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A CRITICAL REVIEW OF AUTOMATED HYDROGRAPHY WITHIN THE CANADIAN HYDROGRAPHIC SERVICE

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INTRODUCTION

Since the late nineteen sixties, the Canadian Hydrographic Service (CHS) has been actively pursuing the goal of acquiring and processing bathymetric data in digital form. During this period there have been major advances in digital technology and to a large extent the CHS has been able to take advantage of this evolving technology. Over the years a core of computer-oriented hydrographers and hydrography-oriented technical personnel has been developed and we have enjoyed patient and supportive managers with whom new ideas and techniques could be openly and critically discussed. Numerous problems have been encountered – some have been overcome while others remain to be solved. In the main, however, reliable digital data acquisition and processing in the field at a reasonable cost is feasible. The means to convert graphical data such as shoreline and foreshore features into digital form is also in place so that we are finally in a position to start building a digital data base from which nautical charts may be produced.

DATA ACQUISITION

The development of digital bathymetric data acquisition in Canada began in 1966 with a system called HYPOS (Hydrographic Position : 1966-1972)[1] which drew heavily on work done in Sweden. Data were collected in the field using

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conventional manual methods and then transmitted to a central facility for computer-assisted conversion to digital form. Radio position data from the launches were prepared daily and transmitted via phone lines, while annotated sounding rolls were mailed to the central facility.

At the central facility, the sounding rolls were digitized onto magnetic tape using a pencil follower digitizer, and positional data was also copied onto magnetic tape. The two tapes were then merged to a single tape.

The data acquisition techniques of HYPOS were unsatisfactory for several reasons. Coding and punching positional data on paper tape for transmission was time consuming and error prone, as was digitization of the sounding rolls. Frequent telephone conversations between personnel at the central facility and the field party were required to clarify errors and interpret annotations on the sounding rolls. In addition, sending sounding rolls by mail proved to be slow and unreliable.

Development of a second system called HAAPS (Hydrographic Acquisition and Processing System : 1968-1977)[2] was begun in 1968. The design objective of HAAPS was to record bathymetric data in digital form on the launch directly and in real time. Suitable depth digitizers were purchased in 1969 and a data coupler was used to digitize Hi-Fix lane counts, acquire time and depth data, and drive the recording device, originally a paper tape punch. In 1970, the paper tape punch was replaced by a magnetic tape drive because of its many advantages in terms of data storage and reliability.

The data acquisition portion of HAAPS suffered from a few major shortcomings. To begin with, the data coupler sampled at a fixed time interval and if a particular sensor was in the middle of acquiring a new reading, data would either be punched incorrectly or truncated. In addition, no validity checks were performed on the data. Secondly, no check was made on the magnetic tape to see if data were correctly recorded.

In 1973, work was begun on INDAPS (Integrated Navigation, Data Acquisition and Processing System : 1974-Present)[3], a HAAPS replacement. The design philosophy called for a mini-computer to control data acquisition and filtering, data recording and provide navigation information for the helmsman. Three data acquisition systems were acquired for field deployment in 1974. Initial teething problems with the systems were in large part corrected by hardware re-packaging, prior to the 1975 survey season, and subsequently a number of fairly successful surveys were completed using the systems.

The major shortcomings of INDAPS are due to its large size, high power consumption, complexity and unreliability of the data recorders that formed part of the system. The system occupies a standard 48 cm rack, stands about 1 metre high, weighs about 100 kilograms and consumes 300 watts of power at 115 volts A.C. These physical characteristics presented a substantial installation problem on 7-metre launches. The high vibration, and temperatures of the launch environment also proved to be troublesome. Hardware complexity mitigated against the systems in the launches and necessitated frequent maintenance by technical personnel. The cartridge tape recorders also suffered problems on the launches. It is noteworthy that the incidence of erroneous or incorrectly recorded data was drastically reduced in comparison with HAAPS and from this standpoint, the systems were successful. It should also be pointed out that on larger vessels where the environment is more benevolent, the systems continue to perform satisfactorily.

In 1975, specifications for PHAS (Portable, Hydrographic Acquisition System : 1976-Present)[4] were prepared, drawing on the experience gained with INDAPS. PHAS is packaged in a single, rack-mountable splash-proof metal case, 30 centimetres high, 46 centimetres deep, weighs 22 kilograms and consumes 100 watts of power at 24 volts D.C. The system makes use of microprocessor technology throughout and is functionally equivalent to INDAPS with the exception of the navigation function. Four units were manufactured in 1976 and an additional three units in 1977.

