Bathymetric measurements - principles and utility

Aurel Saracin, Alexandru Calin

Abstract **—** At this time, when marine and river navigation intensifies, it is necessary detailed knowledge of the water bottom topography of the river navigable channel and marine coastal areas. Sonar sounding systems, multibeam ecosounders systems or those using interferometry, is investigating ways water bottom topography, to identify sedimentary deposits or to achieve the necessary studies hydrotechnical constructions. The importance of bathymetric measurements is noted in several projects implemented in Romania, presented in this paper.

Keywords**—**bandwidth, beamwidth, depth, echosounder, seafloor, signal, SAS interferometry, Danube Delta

I. Introduction

Increasingly, it calls for the mapping of bottom water of rivers, lakes and especially in areas of maritime coastline. Recreational and commercial navigation on rivers and lakes require accurate information about underwater topography, but not infrequently the time evolution of matter and silt deposits to appreciate the moment when interventions are needed for safe navigation of ships dredging increasingly higher.

In seaside areas may require investigations of bottom water to estimate the amount of work for setting up new ports, to discover the exact position of wrecks that needs to be investigated or even submerged archaeological sites to explore. Often it is necessary to accurate mapping seawater bottom in order to estimate more precisely the needs of installing offshore oil exploration and other underground resources.

It is not insignificant need for three-dimensional modeling of terrain (MDT) undersea volcanic areas or in large mouths of major rivers which evolve relatively quickly.

It's easy to understand the concern to get the most accurate information about the landscape and objects that are on the bottom of the water.

The first sonar designed in the same way modern sonar is, was invented and developed as a direct consequence of the loss of Titanic in 1912, where the basic requirement was to detect icebergs in 2 miles distance. Underwater sound is used both by whales and dolphins for communication and echolocation.

SONAR is the acronym for SOund Navigation And Ranging. Sonar technology is similar to other technologies such as: RADAR = RAdio Detection And Ranging; ultrasound, which typically is used with higher frequencies in medical applications, seismics, which typically uses lower frequencies in the sediments [17], [18].

Sound is pressure perturbations that travels as a wave. Sound is also referred to as compressional waves, longitudinal waves, and mechanical waves (see Fig. 1). The acoustic vibrations can be characterized by the following:

- Wave period T [s]
- Frequency f = 1/T [Hz]
- Sound speed C [m/s]
- Wavelength λ = C/f [m]

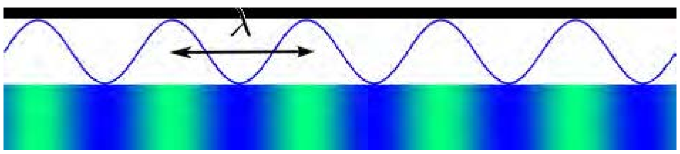

Fig.1

Range defined as the radial distance between the sonar and the reflector, can be estimated as follows:

- A short pulse of duration Tp is transmitted in the direction of the reflector.
- The receiver records the signal until the echo from the reflector has arrived
- The time delay τ is estimated from this time series

The range to the target is then given as

$$R = \frac{C\tau}{2} \quad (1)$$

The sound velocity c has to be known to be able to map delay into space.

II. Principles of DEPTH MEASUREMENT

The basic signal model for an active sonar contains three main components:

1. The signal which has propagated from the transmitter, through the medium to the reflector, is backscattered, and then propagated back to the receiver. The backscattered signal contains the information about the target (or reflector) of

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interest. It depends on the physical structure of the target and its dimensions, as well as the angle of arrival and acoustic frequency.

2. Reverberation is unwanted echoes and paths of the transmitted signal. This is typically caused by surface and bottom scattering, and/or volume scattering.

3. Additive noise is acoustic signals from other sources than the sonar itself.

The sonar equation is an equation for energy conservation for evaluation of the sonar system performance. In its simplest form, the equation states the following:

$$Signal - Noise + Gain > Threshold \quad (2)$$

where *Threshold* is the value for which the signal after improvement (gain) is above the noise level.

Active sonar signal processing can be divided into a number of different stages [16], [17].

- Preprocessing: filtering and applying time variable gain (TVG).
- Pulse compression: matched filtering in range (convert the time spread coded pulses to “delta”- functions).
- Beamforming: direction estimation (or matched filtering in azimuth). This is to convert element data in an array into directional beams (array signal processing).
- Detection: detection of potential targets (e.g., a fish, a submarine).
- Parameter estimation: estimation of position and velocity of the detected object.
- Classification: target recognition, pattern recognition.

Bathymetry derived from measuring water depth with different devices. Water depth estimation using bundles can have two approaches: measuring the response time of a reflected signal emitted by a predefined angle or steering angle measuring the reflected signal at a given time.

