Development of a Software Package for the Automation of Measurements in Bathymetric Mapping

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Key words: Hydrographic software, bathymetry, GPS, echo-sounder, mapping.

SUMMARY

The development of a software package for the automation of measurements in a hydrographic survey mainly oriented to the bathymetric mapping in inshore and coastal areas is discussed. A data collection system composed by a portable echo-sounder and a dual-frequency GPS receiver is used for the determination and simultaneous registration of horizontal coordinates and depths. The functionality and applicability of this system is validated through the aforementioned software in a small-scale hydrographic project in the Thermaikos Gulf. In the frame of this project RTK and DGPS tests were carried out at the same time with the depth measurements in order to investigate both the accuracy and the reliability of the entire process. Finally, some conclusions on the automation of bathymetric mapping are drawn, while the problems and possible future improvements related to the system function and the software performance are addressed.

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1. INTRODUCTION

Over the past several years, coastal and inshore hydrographic surveys oriented to bathymetric mapping have been fully automated and their centimetre accuracy may be considered adequate. The use of a GPS receiver along with a single beam echo-sounding device, which is the case studied in this paper, provides a simple and low-cost solution for producing bathymetric maps. The automation of the surveys is based on the measurement equipments' ability to provide digital output of the measurements and on the implementation of specifically designed software.

Existing hydrographic surveying software available on the market or the Internet provide different features according to the surveying needs and the available budget. Some software combine the output of the measuring equipment and are primarily used for data collection purposes as a data-logger (Windmill Software, 2004; Maritek, 2004). Other software, apart from the data collection functionality, provide real-time navigation tools which aid the survey crew, while at sea, to better organize and determine the progress and deal with possible problems of the survey (Bruttour, 2004; Trimble Navigation, 2004; Innerspace Technology, 2004). On the other hand, more sophisticated software (Reson, 2004; Coastal Oceanographics, 2004; Quality Positioning Services, 2004; HydroSupport, 2004) deal with the whole hydrographic campaign by providing to the user tools for organizing a campaign, visualizing the measurement data and creating maps (2D, 2.5D, 3D) in real-time, error-detection, archiving data in databases and exporting the data in various formats for use in Computer Aided Design (CAD), Geographical Information Systems (GIS) or other hydrographic software packages. Another characteristic of the software is their complexity and the algorithms they use where no modifications or additions by the user are allowed.

The developed software package described herein, entitled SeaSurvey, has been specifically designed for research purposes. This object oriented software is open to changes and additions, low-cost and can easily be used for testing new algorithms and functionality regarding bathymetric mapping. The SeaSurvey software incorporates features for data collection and navigation tools emphasizing certain surveying techniques. It uses as input the digital output of an echo-sounding device combined with the one of a Global Positioning System (GPS) receiver. Hence the SeaSurvey software was not made to compete with other existing commercial software, where most of them have much more functionality and are compatible with a variety of equipment, but to become a research tool for testing and implementing new measuring techniques and algorithms correspondingly. It is primarily oriented towards hydrographic surveying in closed sea areas and in shallow waters (depths less than 100m).

The functionality, performance, usefulness and reliability of the SeaSurvey software were validated in a small-scale hydrographic surveying project in the Thermaikos Gulf, in Northern Greece. Different measuring methods were used for navigating the survey vessel, including Real Time Kinematic (RTK) and Differential GPS (DGPS) which were also compared to the simple navigation solution.

Finally, based on the field campaign and previous experience, the abilities of the software as well as problems and improvements needed were assessed and conclusions were drawn with respect to bathymetric mapping.

2. BATHYMETRIC MAPPING

2.1 Data Collection Measuring System

The most common practice in hydrographic surveying is the combined use of a GPS receiver with a portable echo-sounding device. The GPS provides the position while the echo-sounding device is used for depth determination. Usually the GPS connects, along with other instruments if used, to the echo-sounding device, which in turn connects to either a notebook computer or Personal Digital Assistant (PDA) running appropriate software for logging the output. In other cases the GPS, the echo-sounding device and other instruments connect directly to the data logging system.

The synchronization and matching of the measured depth to the measured location based on time is also a critical task. Both must refer to the same point and possible delays may lead to errors which cannot be corrected afterwards. This matching task can be performed either by a software or hardware. Manufacturers advise users to implement the hardware approach (Bruttour, 2001), since it minimizes any additional delays referring to transmitting the measurement data to the software, as well as to the computer system's processing capacity (CPU usage, free memory). In cases where there is a need to use concurrently more than one instrument (e.g. heave compensator, tide gauge) for improving the accuracy of the measurements, the hardware approach should definitely be used.