Although PHAS has not seen extensive deployment, it has proven to be very reliable, easy to install and maintain. There is every indication that PHAS will see successful use for some years to come.

To overcome the lack of a navigation function in PHAS, a navigation module, INDAS (Integrated Navigation and Data Acquisition System : 1977-Present)[5] was developed in-house in late 1976 using standard, off-the-shelf components wherever possible. INDAS is similar in size to PHAS but weighs 15 kg and consumes less power. Four units were constructed and have been deployed for three field seasons in the Arctic in tracked vehicles and two seasons in launches. Depth acquisition was incorporated in 1977 so that with the addition of an external recorder, INDAS can log data as well. A total of 18 units are being manufactured commercially for deployment in 1979 either as stand-alone units or in conjunction with PHAS.

Summary – Data Acquisition Problems

Experience gained with the above systems permits the examination of several factors which must be considered when either designing or purchasing a data acquisition system for hydrographic use. These include ease of installation, reliability, operational simplicity and cost.

Probably the most important feature of any system in terms of user acceptance is operational simplicity. A system such as HYPOS which requires the transcription of data semi-manually and involves several steps in the process, all of which are error-prone, illustrates the problem. The procedures involved complex instructions and sequences which were time-consuming. In addition, when errors did occur, they were difficult to correct. HAAPS, while simple to operate, provided little or no feed-back to the user on such matters as data reliability and recording integrity. Thus, when poor quality data was recorded and sounding lines had to be re-done, user frustation was high and confidence was low. This created a tendency for users to shut the system down in favour of purely manual methods whenever possible. In addition, morale of personnel performing the data processing function was affected because relatively small amounts of poor data cast all of the data in a bad light. This in turn led to an inordinate amount of time being spent on computer programming to detect and correct the data.

INDAPS went a long way towards solving operational problems because it involves a high degree of user interaction via command push-buttons, a television (CRT) type of real-time data display – and an audible alarm. Whenever data quality becomes marginal, as detected by the filtering algorithms in the software, error messages are displayed on the CRT and logged on a printer. If data quality continues to drop, an audible alarm is sounded, a message displayed on the CRT and printer and the system ceases data acquisition to prevent the recording of bad data. The operator can then assess the problem and take whatever action is necessary. In addition, the system provides a read-after-write capability on the tape recorder and will re-write the data when errors occur. Thus, the operator has a high degree of assurance that only good data are being recorded and that they are being recorded correctly. Both PHAS and INDAS employ this philosophy, both enjoy high user acceptance.

The second important factor which must be considered is system reliability. Data acquisition systems have a very high profile because their failure is so frustrating to the operator and devastating to production – the reason for the failure is seldom obvious and technical personnel must be called in to find and repair the fault. In addition, survey operations are halted, which further compounds the aggravation. This is not the case with other equipment such as the echo sounders which may break down but usually for obvious reasons such as a broken stylus, or jamming of the chart paper – both are faults which the operator can correct or at least understand. Thus, data acquisition system failures tend to be remembered by the users out of proportion to their frequency of occurrence.

In terms of reliability, experience has shown that the data recorder itself is the most vulnerable. We have tried reel-to-reel and DC 300A cartridge tape recorders and have found both systems to be less than satisfactory in a small (under 12 m) launch environment although they are suitable for larger vessels. The search is still on for a good, reliable recording medium.

Hardware complexity plays a major role in reliability both from a maintenance standpoint as well as the probability of breakdown. A system such as INDAPS, which contains a large number of printed circuit boards and consequent inter-wiring, is much less reliable than either PHAS or INDAS which contain very few boards. Hardware trouble-shooting is difficult and time-consuming on complex systems so that mean time to repair can be of the order of a day instead of the half hour which it normally takes to repair higher technology systems. PHAS and INDAS have benefitted from the latest microprocessor technology utilizing large scale integration (LSI) which in addition to being inherently more reliable, minimizes the number of components. Therefore, with PHAS and INDAS, repairs for the most part consist of printed circuit board replacement and lower system down time. On a practical note, we have found that routine inspection and cleaning of printed circuit board edge connectors pays dividends.

