applications. The future development trends are discussed and presented.

Introduction

With the development of modern computers, as well as space and communication technology, significant changes have taken place in surveying and mapping science and techniques, from its theory to its application. As early as 1990, the International Union of Surveying and Mapping (IUSM), gave a new definition to surveying and mapping. Namely, that, it is a branch of science, engineering and technology, which deals with the acquisition, measurement, processing, analysis, explanation, description, distribution, usage and evaluation of geo-spatial information. Marine surveying is an essential part of surveying and mapping science and technology, and its major mission is to measure and describe the parameters of ocean geometry and physic. Its purpose is to provide information on ocean space, required for human activity. In recent years, with the improvement and development of computer technology and information acquisition, an outstanding change has also occurred in the branch of marine surveying. Besides traditional hydrography, many new branches of marine survey, such as marine control survey, marine engineering survey, seabed topography, marine gravity and marine magnetism survey, have shown their value. Three areas of technology, i.e., airborne laser hydrography, shallow water multibeam depth echo sounding and digital side scan sonar, are thought to be the newest technology for shallow water hydrographic surveys owing to their high speed and high resolution. The application of this new equipment has resulted in an important change from point and line survey mode to swath measurement. Breaking through the traditional limit of time and space, marine surveying has at last advanced to a new stage where digital survey methodology, computer technology and 3S (GPS, GIS, RS) technology plays an important role. In the past few years, significant progress has been made in the study of hydrographic survey technology in China. They are briefly summarised in the following:

(1) There is an increase in the different types of survey equipment available.
(2) In data acquisition and collection, there has been a change from ana-

logue recording to digital and automatic recording.
(3) In data processing, a change from manual processing to automation has occurred.
(4) Standardisation and the development of networking have been emphasized in data management systems.
(5) More attention has been turned to application in the study of basic survey theory.

Progress in Survey Equipment

Multibeam Depth Echosounding Technique

The multibeam echosounder is a relatively new type of hydrographic survey system with high accuracy, high resolution and high efficiency. It is designed for mapping 100% of the seafloor. In recent years, multibeam echosounding systems, especially shallow-water mapping systems, have been developing rapidly for various applications, from hydrographic surveying to underwater inspection, from mine hunting to shoreline studies. Multibeam echosounders are quite different from conventional single beam echosounders, in their principles of operation and also in the way they are constructed. Unlike conventional single beam echosounders, the multibeam depth echosounder is a complex survey system in which multi-sensors are used. Seabed topographic survey technology has made great progress owing to the development of the multibeam depth echosounder (Mccaffrey, 1981; Tyce, 1986; Atanu and Saxena, 1999; Li, 1999).

In order to meet the requirements of different marine activities, China began to introduce multibeam depth sounding systems from abroad in the early 1990's. To date, many types of such system exist, including the new generation products, which have been extensively taken into use in marine science research, marine resource and environment investigation, hydrographic surveying, marine engineering projects, port maintenance, monitoring of geologic catostrophy investigation and under water archaeology. They are playing an important role in the sustainable development of the economy and society of China. Since the middle 1980's, China has been involved in the study of multibeam echosounding systems. During that period, only a prototype was developed and some tests have been made. No practical products were developed due to technical and funding reasons. In the early 1990's, China began to invest again in research of multibeam echosounding systems. The H/HCS-017 multibeam echosounding system was developed successfully in 1997 by Haerbin Shipping Industry University and deployed in the following year. The H/HCS-017 echosounder comprises a transducer array, a transmitter subsystem, a receiver subsystem including beamformer and special digital signal processors, a bottom detector unit, and an operator unit for data transfer with external interfaces. The complete mapping system also includes the additional units: (1) vessel motion sensor; (2) positioning system; (3) sound speed sensor; (4) postprocessing system. The H/HCS-017 system operates at a frequency of 45 kHz. It has 48 beams with a beamwidth of 2° across-track and 3° along-track. The system is designed to operate in water depths from 10 to 1000 m below the transducer. It has a swath width of up to 4 times the water depth. The swath angle is 120° degrees. The H/HCS-017 system is capable of meeting the present IHO standards. The successful development of the H/HCS-017 system has shown that China had achieved a great step forward in the study of hydrographic survey equipment (Chen, 1999; Zhu, 1999).