Multibeam echosounders systems emit a pulse that propagates bidirectional higher strip covering the bottom.

Interferometric method of investigation is a simple and fast with high coverage of the area studied and higher precision rendering relief bottom, than the other methods above mentioned.

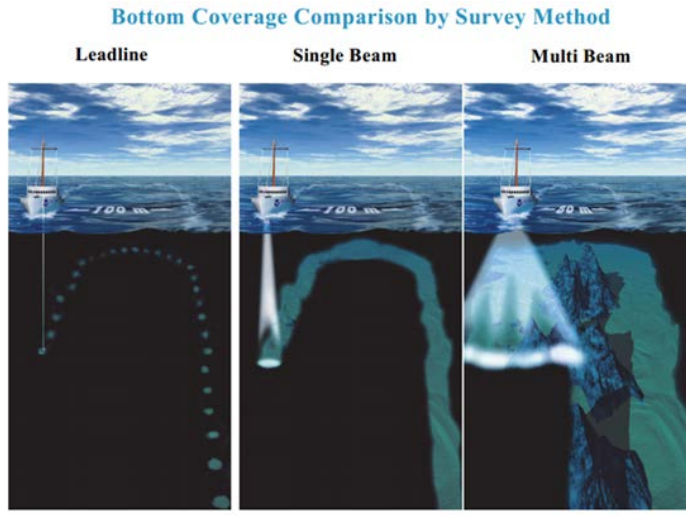

Fig. 2

The principle of mapping the seafloor with multibeam echosounders is as follows (see Fig. 3):

- The multibeam echosounder forms a large number of beams for each ping. The beams are in different direction, spanning a fan cross-track of the vehicle.
- Along each beam (or direction), the range (calculated from the time delay) to the seafloor is estimated.
- The range estimate in each beam gives the relative depth of the seafloor relative to the vehicle. This is again transformed into a map of the seafloor along the fan.
- The vehicle is moving forward, and consecutive pings gives a continuous map of the area surveyed.
- The map resolution is determined by the 2D beamwidth and the range resolution.

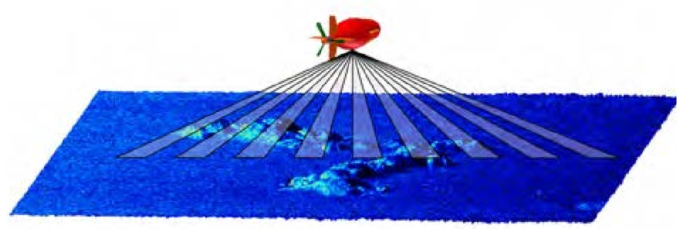

Fig. 3

Multibeam echosounders are commonly used in mapping of the seafloor. The swath width of a multibeam echosounder is typically 4 to 10 times the sonar altitude (dependent on which system). Figures 4 and 5 shows an example map produced from data collected with a multibeam echosounder on the HUGIN AUV [19], [20].

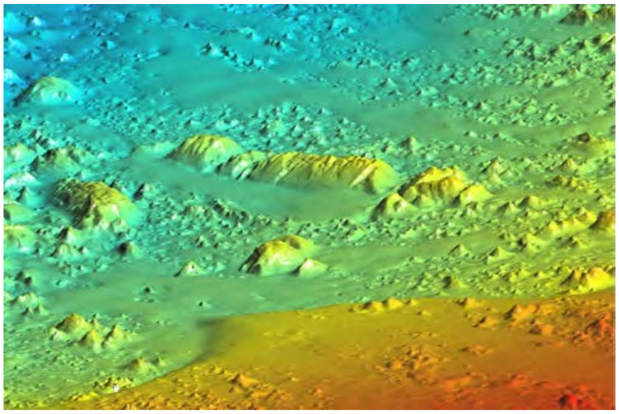

Fig. 4

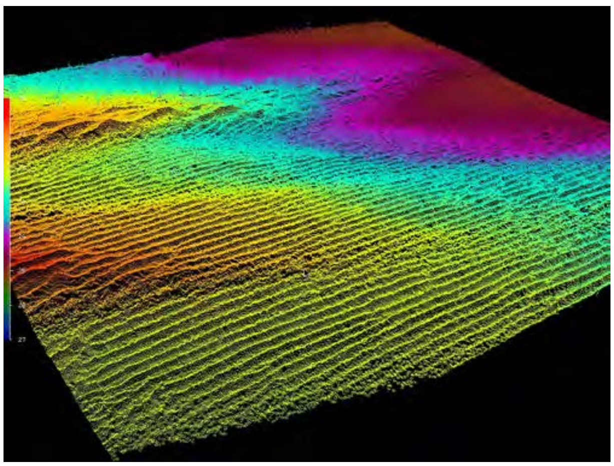

Fig. 5

The spatial resolution of a sonar system is determined in terms of beamwidth and bandwidth of a transmitted pulse. The bandwidth of the transducer is the dominant factor conditioning the range resolution ΔR [1]:

