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SEABED MAPPING

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ABSTRACT

Navigational charts are the marine equivalent to topographic maps. Both use measures of height/depth points and outlines to depict an image.

The arrival of multibeam hydrographic echo sounders in the early eighties marked a true revolution in seabed mapping, achieving results for marine measurements almost equivalent to those obtained on land.

There came a change from validating specific data to having a continuous registration of the seabed. These technologies have even indirectly made it possible to obtain a highly precise verification of the composition of the marine seabed with errors smaller than 10 centimetres.

The equipments for bathymetric studies are installed in ships arranged for mapping the seabed. These are usually oceanographic ships for mapping deep waters and small-size boats for shallow waters. In the first case, the detailed studies of deep zones serve as an important research component, whereas in the case of bathymetries for coastal or shallow waters, the foundation is more technical, as in the case of navigable channels, which must be periodically dredged, of harbour works, regeneration of beaches, etc.

Key words: Hydrography, Bathymetry, Echo sounders, Multibeams.

INTRODUCTION

Hydrography, in general, is similar in many aspects to research on land and many of the techniques used are the same, or extensions of them. Navigational charts are

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the marine equivalent to topographic maps. Both use measures of height/depth points and outlines to depict an image, but where the person using the map can visually verify the details shown, the user of the chart cannot do it. The person using a chart, therefore, blindly depends on the precision and reliability of the hydrographer´s work.

Marine measurements have always been less precise than their equivalents on land, although in the last few years with the technological development of transducers and positioning systems (differential GPS, dynamic positioning, inertial systems, etc.) an important evolution has been achieved, obtaining results close to those obtained on land. Due to this evolution, seabed mapping has lately experienced an enormous improvement in its accuracy. From the archaic but effective sounding lead, which prevailed up until the 20^{th} century, there has been a change to the current multibeam echo sounders that map the seabed with great exactitude.

The need for knowing the depth of specific shallow zones has always existed, understanding that the safety of the boat depended on this data in the case of calling at a port or bay. Knowing the precise draft in conditions of low tide, permitted entrance of particular ships with a maximum draft equal to the one measured plus the established margin of safety. In addition to draft data, it is equally important to identify the composition of the seabed. Evidently, it is not the same for a ship to run aground on rock or coral reef, as on a muddy bed, for in the latter the possibility of recovering the ship in case of stranding is much more feasible. In the same way, depending on the type of seabed existing, some anchors will be more adequate than others.

The equipments for bathymetric studies are installed in ships arranged for seabed mapping. These are usually oceanographic ships in the case of deep waters and small-sized ones in shallow waters. In the first case, the detailed study of the deep zones has an important research component, whereas in the case of the bathymetries of coastal or shallow waters, the foundation is more technical, as in the case of navigable channels that must be periodically dredged, of harbour works, regenerations of beaches, etc.

DESCRIPTION OF AN ECHO SOUNDER

The echo sounder is a telemetry system based on echoes adapted to the marine environment. This apparatus emits sound waves with a specific frequency, which after reflecting off the seafloor are received once again. Subsequently, the apparatus, using a simple calculation, finds the distance between the echo sounder and the seabed. Given that data for the speed of sound is known as well as the elapsed time between emission and reception, the distance fulfilled by the wave in half of this time, that is, the distance from emission of the wave until it touches ground is the depth between the boat and the seabed.

There are two types of echo sounders, multibeam and single-beam, which moderately differ from each other in regards to range, frequency, amplitude of beams, etc.

Source: http://www.hydroacoustics.com/

Figure 1. Image of a multibeam echo sounder scanning (Hydroacoustics).

As its own name indicates, a multibeam echo sounder has several beams, against only one of a single beam. The latter emits a beam of waves directed downwards with an angle of 1º.5. This means that with the single beam we will only know the depth existing right below the ship. On the contrary, the multibeam emits a multitude of beams, between 101-80 depending on the model, attaining coverage of 6 to 7 times the depth. That is, if we are in an area of 50 metres depth we will know the exact draft of a strip of 350 metres in width. The great advantage of the multibeam technology is the elevated coverage of the floor, which makes it possible to scan a large floor surface with a single pass ensuring that, contrary to the single beam echo sounder, no dead zones have been left between non-adjacent lines. Remember the sinking of the "Urquiola" at the entrance of A Coruña, because of "needle" rocks that had not been detected when the navigational chart was elaborated.