According to the need for modern hydrographic survey development, the International Hydrographic Organization (IHO) promulgated a new version of the hydrographic standard, namely IHO S-44, at the International Hydrographic Conference in Monaco in September 1994. 100% coverage of the seafloor is required in the new edition of the IHO S-44 standard for the higher orders of hydrographic surveying. In order to meet the requirements of different users, the manufacturers of multibeam equipment are making a great effort to develop sounding technology for full ocean depth, higher resolution, higher accuracy, and modular and integrated concept design (Huang, Zhai, Ouyang, et al., 2000). It should be noted that during the last decade multibeam technology has improved technically, the price level has dropped, and the system electronics has been made much more compact. It can be said that multibeam technology has now advanced to a stage where many users will benefit from taking it into use. The main motivation for going from single beam echo sounding to multibeam echo sounding is the capability to produce maps of much higher quality and with much more details than previously, with a high productivity rate and reduced cost per area unit. Although the capital cost of multibeam echo sounders is higher than for conventional survey echo sounders, they produce maps at lower cost than before, and with better quality. The quality of the maps is higher, not because each sounding is more accurate, but because of the dense sounding pattern. The dense soundings reveal all the significant underwater features, and eliminate the large errors generated by having to guess (or interpolate) what the seafloor is like between the survey lines. It is because of these facts that more and more hydrographic institutions and other organisations are considering replacement of their existing equipment for mapping the shallow seabed by the new generation of multibeam systems. Now on the international market of multibeam echo sounder, almost every manufacturer claims that its product adheres to the most accurate IHO standards for hydrographic surveys. That is to say that the new generation of equipment is ideal for hydrographic surveying today. The trend in this field is toward making the systems of lighter weight so that they can be deployed on smaller vessels and capable of collecting accurate data at higher speed. It should be noted that, with the development of modern digital computer technology and other powerful techniques, the hardware configuration of the new generation mutibeam echo sounder has now at last advanced to a stable stage. In many countries multibeam survey equipment is now the standard tool for seabed mapping . The difference in basic mechanical design features of multibeam echo sounders from different manufacturers has become smaller and smaller. In such a case, from a hydrographer's point of view, the most important problem which remains to be resolved is: how such a high volume of data from a multibeam system, particularly in the case of very shallow water, be managed and processed effectively from raw sounding data to the final map? With modern, high-speed workstations available today, the data processing capacity has increased to such a level that it is sufficient to support the needs for cleaning and editing multibeam data, and for chart compilation. While the capability to visualise multibeam data in near real time has become standard for the 2D case, a more recent development is the capability to display the seabed terrain in 3 dimensions as the data is collected. In China, the first nationally produced multibeam system mentioned has just been deployed operationally. There still exist many problems to be studied, where improvement should be made in this new sounding system in order to increase the accuracy and reliability of sounding. The data processing is most significant to the H/HCS-017 system. As to the application and management of multibeam sounding data, we propose that the manufacturers of multibeam equipment and other organisations consider the need for uniformity of data format and post-processing software in order to get a rapid development for the multibeam technology.

Airborne Laser Sounding Technique

The application of lasers to hydrography was pioneered in Australia during the 1970's and 1980's by the Australian Defence Science and Technology Organisation. This work opened up a new field for hydrographic survey, i.e., the airborne laser sounding technology (Wehr and Lohr, 1999; Baltsavias, 1999).Airborne laser depth sounding (lidar bathymetry) is thought now to be one of the most promising techniques for rapid and high density sounding of shallow waters because of its high mobility, cost effectiveness and easy administration due to a low need of manpower (Andrew, et al., 1998). In China, work for testing the principle of operation for airborne laser depth sounding has taken place since the middle 1980's, but did not advance to a practical stage until the middle 1990's (Tang, 1998; Guan, et al., 1999). The Shanghai Institute of Precise Optical Mechanism has been involved in the development of airborne laser sounding systems since 1997. A prototype machine was produced in 1999. The system was installed in a helicopter, and some trial surveys over the sea were carried out in 2000. The Chinese airborne laser sounding system is called Airborne Laser Sounding and Mapping System (ALSMS). It is comprised of a laser depth sounder subsystem, dynamic positioning subsystem, data acquisition and control subsystem, ground analysis and processing subsystem, and flight support subsystem. The key specifications of ALSMS are designed to be:

- Laser pulse rate: 200Hz.
- Operating altitude: 500 m (variable).
- Operating speed: 60 to 100 m/s.
- Sounding density: 10-m grid (variable).
- Scan swath width: 240 m.
- Maximum depth: 50 m.
- Vertical accuracy: ±20 cm.
- Horizontal accuracy: ±5 m (DGPS).
- Survey rate in excess of 50 square kilometres per hour.