The GPS output format usually used is the National Marine Electronics Association (NMEA) format (see, e.g., Leica, 2002;Hoffman-Wellenhof et al., 1997), while the echo-sounding devices use either standard (for e.g. ODOM, ODEC, ATLAS, and NMEA) or custom-defined formats. In the last case, the software must support these formats or have the option for defining the format of the data. After examining the input for possible errors, the data logging system outputs the data to files or databases, either by using the raw data format or a software-specific format.

Depending on the desired accuracy for horizontal positioning and the available equipment and software, different measuring methods may be used. Excluding the navigation solution which is inaccurate for developing bathymetric maps, relative positioning including the post-processing and the real-time measuring methods, DGPS and RTK, provide adequate results. The first of the methods mentioned leads to the use of the navigation solution for the navigation of the survey vessel and post-processing of the data for retrieving results, while the two other methods provide the position in real-time which can be used for navigation and can be recorded together with the measured depth.

Most of the available sounding devices provide the option for acquiring more than one sounding per second that is measuring more than one depth per second. Some of the latest models of GPS receivers also provide positioning data at these rates, but the matching of both depth and position should be considered. In cases where the observation rate of the GPS is no more than one observation per second, acquiring depth data at higher rates while the survey vessel is moving requires the use of interpolation for calculating the coordinates matching the additional depth values in between two GPS observations. Hence, the velocity of the survey vessel and preferred density of the measurement determines the usefulness of retrieving depth values at higher rates.

2.2 Echo-sounding Lines

A hydrographic survey oriented to bathymetric mapping apart from choosing the right measuring methods, equipment and software needs also to be well organized regarding the courses followed by the survey vessel. This is achieved by using echo-sounding lines for guidance, minimizing by this way the cost and time for surveying a predefined area (see, e.g., Lurton, 2002; MacLennan and Simmonds, 1995). If there are existing maps of the survey area the echo-sounding lines are defined at the office, otherwise, if supported by the software used, they can be defined/calculated on-board the vessel.

During the survey, the chosen hydrographic software plays a significant role for the reliability of the measurements. If the software is used only as a data logger, then it is necessary to watch the displays of the measuring instruments for ensuring their valid operation, unless the software displays on screen information or even the results of the measurements in real-time. Additionally, by displaying the results, the surveyor can better monitor the progress of the measurements, ensuring the full coverage of the area in addition to navigating the vessel.

Using the calculated azimuth of the moving vessel and echo-sounding lines and viewing at the same time on the computer's screen a map basis, where available, and the location of the vessel the navigation of the survey vessel becomes much easier. There are though two issues, which need to be addressed, in order to definitely assure that the displayed information aids truly in navigating the vessel. These are the measurement observation rate of the GPS and the refresh and update rate of the on-screen displayed data, whose importance is also related to the vessel’s size and the survey area. It is essential, especially for navigating the vessel when it needs to change course or stay close and follow the echo-sounding lines, to acquire GPS data at a high rate as well as display them in real-time to the user. Smaller vessels are easier to navigate and hence the observation and display rate may be lower but for larger ones there is a greater need for accurate real-time results.

3. SEASURVEY SOFTWARE

3.1 Overall Description

The SeaSurvey software was developed using Microsoft Visual C++. The core of the software, which includes all the calculation and processing tasks, was written in pure

ANSI/ISO C++, while the graphical environment along with the graphics representation of the measurements was implemented using the Microsoft Foundation Class (MFC). The structure of the program may be analysed in three segments. The first segment is the collection of the data, the second segment is their analysis and the third segment is all about displaying them on the screen. In figure 1, a flowchart of the software is presented.