System installation is another area in which problems have arisen. Basically, a small, rack-mountable, lightweight system which will operate on 24 V D.C. is ideal, since space and power are at premium on small vessels. Both PHAS and INDAS fall into this category and can be installed by one person and be operational within a half hour. INDAPS, on the other hand, requires at least two people for the better part of a morning. In addition, a special stand-alone 3 kilowatt generator for 110 volts, 60 hertz must be installed in the launch. INDAPS is also quite sensitive to heat build-up so that arrangements have to be made to ensure adequate ventilation.

The last factor to be considered is cost, although it may be argued that this should be the primary consideration. In the early 1970's, a HAAPS data acquisition system cost about $22 000 (Can.) and in 1974, an INDAPS system with vastly improved capabilities cost about the same amount. PHAS, which in all respects except navigation is superior to INDAPS, costs about $ 12 000 (Can.). INDAS is functionally equivalent to INDAPS with the exception of a data recorder and was commercially available in 1979 for about $ 12 000 (Can.). Thus we have seen, over a ten-year span, a tremendous increase in reliability and capability, along with a sharp decrease in size and power requirements; all this and a 50 percent drop in price as well!

FIELD DATA PROCESSING

The second aspect of computer-assisted hydrography concerns the processing of digital bathymetric data. This phase breaks down into two functional areas: field data processing and central facility data processing. Field data processing takes place while the party is in the survey area and as soon as possible after data acquisition, while central facility data processing occurs after the survey party returns from the field.

Our experiences with HYPOS, where data, basically in analogue form, were sent by the field party to the headquarters area for processing, pointed out the *necessity of locating the data processing function with the field party.* With HYPOS, the field hydrographer to a large extent lost control of his data processing. Because central facility staff were not familiar with the area being surveyed or the circumstances under which the data was collected, problems often went undetected until the processed data arrived back to the field party for checking. Since the turn-around time was up to three weeks, this caused a number of problems. The long time delay between data collection and data reduction also caused difficulties for the field hydrographer in maintaining a sense of continuity. It is difficult to quantify these factors; however, they play a very important role in user acceptance of any system.

Despite the shortcomings of HYPOS, it was an extremely valuable learning experience. A fairly extensive suite of computer programs were developed which performed positional data co-ordinate conversions, plotted circular and hyperbolic lattices, plotted soundings at the proper scale and projection, removed sounding 'clutter', performed error correction and maintained master data files on magnetic tape to name a few. The work put into sounding selection algorithms provided the necessary background for the development which was to follow with HAAPS. Indeed, a substantial number of the programs developed during the latter years of HYPOS are still in use.

The experience of HYPOS also helped to bring the total problem into focus, in particular, the absolute necessity of putting field data processing back into the hands of the hydrographer. The only way to accomplish this is to place the data processing computer in the field with the survey, either aboard a mother ship or at the base camp of a shore party. Since the system is liable to be located in what is referred to as a 'degraded environment', care must be taken in the selection of a computer. Unless the time and expense for a properly air-conditioned, powered and clean room is to be allocated, large systems should be avoided. This leaves a class of systems commonly known as 'mini-computers'.

In the late 1960's, as part of the HAAPS system, a decision was therefore taken to acquire a modestly sized mini-computer configured as follows : a magnetic tape drive, high speed paper tape reader/punch, 10 character/second terminal and a low resolution (0.1 mm) drum plotter. The system was housed in two standard width racks, which were about 2 metres high. The programming language chosen was FOCAL, a high level interpretive language which, although slow in execution speed, is highly interactive. At the time of purchase, a system such as this cost about $ 45 000 (Can.).

The scheme devised for the processing of HAAPS data tapes on the mini-computer was generally as follows :

1. Scan through the tape and locate erroneous radio position data (Hi-Fix lane jumps, data drop-outs and so forth) and print the results on the terminal.
2. Prepare a list of water level reductions.
3. Scan through the tape, skipping over problem areas from step 1, select hydrographically significant depths, convert the radio position to U.T.M. co-ordinates, apply water level reductions, plot the sounding, punch the results on paper tape and print them on the terminal.
4. Collect all the paper tapes and copy them onto a magnetic tape master file for further processing back at headquarters.

This scheme worked fairly well as long as the data collected on the launch was relatively error free. Plotted sounding data was collected onto a single sheet so that the progress of the survey could be monitored and contours developed. A single operator could process about two launch-days of data per day so that the turn-around from data acquisition to plotted soundings was often within a day.