Data processing and mapping technology is an important part of ALSMS. During the development of ALSMS, many key techniques involved in data processing and mapping, such as the dynamic effect of the carrier's attitude, the corrections for tide and wave, the quality control of sounding data, the data fusion of neighboring swaths, and so on, have been studied in detail. For production of accurate bathymetric maps with full control of the map accuracy, it is necessary to post process the collected sounding data. For this purpose, a software system, which includes the necessary software modules for data post-processing, has been developed for ALSMS (Huang, et al. 2003). The system is designed to treat the high volume data sets in a block-wise manner, each block being of a size which is optimal for efficient processing by the workstation. The results of data from the software system are finally exported to terrain modelling and cartographic system.

As a new complementary technique for shallow water hydrographic surveys, ALSMS will be used in combination with the conventional acoustic or mechanical methods. The optimum and most economic way of combining these different techniques will be gradually developed from future experience. Chinese hydrographers will continue to be actively engaged in data quality assurance, system upgrades, and advanced algorithm development. Chinese scholars are making a great effort to enhance the laser pulse rate and the capability of minimum survey depth of the system. Their targets are 1,000Hz of laser pulse rate and 0.5 m of minimum survey depth. The introduction of ALSMS means that China attaches great importance to the application of aerial remote sensing technology in hydrographic surveying.

Progresses in Information Acquisition Technology

Information acquisition technology is an important step in the process of hydrographic surveying. China began to pay attention to research of automatic information acquisition systems for hydrographic surveying (AIASHS) in the early 1980's. An offshore automatic information acquisition system for hydrographic surveying was developed successfully by the Tianjin Institute of Hydrographic Surveying and Charting (TIHSC) in 1985 and put into use in the following year (Guan, et al., 1988). It marked the beginning of a new era where the conventional operating manual mode for information acquisition of hydrographic survey would be replaced by a new automatic one. Since then, Chinese researchers have been making increasing effort to improve the stability and reliability of AIASHS. With the rapid development of computer technology and the introduction of new positioning instruments, different new styles of AIASHS have been developed successively in China to meet the increasing needs of rapid and high precise sounding and charting. A multifunctional AIASHS was developed by the TIHSC in 1990, which can fulfil automatically the acquisition, recording, merging and processing of sounding and positioning information from different types of sensors (Guan, 1991). In addition, the multifunctional AIASHS has the function of assisting navigation. It has already been used widely in large scale hydrographic surveying, pipe laying on the seabed, harbour and channel dredging, profile surveying and marine resource investigation in China. After several years of applications, modular, standard and portable designs for AIASHS are desired in following years. Such an AIASHS has been developed by the TIHSC in 1995 (Zhao, 1998). It possesses the functions of planning survey lines, automatic navigating, acquiring and recording data, monitoring data quality, and processing data and compiling raw maps. Automatic acquisitions and merges of different information from a hydrographic survey can be realised in the new AIASHS. During the survey, one can use the real-time displays to verify if the whole survey area has been covered by soundings. The comparison between results from different overlapping or crossing survey lines can be used to assess the quality of collected sounding data.

The trend in this field is toward making the functions of AIASHS more integrated, and the system to be of lighter weight so that it can be deployed on smaller vessels. At present, Chinese scholars are devoting themselves to the development of measuring precise height from RTK-GPS measurements. Their purpose is to develop a new type of AIASHS using GPS height to eliminate the effects of tide, wave and dynamic draught. Such a system will be very useful for providing accurate hydrographic surveys of inshore, harbours and channels.

Progress in Data Post-processing Technology

The level of survey data processing technology directly affects the quality of survey data results. Having finished the development of an automatic information acquisition system for hydrographic surveying, the TIHSC began to pay attention to the procedure of data post-processing. A Hydrographic Survey Data Processing and Mapping System (HSDP&MS) was developed successfully in 1999. It has subsequently been improved and perfected. The HSDP&MS consists of a sounding data post-processing subsystem and data visualisation subsystem. The sounding data post-processing subsystem has the following functions:

- Input of collected data.
- Automatic deletion of different types of blunder.
- Automatic detection of abnormal data using robust method.
- Position processing (including instrument offset correction).
- Sounding data editing and cleaning.
- Depth correction (including corrections for draught, sound speed, tide level, and datum of soundings).
- Compensation and test of systematic error.
- Evaluation on the quality of sounding data.