$$\Delta R = \frac{C}{2W} \qquad (3)$$

where C is the speed of sound and W is the bandwidth of the signal. The larger the bandwidth the higher the range resolution, which is the ability to discriminate returning signals from particular adjacent targets. The bandwidth of a typical transducer is usually about 10% of the operational frequency, thus the association of higher range resolution with higher frequencies. In the same sense, the angle resolution Rθ is proportional to the frequency,

$$R\theta = \frac{C}{FL} \qquad (4)$$

where F is the centre frequency and L is the length of the aperture (aperture refers to the physical extent of the transducer through which sound waves are allowed in or out, basically to limit the spatial propagation of sound radiation). The angle resolution is the ability to discriminate the direction from where an echo is returning to the transducer. It is related to the beamwidth θ_{bw} of the transducer, expressed in the form

$$R\theta \approx \theta_{bw} = 0.88\frac{\lambda}{L} \qquad (5)$$

where λ is the acoustic wavelength and the constant term 0.88 is a rough approximation when aperture lengths L are greater than 4λ (narrow beamwidth at high frequencies).

The area A ensonified by a pulse within a beam is the product of the range resolution ΔR projected on the horizontal by the extent of the angle resolution Rθ in the same plane, at the grazing angle ϕ (Fig. 6)

$$A = \frac{\Delta R}{\cos\phi}\cdot R\theta = \frac{C}{2W\cos\phi}\cdot\frac{Rc}{FL} \qquad (6)$$

This equation denotes that the instantaneous area of ensonification by the pulse within the beam is proportional to the slant range R but inversely proportional to the operational frequency F for a given aperture L, thus higher frequency leads to potentially higher spatial resolution in the along-track dimension. Additionally, because the frequency dependent term bandwidth W, is also in the denominator, the higher the bandwidth the higher the across-track resolution.

Spatial resolution of an acoustic beam differs to some extent to that described to above in terms of the footprint dimension. Each beam in an MBSS produces a bathymetric sounding solution. Bottom detection within a beam is determined by the finite area of ensonification or footprint as a function of beamwidth, beam angle of incidence, and depth.

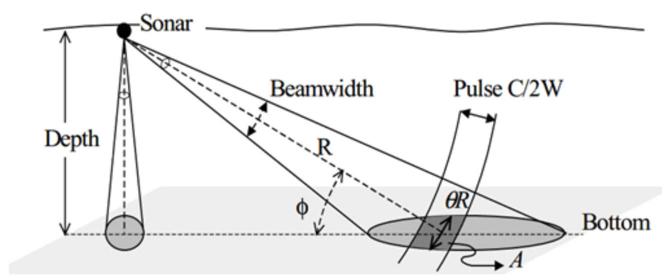

Fig. 6

The footprint dimension in the athwartship direction f_a is estimated by

$$f_a = \frac{2d}{\cos^2\theta}\cdot\tan\frac{\varphi}{2} \qquad (7)$$

where d is the measured depth, θ is the angle of incidence, and φ is the receiving beamwidth in the across-track direction. From the above one can see that, assuming a flat surface and constant depth, the footprint increases its dimensions with increasing angle of incidence. Therefore, the resolution is expected to be maximum in the nadir region and to gradually decrease toward the outer part of the swath.

The backscatter strength of the seafloor is the incoherent returning energy of an acoustic pulse transmitted in the water column at a certain range and angle over a finite area of seafloor. The spatial variability of backscatter strength can be determined with MBSS as a result of the interaction between the seafloor physical properties and acoustic energy. Acoustic backscatter is dependent on several variables:

• A reflection coefficient caused by the difference of acoustic impedance between sea water and bottom materials.

• The surface roughness as a function of the acoustic wavelength.

• The volume reverberation that must also be expressed in terms of acoustic wavelength.

In theory, different seafloor types return a characteristic response signature, which makes viable the implementation of sea bottom classification systems. In practice, this is far from being achieved since the three phenomena mentioned above are individually complex and the combined effect is almost unmanageable [14].

The backscatter intensity also varies as a function of the angle of incidence of the acoustic pulse. The angular variations of intensity normally behave in a Lambertian pattern assuming a flat surface; in practice, the Lambertian assumption is not totally profile in order to compute the real angle of incidence and the footprint area ensonified. Additionally, short swath series can be used to correct real angle of incidence in the fore-aft direction where slope variations also contribute to an angular dependency.