In order to minimize the errors we have to take into account a series of variables, which are:

Speed of sound in water

The waves emitted by an echo sounder are sound waves with a frequency of between 50 and 200 KHz. in the case of the multibeams, and between 2 and 600 KHz. in the single beams. The travelling speed of these waves depends on the density of the medium through which they move, which in our case is water. At a greater water density, there is a greater travelling speed. The problem is that water does not always have the same density in the same zone, varying seasonally, and is very different from some geographic areas to others, not to mention the differences between the density of water in ocean and that of a river or a lake. For this reason, it is necessary to introduce the density data into the working software of the echo sounder in order to correctly calibrate its travelling speed. This data must be obtained and corrected prior to each data collection. In order to do this, a density profile is fulfilled by launching a C.T.D. instrument (Conductivity, Temperature, Depth) to the maximum depth in which we are going to measure and introducing the density values of each depth at the time of processing the data in the echo sounder computer.

Placement of the transducer

The echo sounders have an emitting head, denominated transducer, which is usually placed against the hull of the ship. Its own coordinates must be well calculated with respect to a central point of the ship, which will serve as point 0, since the greater or lesser precision of the measurement will depend on it. The system is placed with a differential GPS, which in turn is based in reference to the localization point of the echo sounder. The draft variations produced in the ship must be corrected in the multibeam software since if, for example, the ship drafts 1 more metre because it is loaded with fuel, the measurement obtained will be 1 metre less than the real one.

Reference system

The depth measurements taken by the echo sounder must be spatially referenced, that is, a latitude and longitude must be assigned to each point of measurement of the depth. The ship is equipped for this with a positioning system, logically differential, which gives each depth sounding its latitude and longitude. This system is composed of a differential GPS (DGPS) and a movement sensor. There are currently several systems for obtaining a differential positioning; the most common ones are the ones previously mentioned, the DGPS, RTK (Real Time Kinematic) and the Omnistar system.

The RTK is fixed on a base station situated on a land point with known coordinates that receives a GPS signal with it´s standard error. This station, by knowing its real position with an exactitude down to the millimetre - without error -, sends this error in latitude and longitude made by the radio satellites, to the GPS station of the ship, which can consequently correct it directly and apply it to its position. The accuracy obtained with this system is of less than 5 centimetres in longitude and latitude. The inconvenience is that the radio signal has a maximum range of 10 kilometres and that the station must be placed on land and have known coordinate points - normally geodesic points - near our working zone.

Source:
http://www.novatel.com/products/index.htm

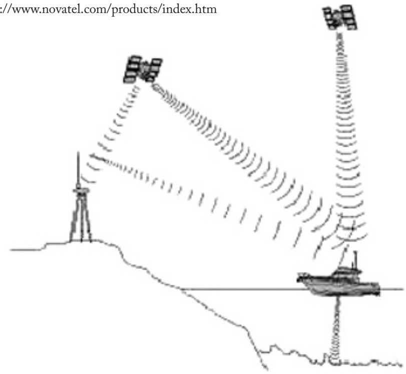

Figure 2. Scheme of the omnistar system (novatel).

The Omnistar system is simpler, as it is a based on the ship receiving the already corrected and very accurate signal from a satellite. This satellite does not belong to the GPS system, but it belongs instead to a company that rents its signal through payment of an annual fee for its reception. This company sends the correction through powerful radios to its satellites and these, in turn, send it to "its clients". The accuracy is somewhat worse than the RTK system, having an error range comprised between 10 and 15 centimetres in longitude and latitude.

