

IMPACT OF BATHYMETRIC SYSTEM ADVANCES ON HYDROGRAPHY

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Introduction

1. History of determining the sea floor depths dates back to more than 3700 years. The quest to fathom the ocean bottoms has given the birth to science of HYDROGRAPHY. The first evidence of the hydrography trade was found in the tomb paintings of the Egyptians of around 1800 BC era. At the initial stages Egyptians used the sounding poles, sinkers and the lines to gather information about the topography from very shallow waters say to a maximum of 10s of fathoms. The main aim of gathering this information was to ascertain the safe navigation routes around the shores. By first century BC the capability to get the depth information improved to about 1000 fathoms in the Mediterranean Sea. The first account of any one using a line and a weight to probe the depths of the oceans however dates to 100 BC. Regular soundings in the proximity of a landmass started only during first century AD.

2. The information during these periods did not say anything about the position of the sounding. The identification of a nearby landmass and the coastal configuration remained only in the memories of the in-charge of those who commanded the ships/boats used. In fourth century AD an Indian commander of a fleet, namely Suparaga used the knowledge of the star positions to orient himself with respect to a particular coastal land configuration. He also developed the art of signs for regulating his course and in effect started the charting of sea route not only based on the star positions but also depended on the ocean color, nature of fish in a particular area, birds in the surrounding coastal area and the mountain shapes in a particular nearby land.

3. This state of navigation, charting and depth finding techniques continued in almost similar manner till the discovery of the magnetic compass in the 12th century. By 15th century with the efforts of Portuguese sailors, a scientific method of charting, map making and depth sounding came in to existence and the initial sea route maps were generated. A first atlas of shipping route came in to existence in 1584, which was prepared by Lucas Jans Waghenaer of Holland. During all these times heavy ropes were used for sounding purpose. In a scientific expedition lead by Charles Wilkes, use of a metal wire in place of heavy cotton or fabric ropes was made for the first time. Various improvements were made in the wire sounding machines by late 19th century period. By this time the star positions were effectively used to prepare the navigation charts close to shore areas and in some deep-water domains. A real thrust came in the hydrography after the discovery of the sound wave propagation was proved to be most effective means of depth ranging in 1912, which was improved to great extent by 1918.

4. Geodesy, which is a science of measuring and monitoring of shape and size of science, is used specifically as a spatial reference system in the domain of navigation and hydrography, be it for the oceans or for the navigation in the space. Various reference datum have come in to existence for the purpose of accurately understanding the position in a given reference frame while a hydrographic survey is under progress. Any depth measurement without position will be of no significance.

5. Twentieth century has been the century of the scientific and technological advancement in all the fields. The science of the hydrography also gained vastly from these advances. Hydrography can be divided mainly in to sounding techniques, navigation techniques & reference frame, the ancillary systems like motion or the inertial reference systems, water column physical characteristics measuring devices and lastly the non acoustic depth determining systems like **LIDAR (LIght Detection And Ranging)**.

All the depth-determining systems are coupled with the navigation and inertial measuring units to generate the bathymetric charts to varying accuracies based on the type of systems used for the purpose. Satellite altimetry and marine gravity can also be used in collocation to provide an estimate of bottom topography.

6. We shall now look in to the rapid progress in the technological advancement in all the related hydrographic fields. It should be kept in mind that the environment in which the data is collected is dynamic in nature and therefore only certain data may remain useful and of permanent nature with most of the other data having a limited duration of life. With the development in the sea-faring activity, development of harbors in all parts of world was given highest priority for taking lead in the international trade. Even after advancement in the aviation field, the sea-route is the most preferred for cargo movement.

7. There are many types of information necessary to have a proper control on the maritime governance to effectively manage the terrestrial and maritime spaces. The field of Hydrography has therefore developed in to many branches with the growth in different sectors with specific mandates to provide more sophisticated and an easy approach in achieving the final targets in respective branches. This could mainly be divided in to Charting agencies, Port & Harbor authorities, contract survey companies, client survey companies, software & equipment manufacturers, offshore industries & ocean engineering, hydrographic research organizations and hydrographic law enforcing bodies. With the hydrographic activity at its core the field caters to Oceanography, coastal engineering, Geodesy, positioning fixing aspects, equipment & software developments, deep-sea surveying and underwater ROV; AUVs, the submersible technology development and the offshore oil field exploration.