However, as was mentioned previously under *Data Acquisition*, the HAAPS data loggers were prone to recording bad data. Computer programs were therefore in a constant state of flux in an attempt to detect and reject erroneous data during step 3, above. To compound the problem, correction of errors on paper tape necessitated punching a new tape, which was slow and tedious. Also, in the generally high humidity environment of a ship or shore camp, the paper tape reader/punch would frequently jam, which meant that the copy operation had to be started over again. Finally, since FOCAL programs execute relatively slowly, in computer terms, under optimum conditions one launch day's data would take about an hour to process – typically closer to two hours due to error correction.

The design philosophy of INDAPS called for reliable data acquisition and recording along with a more powerful data processing computer. The mini-computer used for data processing is configured as follows: dual cartridge tape drive, CRT terminal, 100 character/second printer and a low resolution (0.1 mm) plotter. The computer is housed in a single, standard width rack about 1 metre high and includes all of the necessary hardware to function as a data acquisition system. The processing scheme used is functionally the same as for HAAPS with two exceptions: programs are written in FORTRAN IV and stored on cartridge tape and all data processing is from cartridge tape to cartridge tape. With this system the typical processing time for one launch day's data is about 45 minutes, not significantly faster than the HAAPS processor. However, since data quality is much higher, time spent correcting errors is significantly less. This is also the case with data recorded by PHAS; data is processed on a HAAPS computer system which was upgraded to include a dual cartridge drive. The processing time required is similar to INDAPS, thus, the computing power of the system used to process the data is not as significant a factor as we once thought it was.

Regardless of which processing system is used, the most important factor which has emerged in terms of processing time is data quality. If the data which is recorded by an acquisition system is 'clean', then any processing scheme desired has a strong likelihood of success. It is axiomatic, on the other hand, that of the order of 80 % of the time taken in performing data processing may be spent on detecting and correcting erroneous data which may be of the order of only 2 % of the total! Thus, when designing processing software, extreme care should be taken to ensure the error detection and correction programs are efficient and easy to use. Our own processing schemes are currently being revised in these critical areas due to mounting user dissatisfaction.

Another factor in relation to data processing is the question of who designs and writes the computer programs. In the early 1970's a policy of training all hydrographers in computer programming was adopted. There were two reasons for this policy: necessity and practicality. Field hydrographers have always processed their own data manually and are therefore the logical candidates to process their data using the computer systems. Thus, training in computer operations was an absolute necessity. The field hydrographer is also the person who knows best how the data should be processed and is the one who has to live with the system on a daily basis. Therefore, it is much more practical to teach hydrographers how to write computer programs than it is to teach hydrography to computer programmers.

Computer programmers must be available to write specialized software, maintain operating system software and for consultation. Hydrographers should not be expected to be programming or computer experts but should be sufficiently proficient to handle the small problems which arise daily. System design and implementation must be undertaken by hydrographic, engineering and computer programming personnel working closely together to achieve a solution which is optimized for all concerned.

OFFICE PROCESSING

The acquisition and processing of digital bathymetric data in the field constitutes only a portion of the total process. However, it is important to point out that all data processing and editing should be completed in the field. When the field parties return to the office, further data processing must take place to produce final field sheets which contain titles, shoreline, foreshore details, aids to navigation, and so forth, in addition to bathymetry. Data must also be archived for future reference purposes.

The current status of this process, which utilizes a large computer system, is as follows :

- all soundings for a particular field sheet are collected onto a single magnetic tape file and all overprinting soundings removed;
- a large flat-bed plotter is used to prepare a field sheet base projection plot on plastic which contains the title, bar scales and survey control;
- lastly, the soundings are plotted using this same plotter.

From this point onwards, all remaining information is hand-plotted and all digital information contained on the sheet is stored on magnetic tape. All of the hardware is presently in place to permit the digitization of the hand-plotted data, so that, hopefully within a year, we will have the capability to produce a completely digital field sheet. The system called GOMADS (Graphical, On-Line, Manipulation and Display System) was developed within the CHS over a period of years starting in the mid-1970's. This mini-computer based system was primarily designed for computer-assisted cartography but should prove to be most useful for field sheet applications.