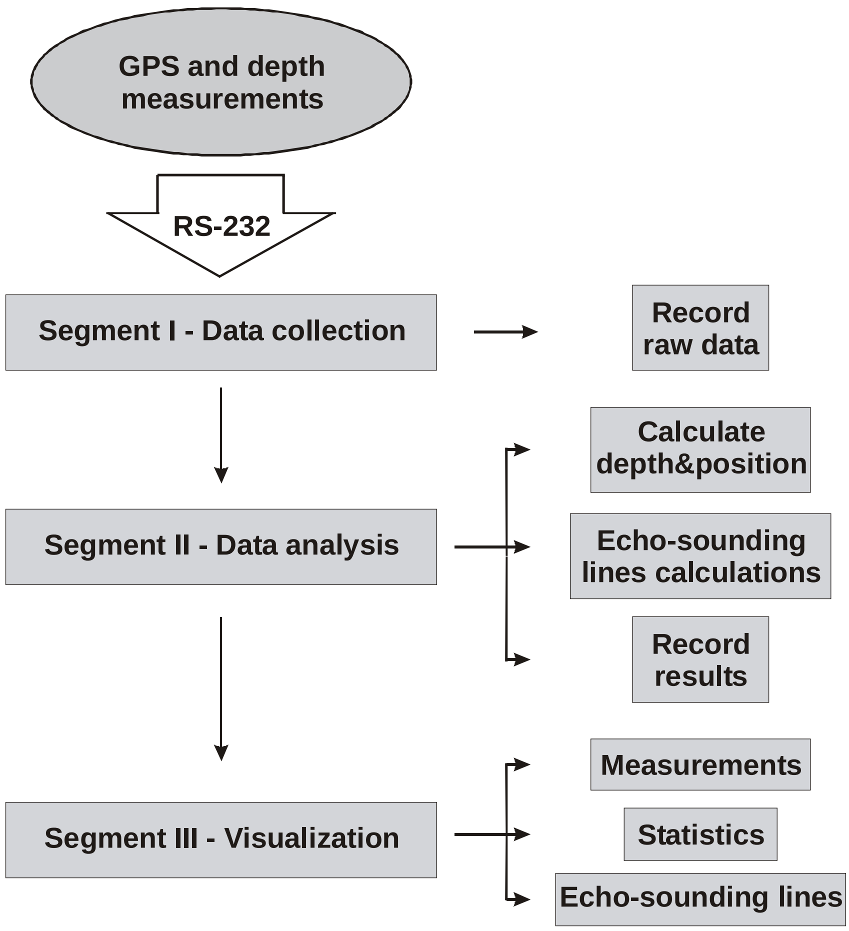

Figure 1: SeaSurvey software flowchart

The collection of the data involves the input of the measurement raw data into the software and their logging. The transmission of the data to the software is done using the serial ports of a computer. In case that the software is run on a notebook without serial (RS-232) ports, there are available on the market *serial to universal serial bus (usb) adapters* which create virtual communication ports. A dedicated thread is used by the software for monitoring and retrieving data from the buffer of the serial port for avoiding delays and conflicts with the rest of the software (Kruglinsky, 1998). When receiving the first available measurement, the software needs to find the beginning or end of the transmitted message, in order to start recording the messages retrieved. These messages are first stored in a user-defined file and then to the memory of the computer for using them in the other two segments of the software. The currently supported message is the "CeeStarBasic+GPS message", which is a custom message of the CeeStar echo-sounding device (Bruttour, 2001). This type of message contains both the NMEA output of the GPS receiver, which is directly connected to the echo-sounding device and the depth measurements.

In the data analysis segment of the software, the retrieved info from the first segment, is initially validated for probable transmission errors and the values of position and depth are extracted. These values are checked for their validity and recorded in a new file. Another check is performed by the software according to the user specified parameters concerning the soundings per second and the GPS measurement observation rate. If the soundings are retrieved at a higher rate than the observation rate, then a simple interpolation is used for calculating the position values in between two GPS measurements.

Since the data in the next step will be displayed using a two-dimensional (2D) map window, there is a need for transforming them into a two dimensional plane. Functions have been implemented for transforming the data from the World Geodetic System 1984 (WGS'84) to the Hellenic Geodetic Reference System 1987 (EGSA'87), which is the official Hellenic datum and finally to the Traverse Mercator 1987 (TM'87) projection used in Greece. These results are also saved in a separate file. It should be noted that all records of the logging files are time-stamped. The last calculation performed is related to the echo-sounding lines. The software supports the use of echo-sounding lines, which can be input into the software by using an ASCII file containing their coordinates and has no limitations concerning their number. After the software starts to record the measurements and if the feature has been activated by the user, it continuously finds the survey line which is closer to the position of the vessel and calculates both the azimuth of the vessel's movement and that of the survey line. This feature can be used for navigation purposes.