The advantage of this system with respect to the RTK is that it does not need a land station and that it is only necessary to have a small size receiver antenna in the ship. The inconvenience is the yearly payment to rent the satellite.

Movement sensor

In order to keep the typical movements of a ship in the water from altering the measurement of an echo sounder, a movement sensor is installed in a central area of the ship, that is, over the centreline of the ship and as close as possible to the water line.

While navigating the ship experiences movements through the hydrodynamic action of the water such as the roll, pitch and yaw. Furthermore, there are movements that occur due to the action of an unbroken wave that vertically elevates the ship without producing a pitch.

The movement sensor corrects these deviations from the "rest" position of the ship instantly, for which at the time of calculating the sounding in each point, this offset is already corrected.

Source:
http://www.tss-international.com/products2.html

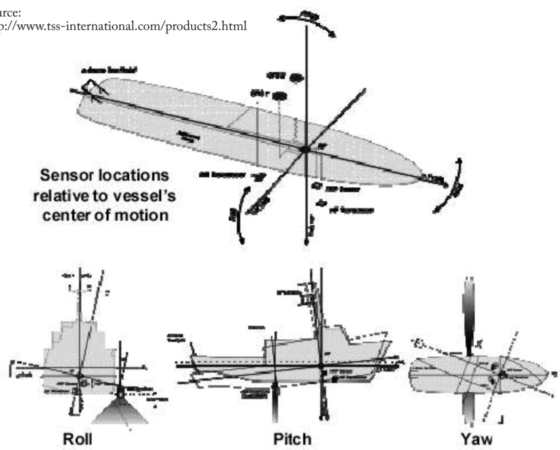

Figure 3 – Scheme of the movements of a ship (mahrs).

Apart from these elements, it is of great importance to take into account the effect of the tide, given that it significantly alters the bathymetric measurement. That is, if we are measuring depths at one same point, it will vary according to the amplitude of the existing tide. This makes it necessary to have a tidal amplitude record of the working zone, which can be introduced, subsequently, in the data processing program of the echo sounder in order to correct its effect. There are different methods for this purpose, of which we will discuss the two main ones: the direct measurement of the elevation over the geoid given by the differential GPS, and the data taken from a tide recorder installed in the zone.

In the case of the differential GPS the method is simple: the geoid of the zone being measured is conveniently selected and the data of its elevation over the ship are gathered. This will give us a graph showing an elevation caused by the tide and some small elevations caused by sporadic waves. The series of data can be directly introduced into the echo sounder or can be done later after fulfilling a statistical cleaning of the data. The inconveniences of this procedure are that the biggest error of the GPS is found within the vertical data and, furthermore, that the ellipsoid must be well selected.

In regard to the tide gauge method, it is based on obtaining a temporary series of elevation data, but in this case, issued from a tide gauge installed close to the working area. These equipments are usually found in commercial ports and are generally well calibrated. They are property of the port Authorities, these being the ones responsible for their maintenance. Their data can be downloaded from the Internet almost in real time, thereby obtaining very accurate data. In the case that the closest port does not have a tide gauge, one can be installed with the drawback that a height with which to reference the tide measure is needed. Normally, the ports have known heights referred to the Port Zero in question.

The reference level, on which the bathymetric measurement obtained with the echo sounder is based on, is essential, since depending on that it uses a same measurement it will have different values. Normally the data will be referred to the Lowest Equinoctial Spring Tide or Port Zero, which is an even safer value for navigation as it includes the effect of the atmospheric pressure.

PROCEDURE IN A BATHYMETRIC MEASUREMENT

Demarcation of the Working Area

When planning a campaign for bathymetric measurement the demarcation of the working zone is fundamental. For this purpose, the sounder has navigation software, as if it were a chartplotter, which guides the skipper of the vessel and displays the areas which are being measured. A navigational chart is introduced in this software and if possible with the greatest detail of the coastal shapes.

It is necessary to have an order of magnitude of the surface, which can be measured in a day´s work in order to adjust the daily plots. These parcels will overlap with each other.

It is important to have a strict method in regard to filling the information, since each zone is associated to the tide taken on that same date.