8. With the advent of the magnetostrictive transducers, the first generation echo sounders came in to existence in late 1930s. The SONAR technology advanced with a phenomenal speed due to the naval requirements. In fact the growth of the acoustic oceanography was mainly spearheaded by the stringent coastal safety requirements of the Navy's around the world. The single beam echo sounder became a mandatory device on all Naval Vessels during the Second World War. As a result of attempts to understand the behavior of the underwater acoustic propagation, various technologies emerged to address the sonar exploration and scanning of the ocean environment. The most common being the narrow single beam echo sounders, side scan sonars, sub-bottom profilers, shallow and deep seismic systems, mine hunting sonars, passive and active detecting sonars and the latest tool of multibeam swath bathymetry systems. The evolution of these various systems became more effective, meaningful and prominent with phenomenal advancement in the computational and the signal processing capabilities.

9. The advancement in the Geodesy has taken us from era of sextant measurements in 1960s with a position accuracy of 1 nm in positioning fixing to the transit satellites of 1970s with a position accuracy of 100 meters provided intermittently to the Global Positioning Systems (GPS) with 100 meters or better accuracy being provided continuously and finally to the present day differential GPS system of accuracy upto 10 meters in 1990s. Today the Real Time Kinematic (RTK) GPS can provide a continuous accuracy up to 5 cms in x, y and z-axis.

10. The related essential requirements in a bathymetric survey include knowledge about the proper motion reference or the inertial reference system to understand the dynamics of the platform on which the bathymetric system is installed. It is important to know the transmit/receive angles along with the large moment angles associated with advanced bathymetric systems. A small vessel motion due to roll, pitch or heaving action can considerably change the transmit/receive patterns and in absence a proper inertial reference, would result in erroneous result. The present day technology compared to the

technology of damped pendulum, we have advanced motion systems along with a kinematic GPS system, which can provide attitude measurements to an accuracy of upto 0.01° and heading accuracies of upto 0.02° , ship speed measurements to 0.01 m/s and position accuracies upto 0.02 to 0.1 meter. The advancement in the sensor technology has also made it possible to measure the change in sound speed profile to 0.1 m/s, which is essential for incorporating refraction related range calculations.

11. Tremendous growth in the computing power has enabled handling of voluminous data generated by the state of art systems needed for a bathymetric survey. As a comparison we can say that in a water depth of about 100 meters, a hydrographer can make about 10 lead line measurements. In the same time he can perhaps make 20 to 25 thousand depth measurements. In case of a multibeam bathymetry system will provide more than a million depth readings. It is possible to handle such a voluminous data only because of the advancement in the computation facilities. These systems also provide additional data in terms back-scattered signals, which are much more in terms of the volume of bathymetry data generated by the system. The visualizing techniques have also improved considerably, leading to an easy approach to generate a 3-D visualizing environment and presentation of the 2-D color-coded contour maps.

12. Lastly the development of autonomous underwater vehicles with sonar platforms has been a big boon to the hydrographic community as this allows surveys close to sea bottom making it free of large platform movements and most of the surface noise sources. A remarkable technological advancement in the field of Hydrography over the last 100 years therefore has proved to be boon for the workers in the field of oceanography, oil & gas exploration, field of Geodesy, cartography, equipment and software development, port & harbor authorities. This development has also provided a feeling of safety in different trades as mentioned utilising services of the hydrography and this will continue to improve further for the betterment of the society.

13. We shall now discuss advances in the technology for each of the related fields that come under the multidisciplinary subject of HYDROGRAPHY. We shall mainly deal with SONAR system advancement, advances in the navigational methods, inertial measurement systems and lastly the processing systems and handling of vast multi-source data sets.

Advances in SONAR Systems

14. As mentioned above the acoustic systems have proved to be the only proper means to gather information about the ocean environment issues, which include bathymetry, seabed classification, substrata information below the seabed topography etc. With the advancement in material science various versions of transducers were developed, which included the initial types of magnetostrictive and electrostrictive to present day piezoelectric transducers. The present day technology has provided large power handling capability and therefore to obtain long-range detection of the targets. Early transducers typically provided wide or broad beams of the order of 30° to 60° resulting in a footprint of roughly 0.5 to 1.0 times the water depth and the return echo was thus representative of a large ensonified area. This means that the first seafloor echo return could be from anywhere within the ensonified area. This would result in a defocused and an inaccurate seafloor depth representation. With the advent of piezoelectric transducers, it was possible to use the transducer in an array form, which can provide better power handling with a focused narrow beam width. These types have a better directivity that is governed by the beam pattern diagram. However the eco-sounders, which were the first generation bathymetric systems could provide soundings that were dense only in the along-track direction. Widely spaced tracks therefore provided only sparsely sampled seafloor.