The last segment of the software, involving user interaction and displaying of the data, is very important since it allows the user to take full advantage of the software features, where most of their parameters can be customized. Basic map view functionality has been implemented. An important parameter in this segment is the update rate of the map view. Updating the map view at rates higher than the GPS measurement observation rate is meaningless. The information displayed on the screen apart from the vessel's current and older positions include the echo-sounding lines, the current depth measurement, errors messages, number of records, the vessel's velocity and azimuth and the closest to the vessel's position survey line's azimuth. It is also possible to display a depth profile, which results from the last ten depth measurements and is updated automatically. A screenshot of the software can be seen in Figure 2.

The software is not affected by the type of horizontal positioning measurement method used (relative positioning methods based on post processing of the data, DGPS, RTK), rather it is only affected by the accuracy of the position displayed on the screen. In the case of post processing the real-time results are based on the navigation solution. Since the log files are time-stamped, they can be matched with the post processed results using the time data. In the other two cases, DGPS and RTK, the positioning results are final, which means that they do not need any further processing, apart from a similarity transformation for adjusting them correctly to the EGSA’87 datum (Grigoriadis, 2003).

The software was tested on both *Pentium IV* and *AMD 2100+* computers with 256MB RAM and no problems occurred. It should be mentioned though, that the software consumes a significant amount of CPU time, since it is obliged to continuously retrieve data from the RS-232 port, process it and display it. Hence, the notebook's battery will empty faster than usual requiring users to have extra charged batteries on hand in the field.