The calibration of the speed of the sounders and of the position of the sounder´s transducer must be fulfilled prior to commencing the bathymetric surveys, as well as calibrating the speed of sound in water and the position and draft of the transducer (of the sounder). Theoretically, it should not move from its correct position but, for example, a slight variation in the list of the boat would cause errors in the measurement.

The calibration is fulfilled by placing an iron plate at a well-known distance from the water line, which will provide its accurate draft. This operation must be fulfilled in a sheltered area where the ship will experience the least movement making the calibration easier. In turn, the roll, pitch and yaw of the ship must be calibrated.

Methodology of the bathymetric measurement

The transducer installed has the capacity to read data in an angle that oscillates between 90º and 160º. Due to the way that a multibeam sounder works, the coverage will depend on the depth, finding a gradual coverage increase with the increase of the draft. The multibeams make it possible to measure 100% of the seabed, this scanning remaining reflected in the ship's navigator which is observed both by the skipper of the vessel and by the operator of the echo sounder; the first one to fill the area to be measured with the successive passes, and the other one to control the parameters of the echo sounder which will optimise its functioning.

To aid in this process of "filling in", that is, of covering with passes the entire seabed, it is convenient for the lines to be as straight as possible to ensure the quality of the data being collected. For this, the operator traces parallel straight lines so that the ship can follow them as if they were courses, and in this way the navigator follows them attaining a regular cover of the seabed.

http://www.novatel.com/products/index.htm

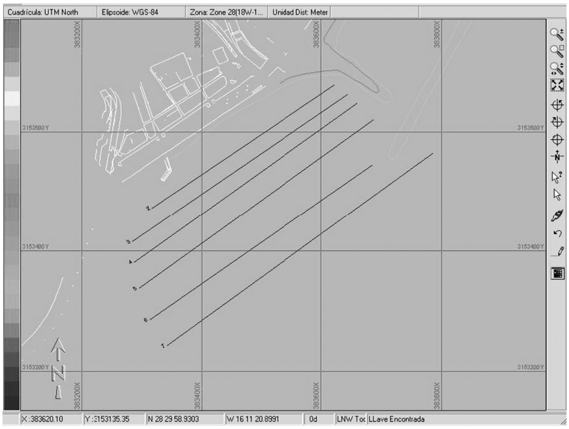

Figure 4. Image of the guide system of the ship with the lines of planned measurement.

The data at the extremes of the scan are the ones that can incur the most errors, since it has a lower angle of incidence, leading to usually eliminating the data obtained during processing. This processing is based on a computer program that statistically eliminates erroneous data. For this reason, the data between two consecutive passes must overlap to a certain degree.

Due to the irregularities that appear in the seabed, such as sudden changes in levels, rocks, etc, the lines that are being performed might not be as uniform as desired, for which the work must be revised to avoid leaving areas of the seabed unmeasured.

In the instance that the accuracy of the survey so requires it, like for example in the case of measurements in the interior of docks, navigable channels, dredging material volumes or dumping of harbour work material, the following procedures can be fulfilled to increase accuracy:

Two passes along each line of planned measurement.

The speed of each one of these passes must be the minimum possible to maintain the correct governing of the boat. In this way a larger number of points in the measure is obtained.

Following the conclusion of the measurements, it is then necessary to proceed to recording the data obtained by the sounder on a CD for its post processing. In this way we ensure having at least two copies of the work.

Methodology of the post process of the data obtained

During the data processing of the information gathered during the field bathymetry campaign, and in addition to the bathymetry and positioning data, we integrate the tide correction corresponding to the work period extracted from the tide recorder or the DGPS.

There are several software models with which to process the data although their functioning is basically similar. The data are statistically cleaned to eliminate wrong data produced by strange rebounds or acoustic noise and are transformed into bathymetric curves exportable to different formats, such as for example, the CAD or in 3D models.

All of these processes are fulfilled graphically and remain reflected in the data tables.