15. After the initial breakthrough in terms of using echo-sounding techniques for seafloor mapping, hydrography entered in to a new era of technology during late 1960's and early 1970's. With rapid development in the acoustic theoretical models, related signal processing algorithms and capability of acoustic electronics in implementing these methods, the first generation multibeam echo sounders came in to existence, initially as classified navy systems and in late 1970's as research tool. The development mainly came from better understanding of ability to measure and control the phase and amplitude characteristics of the bottom returns and in implementing electronic steering mechanism to the transducer arrays for transmission and reception of acoustic signals. This enabled generating high-resolution seabed images.

16. These early-developed systems were far more limited in terms of swath coverage, map generation capability, computation and handling of data, corrections with regards to dynamics of the platform motion parameters. The first generation system provided a swath width of 45° (coverage up to 75% of water depth) with 16 beams. However as the electronic industry's phenomenal growth in the computational hardware in terms of microprocessors, controllers, digital devices etc. also aided in rapid growth in the bathymetric system capabilities including echo sounders, side scan sonars, sub-bottom profilers and in the newly developed multibeam swath bathymetry systems.

17. Now there are systems with about 300% of water depth coverage for deepwater applications to about 750% coverage of water depth coverage for the shallow to medium depth applications. With the effective application of accurate phase measurement of the return signals, the present generation systems are also capable of providing the side-scan imagery and backscatter information of the seafloor. High computational power of the present day processing systems and the development in processing software has enabled handling of voluminous data generated by the multibeam sonars to produce photographic quality seafloor images and also detailed 3D perspectives of the surveyed seabed along with detailed 2D contour maps.

18. There are various types of sonar systems with specific design criteria. They can be classified as broad beam systems like side scan sonars with applications ranging from seafloor mapping to geophysical and geological investing tools, single beam echo sounders with capability of ground discriminating software embedded in to the system providing seabed classification data, multiple narrow beam bathymetry systems and lastly the interferometric sonars. In the present day context, the most widely used systems happen to be multi-narrow beam swath bathymetry systems and at times the side scan sonars depending on the application requirements of a hydrographic survey. In a hydrographic survey the footprint size and the sounding sequence and spacing in the along-track and across-track direction plays an important role in the selection process of multibeam sonars. The performance of the survey system also depends on the vessel speed and the dynamic behavior of the vessel itself. Therefore depending the survey requirements in terms of size of feature detection, size of the area to be mapped and depth ranges to be covered under plan consideration of a survey, there are various multibeam sonars between 12 KHz to about 500 KHz available. Unlike the single beam echo sounders, multibeam sonars have provided a totally new concept about the seafloor morphology as well as about seafloor processes.

19. Present day bathymetry systems cannot be viewed in isolation restricted only to the sonar system part. This needs to be considered as a comprehensive integrated ocean mapping system that would cover the sonar part but also the positioning, motion sensing, processing and presentation subsystems together. As the sonar technology was developing, there was an equal attempt in providing all-round advancement in the positioning, attitude monitoring and post processing systems.

Improvements in the Positioning Systems

20. The multibeam sonars have provided a high spatial coverage of the ensonified area in across track direction. It is therefore necessary to understand the precise positions of the acoustic footprints to know the location of a point ensonified on the seafloor footprint, from where a depth value is determined. This also needs a precise knowledge on the installation geometry of the system transducers on the vessel along with the installed position measurement offsets in comparison to the locus of the positioning system on the ship.

21. As considered earlier, the position accuracies have improved considerably since early 1960s from a 1 nautical accuracy provided by a sextant, we have reached a stage of about 5cm accuracy with the Real Time Kinematic (RTK) GPS/DGPS systems. The in-between stages of the technological advances that benefited the hydrography in terms of a variety of navigational systems include triangulation/intersection-positioning systems using radio frequency range-range navigation concept, range azimuth systems like Theodolite total station, land-based hyperbolic and range-range positioning systems (Mini Ranger and DECA type) etc. These systems mainly catered to the near shore environment with good accuracy. However 1978 was the year of crucial importance, which marked the year of revolution in the accurate positioning in the deep-sea environment with the launch of the 1st TRANSIT satellite. The accuracy of position of geodetic reference stations on land was close to 10 meters over 1000 kilometers prior to satellite navigation era. Now with terrestrial reference systems in position, the same accuracy has been upgraded to 1 cm level. The first version of navigation satellites by US was termed as Navy Navigation Satellite Systems (NNSS). These were further upgraded to Global Positioning System with access for commercial/civil use. The GPS outputs are not only important as far as positioning is concerned but they are also concerned with polar motion and earth rotation parameter measurements, gravity measurement missions, International Terrestrial Frame Reference determination and crust deformation studies. The satellite positioning systems basically use Pseudo Ranging point positioning using at least 4 pseudo ranges for a 3D position fix or Relative (Differential) positioning (DGPS) methodology to provide a position. With Selective Availability (S/A) criteria switched off in May 2000, the single point position performance from GPS improved considerably. A new L2 CS code has been assigned to improve the performance of position fixing receivers to work under adverse condition of low satellite elevation, under foliage and some times even under shadowing conditions.