The function of the sounding data visualisation subsystem primarily includes , terrain modelling, 3D and contouring. It can provide a variety of final products (contour charts, hydrographic symbols, fair sheets, 3-D presentations, etc.) in the form of maps and charts. Detailed functions are as follows:

- Construction of sounding map border.
- Input of sounding data acquired from survey field, and coastline data.
- Transformation of coordinates.
- Redisplay of sounding data.
- Editing of surveying track chart, sounding data chart, nature of the bottom information chart.
- Generation of 3-D map for quality control of sounding data.
- Generation and editing of contour map.
- Editing and modifying of other factors.
- Acquisition of sounding from digital instrument.
- Output of final hydrographic products.

In the HSDP&MS, some of the new theories and methods for data processing have been applied successfully. For the sound velocity correction, many sets of oceanic water temperature and salinity over many years were collected. The corrections of sound velocity in the Chinese sea area were then computed by using hydro statistics, which can be used in hydrographic survey for both shallow and deep water (Shen, et al., 1995). With respect to the correction for tide level, a so-called phase angle difference method, based on the theory of signal processing, has been suggested, with which the correction of the tide level for multi gauge stations can be carried out successfully (Xie, et al., 1988). For the reduction of sounding data to the sounding datum, the tidal range ratio method and the least-square fitting method are proposed to transfer depth datum (Liu, 2000). In the study of quality control and reliability of sounding data, Chinese scholars have introduced the theory of robust estimation to the data processing of hydrography for the first time. A robust method for the detection of abnormal data (including blunders) in hydrography has been suggested in this field, which is called the robust interpolation comparison test based on robust M-estimation by an iterative calculation procedure (Huang, Zhai, Guan, et al., 1999a; 1999b). In order to compensate for the systematic errors in hydrography, Chinese scholars began with a valid significance test of systematic error based on variance analysis. Formulas of compensating systematic errors located in the survey area and survey lines were first derived (Huang, 1990; 1985). In the second stage of the study, filtering position data, as viewed from geometrical field, was suggested to provide an optimal estimation of position data. A new model of compensating systematic errors was then developed, which took into account both direct and indirect influence of ship navigation as well as sounding noise (Huang, 1992; 1993; 1995). In the third stage of the study, a self-calibrating adjustment model of compensating systematic errors in a more extensive sense, as viewed from the physical field, was presented through the construction of an error model (Huang, Guan, Zhai, et al., 1999a; 1999b). Finally, for practical applications, the rigorous methods mentioned above have been simplified in a procedure of two steps processing (Huang, Zhai, Ouyang, et al., 2001a; 2001b; 2002a; 2002b). Some successful experience in applying computer technology to charting, such as the preparation of a digital mosaic of cartographic sources and the automatic drawing of very complicated irregular symbols, have been also obtained in practical applications.

Many corrections in data processing are required for environment effects owing to the characteristic of real-time dynamic observation in hydrographic surveying. It is believed that the frequency and inconsistency of different corrections are the main reason of introducing systematic errors. The accurate calculation of corrections for environment effects remains to be studied in data processing of hydrographic surveying. These corrections include beam-width effect in single-beam sounding, additional sound speed errors in multibeam sounding, wave effect in airborne laser sounding, magnetic effect of vessel in marine magnetism, and so on. During hydrographic surveying, the three types of error, i.e., blunder, systematic error and noise, are present at the same time. Although considerable effort has been made in the study of errors in sounding data, it is important that one has some knowledge about distinguishing the different error models and adjustment systems. It is useful to find a valid method in which it is expected to compensate systematic errors and delete blunder simultaneously (Li, 1988). Many problems of theory remain to be resolved in this field.

Progress in Data Management Technology

Constituting a valid management system for hydrographic survey information is the basis of giving full play to the use of sounding data. As early as the late 1980's, Chinese scholars began developments of hydrographic survey data management technology and its applications. As to the constitution of a standardisation system, many technical specifications for hydrographic surveying data management and its applications have been presented and published during the past few decades. Uniform demand on the classification, encoding and formatting of hydrographic survey information has been included in the standardisation system (Zhai, et al., 2001). As to the establishment of entity, a few data base systems with single factor of hydrographic survey have been built independently in succession. Such a data base system, in general, is comprised of three subsystems, i.e., information management, information applications, and information products. These systems have played an important role in the insurance of navigation safety and the exploration of marine resources (Zhai and Gao, 1996). However, with an increase in the amount and type of marine development activities, the data base systems of a single factor of hydrographic survey cannot meet the requirements from different users. For the consideration of that case, a hydrographic survey data base system in an integrated sense has been recently developed successfully in China. Many modern technologies, such as computer technology, network technology, communication technology, data base management technology, graph and image processing technology, and so on, have been applied in the development of the system. It integrates the functions of acquiring, managing, processing, analysing, improving and producing the hydrographic information (data). The detailed development targets are summarised as follows:

(1) Establishment of data base systems with multi-factors of hydrographic survey.
(2) Development of specialised software interface for digitising the paper graphical products and realising the digitisation management application of history survey data.
(3) Opening of network transmission way of information in hydrography.
(4) Development of statistical analysis software.
(5) Establishment of network distribution system of information and its products in hydrography.