Source: http://www.sidmar.es/sidmar.htm

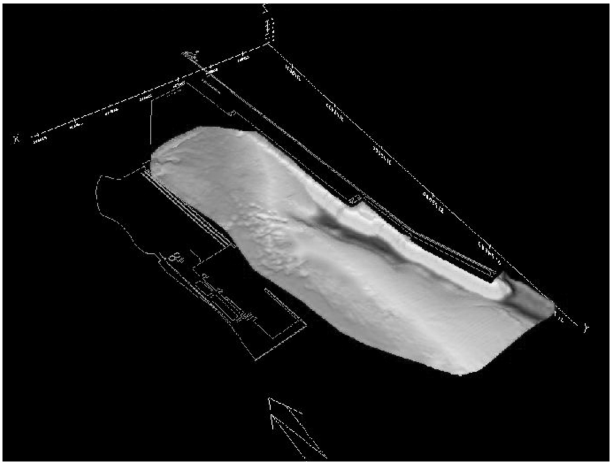

Figure 5. Image of the result of a bathymetry in the interior of a port.

CONCLUSIONS

The arrival of multibeam hydrographic echo sounders at the start of the eighties implied a true revolution in seabed mapping. There was a change from validating sporadic data to having a continuous record of the seabed. These technologies even make it possible indirectly to obtain a highly precise verification of the composition of the seafloor with errors smaller than 10 centimetres.

These methods are becoming popular at a very fast pace in the drafting of maritime work projects, given that a better project will arise from good data. Some Port

Authorities already have precision bathymetries in their ports, with perfectly demarcated depths under each mooring bollard.

It is to be expected that in the next few years its use will become even more generalized, with the subsequent increase in navigation safety in areas of shallow waters.

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T.S.S. S.G. Brown: http://www.tss-international.com/products2.html

CARTOGRAFIADO DE FONDOS MARINOS

La hidrografía, en general, es similar en muchos aspectos a la investigación en tierra y muchas de las técnicas empleadas son las mismas, o una extensión de ellas. Las cartas náuticas son el equivalente marino a los mapas topográficos. Ambos utilizan medidas de puntos de altura/profundidad y contornos para mostrar una imagen, pero mientras que la persona que utiliza el mapa puede verificar los detalles mostrados con una inspección visual, el usuario de la carta no lo puede hacer.

Las mediciones marinas siempre han sido menos precisas que sus equivalentes en tierra, aunque en los últimos años con el desarrollo tecnológico de transductores y sistemas de posicionamientos (GPS diferencial, posicionamiento dinámico, sistemas inerciales, etc.) se ha logrado una gran evolución, obteniendo unos resultados casi equivalentes a los obtenidos en tierra. Debido a esta evolución el cartografiado del fondo marino ha mejorado enormemente su precisión en los últimos tiempos. Desde el arcaico pero efectivo escandallo, que prevaleció hasta el siglo XX, se ha pasado a las actuales ecosondas multihaces que cartografían el fondo marino con una gran exactitud.

Desde siempre, se ha hecho necesario conocer la profundidad que existe en determinadas zonas someras, pues de ese dato dependía la seguridad del barco en caso de una recalada a un puerto o bahía, dado que, si se conocía el calado con exactitud en condiciones de bajamar, se permitía la entrada de determinados barcos con un calado que, como máximo, fuese igual al medido más el margen de seguridad establecido. Además del dato del calado, es importante conocer la composición del fondo. Evidentemente, no es lo mismo que un barco toque fondo sobre roca o arrecife coralino, que sobre un lecho fangoso, pues en este último caso es bastante factible recuperar el barco en caso de varada. Del mismo modo, dependiendo del tipo de fondo existente, serán más adecuadas unas anclas que otras.

Los equipos de estudios batimétricos se instalan en barcos preparados para el cartografiado de fondos. Suelen ser barcos oceanográficos en el caso de cartografías de aguas profundas y barcos de pequeño tamaño en las de aguas someras. En el primer caso, la función del estudio detallado de las zonas profundas tiene un importante componente investigador, mientras que en el caso de las batimetrías de aguas costeras o someras, el fundamento es más técnico, como en el caso de los canales navegables que se deben dragar periódicamente, las obras portuarias, regeneraciones de playas, etc.