22. The present systems use code phase tracking methodology for the differential GPS with either a land base station or a reference radio beacon station to provide accuracy within +/- 5 meters to a range of 300 to 350 kilometers from the vessel based receiver to a sub-meter accuracy in close proximity of up to 5 kilometer from land station or a radio beacon station. Further improvement has lead to present generation real time code phase tracking differential systems that can provide a position accuracy of about 5cm in x, y, and z. Centimeter-level accuracy positioning in real-time based on GPS measurements (or more generally on GNSS measurements) was developed in the mid-1990s. It involves a reference receiver transmitting its raw measurements or observation corrections to a mobile survey receiver via some sort of data communication link. One significant requirement of a single base RTK approach is that the maximum distance between reference and rover receiver must not exceed 10 to 20 kilometers in order to be able to rapidly and reliably resolve the carrier phase ambiguities. This limitation can be resolved by having an array of GNSS RTK receivers overlapping the area of survey covered by the mobile survey vessel.

23. With a growing demand of the offshore survey requirements and the increased demands on a need for accurately locating underwater objects, common positioning tools were found to be inadequate. The accuracy of positioning systems also demanded collocating objects or sites underwater with reference to seabed. As a result of this a

new Underwater Acoustic Positioning system came into existence in early seventies. Acoustic navigation system provided accurate positioning in offshore areas with respect to ocean bottom. This was a useful tool when the terrestrial radio navigation system had limitations in terms of coverage and distance and positioning systems such as Omega and Satellite Navigation were unable to meet the precise positioning requirements of offshore areas.

24. Acoustic positioning systems can be distinguished in the following three ways on the application of their use. The first requirement considered in vessel precise sea keeping as 'dynamic positioning' which involves positioning a surface vessel or platform over a particular point on the seafloor, compensating the influences of waves, wind and currents. This application is used for keeping the ship on the precise location, e.g., deep sea drilling vessel for drilling a particular location where ship has to be present within an accuracy of 3 m so that the drilling unit is in the proper position. Positioning of the 'Glomar Challenger' drilling vessel of US is the typical example. The second requirement involves continuous positioning of the surface vessel navigation in the restricted area far away from the shore to determine the position of an underwater instrument platform in the form of a ROV or AUV or a towed system or relative multi-diver operations with respect to seabed or with respect to object under observation. The advances in acoustic technology, degradation in the performance of a DGPS system in tropical areas owing to ionospheric scintillation and the increasing exploration requirement for drilling in deeper water depths in tropical areas caused further demand for refinement and advances in the Acoustic Positioning Systems.

25. There are several modes of underwater position fixing based on the configuration of the system utilised for this purpose. They can be classified as bearing/bearing, Range bearing, range/range and phase difference measurements. The use of a particular system depends on the type of application envisaged by a user. Different types of APS are as follows:

- (a) Short baseline system (SBL)
- (b) Super- short baseline (SSBL)
- (c) Ultra short baseline (USBL)
- (d) Long baseline (LBL)

Of these above systems, USBL in the form of a long chain and the USBL systems have proved to be extremely useful in the offshore oil industry operations, archaeological operations and for ROV/AUV operations in the shallow to medium depths. Like the requirements of multibeam sonar, the acoustic navigation systems also incorporate the slant range measurements, angle measurements, vessel vertical and horizontal references, heading references and the vessel attitude monitoring inputs. This therefore involves complex mathematical solutions to arrive at a near total positioning solution. In the present century with further improvement in the computing power and miniaturization of the embedded processing hardware, it may be possible address the complex mathematical solutions for developing an ultimate hybrid system incorporating inputs from GPS, Glonass and Galileo satellite based systems, from attitude monitoring and inertial navigation system and can act as global local reference.