A major area of concern rests with the 'raw' data which is collected on the launch, frequently at one second intervals (time, radio position and depth). To appreciate the problem, consider a typical survey launch running for 8 hours at an average speed of 7 m/sec and recording position and depth once per second. The launch will steam about 200 km and collect some 28 800 data points. Of this total, on average at a scale of 1:50 000 we would select 1 sounding out of 30 or 960 out of 28 800 for plotting. At present, only the selected soundings receive close scrutiny and thus about 96 % of the collected data is unverified. As an example of the data volume problem, on one survey sheet containing 20 000 soundings 1 200 000 data points were collected.

Obviously, we cannot continue to archive this 'raw' data without first devising a technique to reduce the volume of data and still keep a representation of the bottom topography. Some work has been done on this problem; however, it cannot progress further until an adequate technique has been perfected for automatically detecting and rejecting erroneous data. Poor positional data can be filtered out with relative ease since the vessel motion is well-defined. Unfortunately this is not the case with depth data and until depth digitizers become more reliable, only semi-automated filtering schemes will work. These schemes involve the detection of 'anomalous' values using a computer and then displaying the data in some fashion so that an operator can compare it with the analogue chart.

Another area which has generated considerable discussion is computer derived contours. We have felt for some time that hand contouring constitutes an extremely valuable quality control technique for the field hydrographer. It is a method for checking data which is fast and invaluable in assessing bottom topography. The investment in time, effort and computing power which would be required to automate contouring in the field would gain little and potentially introduce poor quality control. Manual contouring provides the hydrographer with an excellent opportunity to evaluate his data in the best way possible.

In summary

From the foregoing it should be obvious that the decision to implement computer-assisted techniques in hydrography must be carefully considered. Planning for such systems must take into account user satisfaction, acceptance and involvement from the beginning – users must understand the system and have a hand in the design. Above all else, the system must be reliable and in fact probably more reliable than any electronic equipment which is used. Given today's microprocessor technology, exceptional reliability can be realized; however, the data recorder is still the weak link and should be selected with great care.

All phases of the system from data acquisition through to final field sheet preparation must have a reasonably fast turn-around time, comparable to manual techniques. If this is not the case, then users are likely to be dissatisfied and critical. The system should be fairly simple to use, particularly the data processing programs which should be written to include as much operator 'prompting' as possible.

Users should be encouraged to criticize the system. Quite often, the criticisms centre on relatively minor system 'quirks' which are easily corrected; alternatively, the problem may be a misunderstanding relating to system operation. Regardless of what the problems are, the point to be remembered is that the system is for hydrographers : they must live with the system on a daily basis and it must be tailored to their requirements.

A final note concerns training. All of the hydrographers cannot be involved in the system design and implementation. Therefore, comprehensive training which includes as much 'hands-on' experience as possible should be given as close to the start of the survey as possible. Time and effort spent on training will pay dividends in terms of understanding and avoidance of 'panic' trips by technical personnel to the field party.

THE FUTURE

Computer-assisted cartography will become more and more evident as time goes on. The greatest deterrent in this phase is due to the lack of digital data base from which to work.

The ultimate goal of all these automated techniques and systems is the creation of a digital bathymetric data base from which charts and documents of various types may be compiled. To reach this goal there are three major milestones. The first is reliable, relatively low cost digital data acquisition and processing in the field – it has taken 13 years, but I think we're finally there. Secondly, a system is required which permits the conversion of graphical data into digital form and its subsequent manipulation and merging with the digital bathymetry; such a system must also produce high quality plots. Again, this system is available and in use – over the next few years, its use should increase dramatically; this is likely to create a whole new set of problems, particularly in data management and quality control.

The final milestone concerns the digital data base. Some of the questions which need to be answered here are the following. Which data are to be stored and in what format? How will quality control be maintained? How are the data to be accessed and by whom? What kinds of inquiries are to be handled by the system? What form will output take – digital, graphical or both? What organization and staffing will be required to manage the data base? How large is the data base likely to be? All of these questions are interrelated, complex and will require very careful study and planning over the next few years if a successful system is to be implemented. It is a challenge which can be met only by close co-operation and consultation among all the principals involved including hydrographers, cartographers, computer programmers, equipment specialists and managers. With close co-operation I am confident that computer-assisted hydrography will pay dividends in terms of cost reductions and data flexibility within the next five years.

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