La ecosonda es un sistema de telemetría basado en ecos adaptado al medio marino. Este aparato emite las ondas de sonido a una frecuencia determinada que, tras rebotar en el fondo marino, las recibe de nuevo. Tras esto, el aparato mediante un sencillo cálculo halla la distancia entre la ecosonda y el fondo. Dado que se conocen los datos de velocidad de desplazamiento de las ondas y el tiempo entre emisión y recepción, la distancia recorrida por la onda en la mitad de este tiempo, es decir, la distancia desde que la onda se emite hasta que choca con el fondo, es la profundidad entre el barco y el fondo.

Hay dos tipos de ecosonda, la multihaz y la monohaz, que difieren bastante una de la otra en cuanto a alcance, frecuencia, amplitud de los haces, etc.

Como su propio nombre indica, una ecosonda multihaz tiene varios haces, por uno sólo de una monohaz. Esta última emite un haz de ondas dirigidas hacia abajo con un ángulo de 1º,5. Esto implica que con la monohaz conoceremos solamente la profundidad existente justo debajo del barco. En cambio, la multihaz emite multitud de haces, entre 101-80 según el modelo, consiguiendo una cobertura de 6 a 7 veces la profundidad.

La gran ventaja de la tecnología multihaz es la elevada cobertura del fondo que permite barrer una gran superficie de fondo con una sola pasada por encima, lo que permite asegurar que, a diferencia de la ecosonda monohaz, entre líneas no adyacentes no nos hemos dejado ninguna zona muerta.

Para minimizar los errores hay que tener en cuenta una serie de variables que son:

— Velocidad del sonido en agua
— Posición del transductor
— Sistema de referencia
— Sensor de movimiento

Aparte de estos elementos, es de suma importancia tener en cuenta el efecto de la marea ya que altera de forma importante la medición batimétrica.

PROCEDIMIENTO EN UNA MEDICIÓN BATIMÉTRICA

Delimitación del Área de trabajo

En la planificación de una campaña de medición batimétrica es fundamental la delimitación de la zona de trabajo. Para esto, la sonda tiene un software de navegación, como si fuera un chartplotter, que guía al patrón de la embarcación y le muestra las zonas que va midiendo. En este software se introduce una carta náutica, a ser posible con el mayor detalle de las formas de la costa.

La calibración de la velocidad de las sondas y de la posición del transductor de la sonda se deben realizar antes de empezar los trabajos batimétricos, así como también se llevarán a cabo los calibrados de la velocidad del sonido en el agua y de la posición y calado del transductor de la sonda.

La calibración se realiza poniendo una plancha de hierro a una distancia de la línea de flotación perfectamente conocida. De este modo sabremos exactamente el calado del mismo. Esta operación de debe realizar en una zona resguardada para que el barco se mueva lo menos posible y la calibración sea más fácil. A su vez se debe calibrar el cabeceo (roll), balance (pitch) y alineamiento (yaw) del barco.

CONCLUSIONES

La aparición de las ecosondas hidrográficas multihaces a principios de los años ochenta, supuso una auténtica revolución en el cartografiado de los fondos marinos. Se pasó de validar datos puntuales a tener un registro continuo del fondo. Estas tecnologías incluso permiten indirectamente verificar la composición del fondo marino, siendo su precisión muy alta, con errores menores de 10 centímetros.

Estos métodos se están popularizando a pasos agigantados en la redacción de proyectos de obras marítimas, pues de unos buenos datos, saldrá un mejor proyecto. Algunas Autoridades Portuarias ya disponen de batimetrías de precisión de sus muelles, con profundidades perfectamente delimitadas bajo cada noray.

Es de esperar que en los próximos años su uso se generalice aún más, con el consiguiente aumento de la seguridad de la navegación en zona de aguas someras.