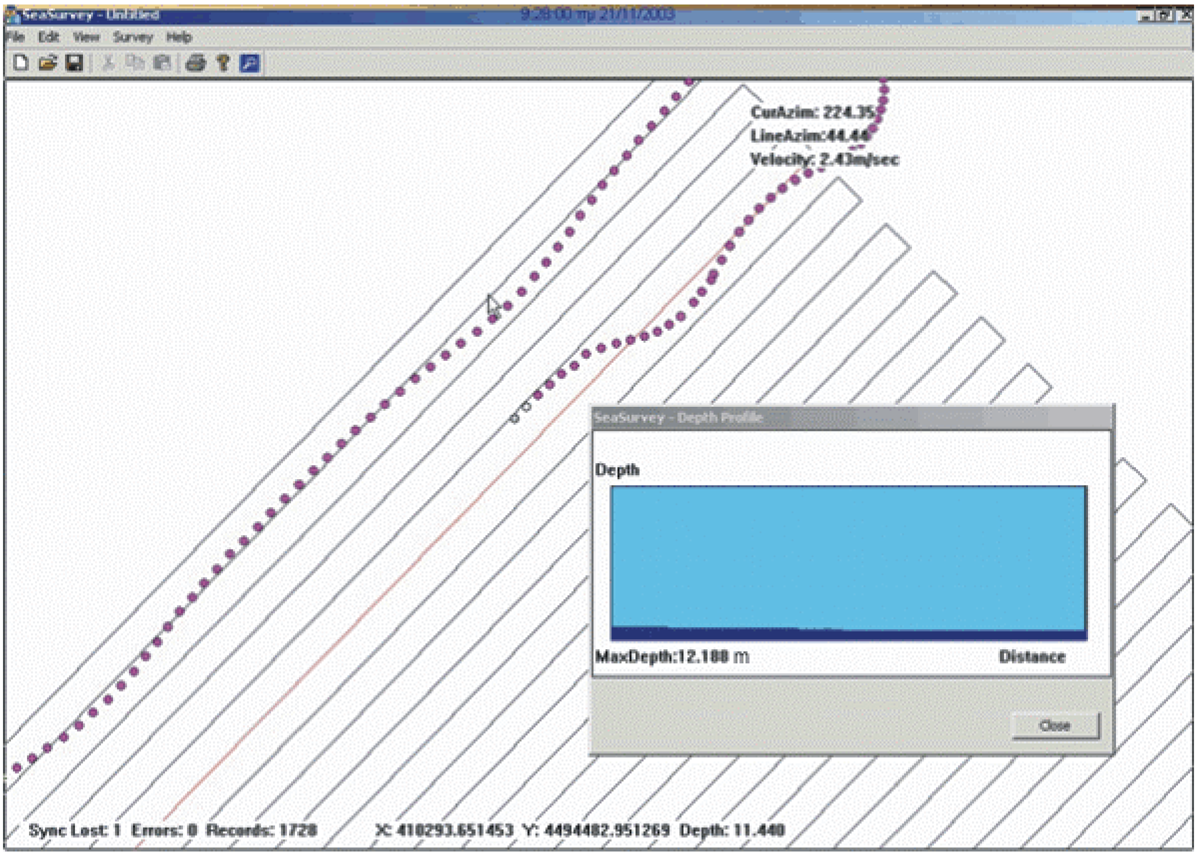

Figure 2: Screenshot of the SeaSurvey software from the test campaign

3.2 Practical Evaluation

The test area for practically evaluating the software is located near the port of Thessaloniki in the south west part of the Thermaikos Gulf. The test aimed in the validation of the performance and reliability of the software along with its features and was conducted in the terms of a small-scale hydrographic survey project.

The equipment used were the CeeStar single beam echo-sounding device manufactured by Bruttour International, two System 300 dual frequency GPS receivers manufactured by Leica Geosystems and a *Pentium IV* laptop computer (Figure 3a). The GPS receiver was transmitting the GGA NMEA message to the echo-sounding device which in turn transmitted to the laptop the CeeStarBasic+GPS message. All the equipments were installed on a vessel (approx. 6m length). The transducer of the echo-sounding device was attached at the bottom of a stainless steal pipe (Figure 3c) and was sunk 25cm below the sea level, while the antenna of the GPS receiver was attached on-board the vessel at the top (Figure 3b1 and 3b2). The pipe was firmly installed on one side of the vessel and almost at its middle (Figure 3d). For the DGPS and RTK observation methods tests, two Satelline 2AS radio modems were used, each of which connected to a GPS receiver.