Advances in the Attitude Monitoring Systems

26. It is a well known fact that during any hydrographic survey, the vessel motions (roll, pitch, heave and heading from true North) need to be compensated during measurements made by the sonar systems as well as for the acoustic positioning procedures to obtain an accurate depth range. Vessel being a dynamic platform for the measurement in the ocean environments undergoes continuous change with regards to its position at a location. This is mainly due to the roll, pitch, heave and yawing motions of the vessel. Particularly after multibeam sonars came in to existence, due to wide

transmission and reception swath characteristics of the acoustic signal, any change in the location of the vessel will introduce an error in the depth determination.

27. For measurement of Roll and Pitch generally Inertial Measurement Systems (IMU) are used while for the heading corrections a two antenna GPS receiver with a difference in the carrier phase measurement approach will provide the heading from true North. During roll and pitch motions of a vessel, the GPS antennae will deviate from its vertical reference and therefore may generate erroneous co-ordinates received from the GPS. These need to be compensated for using the IMUs. The heave movement is a due to the translation of the centre of gravity of an object (a vessel in this case) caused by the swells, sway and waves. The roll and pitch are caused by the rotation of the centre of gravity of a vessel caused by the oscillatory motion of the ship in its transverse and longitudinal axis respectively. During a hydrographic survey, the roll, pitch and heaving motions not only causes errors in the position of the vessel due to the departure of antennae from their vertical reference but also cause errors in the measured depth values as even the transducer also departs from its vertical reference. The heading information needs to be accurate during a multibeam survey or a gravity survey to generate and collocate the 3D and 2D maps with respect to actual ensonified seabed. Any deviation that takes places during transmission or reception of the multibeam signal will result in translation of the ensonified area with respect to along track direction.

28. In the earlier stages a pendulum system was in place to determine the roll of a vessel coupled with potentiometer type sensors. This was a crude way of getting an idea about the roll data that could not be compensated in real time. All the data was subjected to a rigorous post processing with limited computing resources. The attitude monitoring has undergone unprecedented changes with the advancement in the motion sensor technology. By late 1970 gyro stabilized accelerometer based attitude monitoring systems, computing roll, pitch and heave sensing and came in to existence. Doppler sonar principle was also used to compute real time heave motion effects. Till 1990, the motion sensors were not up to the mark for a very high resolution bathymetric surveys. However with fusion technology coming in to existence by this period, a combined inertial system providing both motion sensing and true heading information gather was made possible. Now we have very high grade systems like Applanix POS RS, Applanix POS MV 320, CODA Octopus 180, IXSea Octans, Seatex Seapath 200, TSS Marinus etc. Presently RTK GPS allows a good quality control of motion sensor data.

Conclusion

29. With major thrust towards exploitation of marine resources (both living and non-living) in last few decades, hydrographic applications have gathered enough momentum in commercial, marine transport, engineering, research and international law enforcing organizations. Hydrography has become an integral part of oceanographic and geodetic research. Pressing demands to improve our understanding about oceanographic processes involved in exploration of living and non-leaving resources has provided an unprecedented push to tremendous technological advances in last six decades.

30. With improved knowledge on safe navigation the harbours across the world have gained tremendously. This has helped increase the maritime trade by large volumes in terms of cargo handling. In terms of port activities, the other field that has advanced in the technology is the dredging activity. Latest multibeam technology combined with high-end software support has made the dredging activity more meaningful.

31. Oceanography research is amongst the largest of all the possible users of the hydrography. Any research activity is not complete without a detailed mapping of the study area and accurate positioning of the sampling locations. Geomorphologic and tectonic studies solely depend on the high-resolution bathymetry chart generation, which are used for close seafloor observations using ROVs, submersibles and AUVs. Coastal

dynamics is best example of interdisciplinary research, which uses bathymetry, tides, current, biogeochemical observations, sediment transport and the seafloor classification. Habitat mapping is another branch, which also needs hydrographic inputs in details.

32. Offshore industry has gained immensely from the advances in the technology related to hydrography research. Oil industry in particular which demands precise positioning techniques and well defined sub-bottom details for both exploration and extraction has been more demanding in terms offshore structural developments.

33. Researchers all over the world have contributed towards the electronic and mechanical hardware development not only forced the electronic and engineering industry to come up with faster solutions in terms of advanced systems to generate and handle voluminous data but also helped the related software development in terms different model developments applicable to all possible branches of science and engineering, related to oceanography and naval applications.

34. Navy of course has been one of the driving forces in development of the hydrography and therefore in turn the basic oceanography research. All the science and technology that has been developed today has its roots in the Navy's requirements. With unending demands and requirements there is large scope for further advancement in the science and technology in the field of hydrography.

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