The data base system mentioned above consists of four parts, i.e., hardware component, commercial data base system, specialised data base management software, and specialised application software. The hardware platform and its options include: net-server, high performance workstations, net-exchanger, scan jet, digitiser, plotter, and printer. Oracle9.0 is used as the commercial data base system. The specialised data base management software covers almost all the sub-branches of marine survey, such as coastal topography, single beam sounding, multibeam echosounding, ocean tide, marine gravity, marine magnetism, side scan imagery, and stereophotogrammetry. The specialised application software is comprised of data processing modules corresponding to the sub-branches of marine survey mentioned above. The system is the first set of management entity of hydrographic survey information in China. Preliminary applications have shown that the system is practical and reliable. It opens up a vast range of application prospects for marine resource investigation in China. In the next stage, Chinese scholars will continue devoting themselves to the improvement of this system in order to raise its stability and reliability further.

Suggestions

Mankind has entered the information age. One pays increasing attention to the applications of geomatics and information, which are considered as a part of the national information network. Many governments across the world are making a huge investment in building their national spatial data infrastructure (NSDI) so that every department of government may share its benefit. Digital earth is a natural prolongation of the information expressway and NSDI plans. Its substance is to express the Earth in terms of a digital, network of intelligent information, and visualisation, using high volume spatial data of the Earth. Three major tasks are essential to the construction of the digital earth, i.e., data acquisition, data processing, and data application. 70% of the Earth surface is covered by ocean water, which is an important component of terrestrial space. Therefore, the construction of the digital ocean must be carried out before finishing the construction of the digital earth. In such a case, a major question that needs to be faced by every government in the near future is to acquire, process and apply the ocean spatial data. China is a developing country. Although, as a result of the effort of many years, great progress has be made in hydrographic surveying technology, it must be admitted that the overall level of Chinese hydrographic surveying is far away from that of developed countries. China should pay more attention to the following problems in the near future:

(1) Survey equipment: the potential applied capacity of high and new technology should be considered to improve the accuracy and reliability of sounding system.
(2) For data analysis and processing, consideration of the high volume data obtained from new technology means, some key problems, such as the separation of errors from multi-resources, the fusion of data from multi-resources, the visualisations of graph and image, and the high efficiency transmission of data, must be resolved in advance using modern data processing method and computer technology.
(3) For the basic infrastructure construction, one should attach importance to the match of spatial data from ocean and land. A uniform 3D datum of ocean and land should be built as soon as possible. The management of hydrographic survey data should be considered seriously.
Some work, such as the coordination and distribution system of marine spatial data, the web site of data interchange, and the standard of data exchange, etc., should be accomplished as soon as possible.
(4) For applications and development of information products, the importance of maritime GIS system should be considered. It should be encouraged to develop modern marine geomatics and information industry, which is characterised by digital products, and supported by 3S technology.

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Biographies

Huang Motao is Professor of hydrographic surveying, and Director of the Hydrographic Branch at Tianjin Institute of Hydrographic surveying and Charting, China. He holds a BSc degree and master degree in Geodesy, both from Wuhan Technical University of surveying and mapping. He devotes himself in the research on marine gravity surveying, multibeam echosounding and airborne laser bathymetry. He has presented numerous technical papers covering these fields.

Zhai Guojun is Professor of hydrographic surveying. He works in Tianjin Institute of Hydrographic surveying and Charting, China. He holds a Ph.D in marine geodesy. Recently, he makes research on airborne laser bathymetry.

Ouyang Yongzhong is Research assistant of marine geodesy. He holds a BSc degree in geodesy and now is making research on marine gravity surveying.

Liu Yanchun is Professor of hydrographic surveying. He holds a Ph.D in marine geodesy. He makes research on ocean tide analysis.

Lu Xiuping is Research assistant of hydrographic surveying. He holds a BSc degree in hydrography and is now making research on data processing of hydrographic surveying.

E-mail: zhaigj@163.com