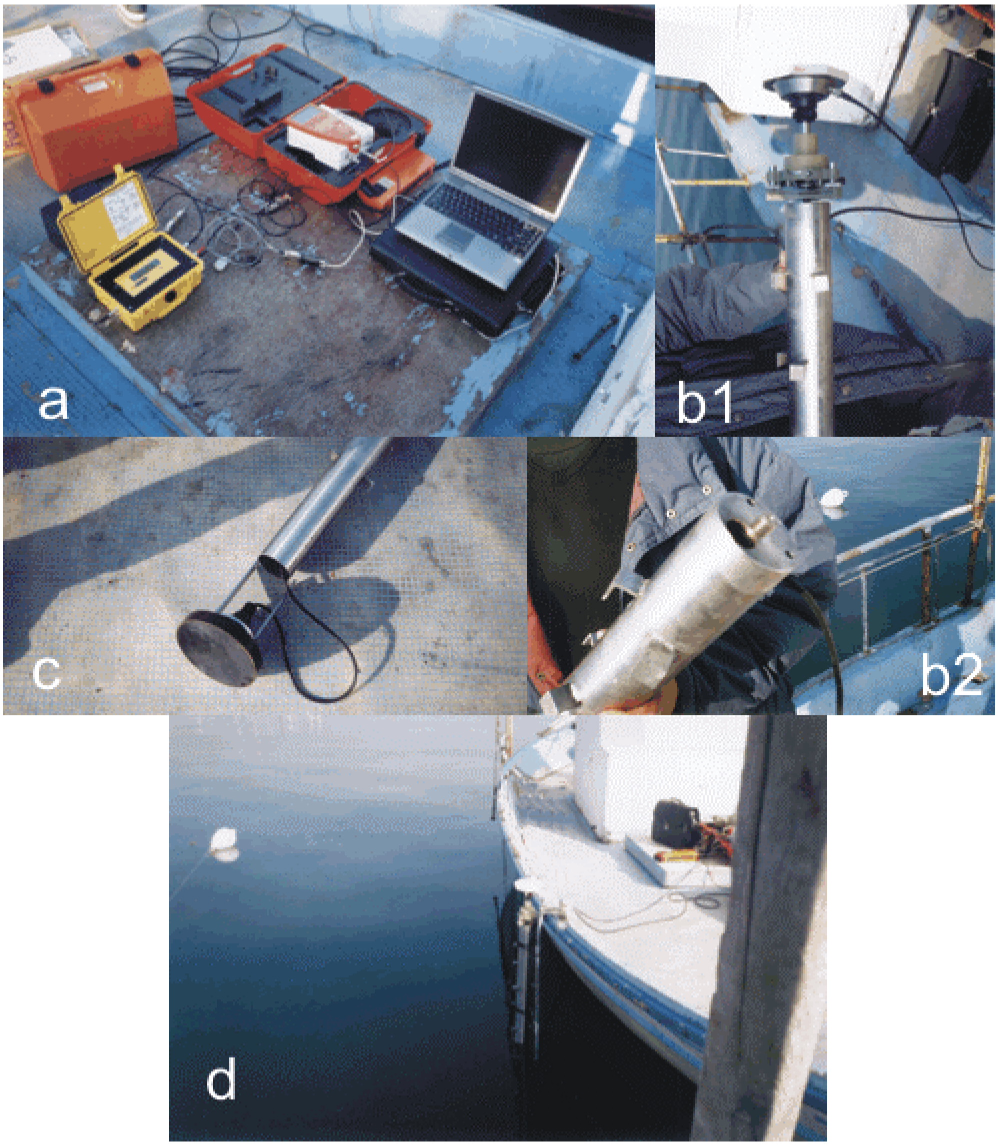

Figure 3: (a) The GPS receiver connected to the echo-sounding device which connects to the laptop, (b1,b2) the GPS antenna attached on the top of a stainless steel pipe, (c) the transducer attached at the bottom of the pipe, (d) the installation of the stainless steel pipe on the vessel .

A calibration of the echo-sounding device was carried out at the beginning of the survey by taking measurements at shallow depths (1-2m) both from the echo-sounder and a surveying rod. The selection of the calibration depths was based on the technical specifications of the echo-sounder which stated that the device is capable of measuring depths up to a 30cm level (Bruttour, 2001). In the next step, the limits of the test area were defined and their coordinates were recorded. These coordinates were used in an auxiliary software for creating the echo-sounding lines of the survey. They were defined inside a rectangularly shaped area and created parallel to each other. The spacing among them was 5m, which is very dense for a common hydrographic surveying project, but they were created this way only for testing purposes.

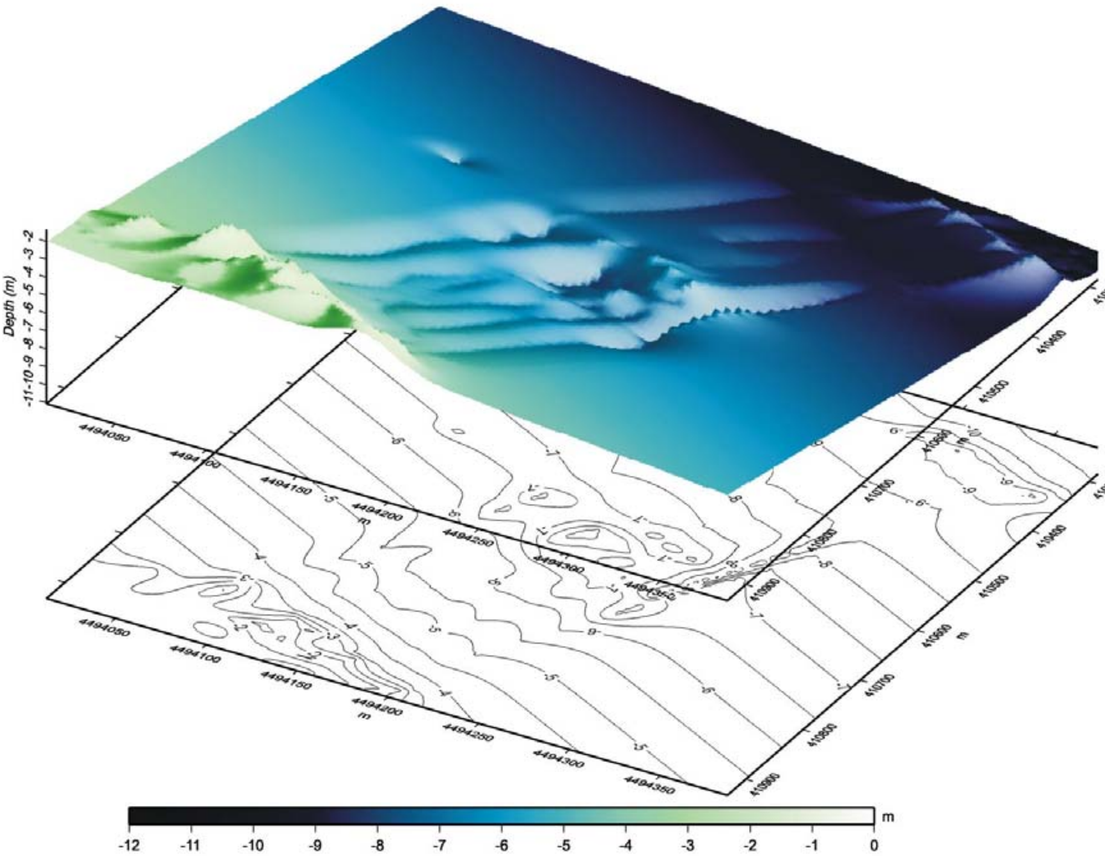

Figure 4: 3D & 2D bathymetric representation of the test area

A number of 2033 depth values were collected during the test measurements, from which a bathymetric map (Figure 4) was created using the Generic Mapping Tools (GMT). The maximum depth found in the area was 10.87m, the minimum 1.33m while the mean depth value was 6.55m. As it can be seen on the map, there is a sudden increase of the depth in the middle of the area. This characteristic was found due to the dense spatial resolution of the collected measurements.

While testing the software, apart from being a reliable data logger and navigation utility, some of its functionality was useful for conducting some simple tests, which provide useful conclusions. The additional tests carried out were:

- Varying GPS measurement observation rates (1, 2 and 5sec*)*
  It was found that the one second observation rate was necessary for keeping up to the echo-sounding lines.
- Varying the vessel's speed
  When trying to shorten the duration of the measurements by increasing the vessel's speed, it was found that the echo-sounding device could not provide correct results for speed greater than 4m/sec. A speed of 3m/sec, though, was found to be adequate and reliable for surveying.
- Varying the GPS-mode
  Specifically, DGPS and RTK were compared with the navigation solution for navigating the vessel. It was found that both modes eased the navigation of the vessel at the same level compared to the navigation solution provided by the on-board GPS receiver. As mentioned before, accurate navigation is useful especially when there is a need to turn the vessel around and bring it back to course for following the echo-sounding lines. The one second observation rate along with the use of DGPS or RTK was found to provide the best solution for navigating the vessel.

Hence, by further implementing the software and adding new algorithms to it, these tests can become more complex and provide the results in real-time.

4. CONCLUSIONS AND RECOMMENDATIONS

The SeaSurvey software is a reliable data logger and navigation tool, which can be easily modified and allows for the implementation of new algorithms for further investigating coastal and inshore surveying techniques and procedures. Certain conclusions were drawn from the test campaign and existing previous experience which can be summed up into the following:

- A low cost and effective solution has been developed, which can be used for bathymetric mapping in coastal areas for shallow depths.
- The combination of GPS receivers with a single beam echo-sounder can be effectively implied for a detailed depth determination.
- A careful design of the survey by choosing the appropriate offset/distance between the echo-sounding lines, the selected measurement method the speed of the vessel and the careful determination of the followed procedures including the calibration of the echo-sounding device are necessary in order to ensure the measurements quality and the credibility of the project.
- The appropriate observation rate, speed of the vessel and offset/distance between echo-sounding lines can lead to the detection of depth irregularities.

Certain features which need to be implemented in future versions of the software include:

- Support for additional equipment by customizing the way the input message is read
- Data storage in a standard hydrographic format (e.g. the S-57 standard format prepared by the International Hydrographic Organization)
- Ability to perform custom calculations with the values read
- Additional visualization, navigation and map tools and statistics
- Full parameterization of its visualization features

- Error control of the depths and horizontal coordinates measured
- Option for transforming in real-time the data according to the results of an already calculated similarity transformation
- Ability to import a cartographic basis of the surrounding land

For all spatial data there are common ways of processing and using them. This approach implies that specialized software relating to specific kinds of spatial data could be easily substituted by a GIS. Most GIS software allow customization through a programming language but this may lead to complex and slower systems, which consume a lot of the computer's resources. Processing the data and archiving using a GIS can be of great value. In particular, processed data can be combined and compared with other types of data. The output of the SeaSurvey software can be easily imported in a GIS software because of its ASCII tab-delimited format and allows for further processing and archiving of the data.

ACKNOWLEDGMENTS

The authors would like to thank Dr. G. Fotopoulos and Mr. G.S. Vergos for suggesting some valuable improvements.

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