A useful implementation for backscatter map generation is to use the geographic variations of mean backscatter intensity where bottom types with different backscatter strength can be resolved. Assumptions made in this approach include correction to all automatic gains, calibration of Tx/Rx beam patterns, actual across-track profile correction, and no refraction. In qualitative terms, high contrast sediment types can be discernible (rock outcrops/boulders, coarse sand, fine sand, mud) without some of these assumptions, especially in flat seafloor surfaces, however, these premises should be considered if quantitative estimations are desired. Moreover, with the collection of seafloor physical properties like grain size, surface roughness, impedance, etc., one can relate the measured acoustic responses of discrete locations to specific bottom types and generate surfaces of corresponding attributes. Research has been conducted [15] to extract the most from the backscatter strength and to develop seafloor classification tools that make use of backscatter angular dependency functions, which should describe different bottom types with higher accuracy.

A. *Syntetic aperture*

A real aperture sonar is limited by a range-dependent along-track resolution. In order to achieve high along-track resolution, one must have very high frequency and short range. This reduces the area coverage rate and makes the sonar impractical for surveying of large areas. A solution adapted from radar is to use synthetic aperture processing [2; 3]. In synthetic aperture processing successive pings (or pulses in radar terminology) are coherently combined to synthesize a longer array.

In synthetic aperture processing one has to move less than half the receiver element size between pings, in order to avoid undersampling lobes [2]. Since the phase velocity is a factor of $2 \cdot 10^5$ lower for acoustic waves in seawater than for electromagnetic waves, this imposes an impractical limitation. It is therefore common to use a large number of elements along-track to increase the area coverage rate [4].

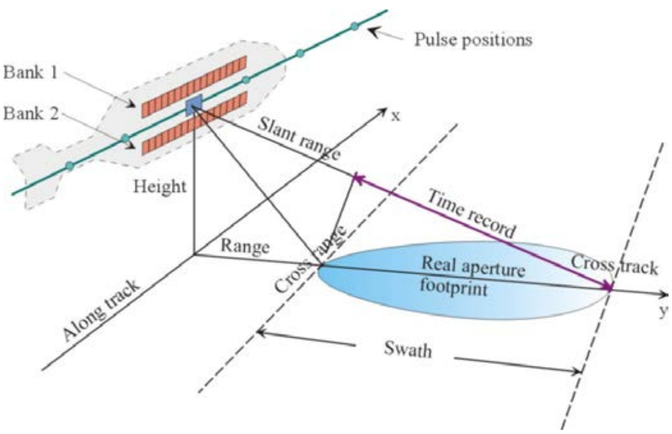

Fig. 7

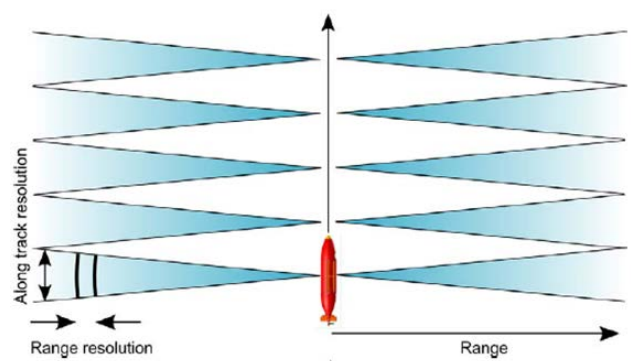

Fig. 8

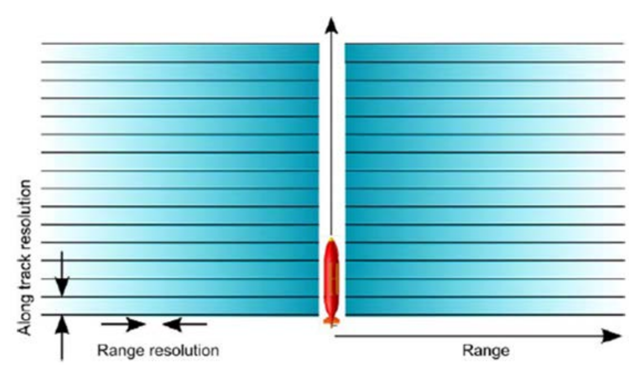

Fig. 9

Another serious constraint is the need for accurate navigation. Navigation errors larger than a fraction of a wavelength over the synthetic aperture will cause defocus in the synthetic aperture images [3]. Since the length of the synthetic aperture increases with range, the navigation constraint becomes range dependent. Thus the image quality is often range dependent even if the theoretical image resolution is not.

On small platforms such as AUVs, inertial navigation systems alone can not provide the desired navigational accuracy, so micronavigation techniques which use redundancy in the data to estimate sensor translation has been developed. One of the most common methods is the displaced phase center antenna principle (DPCA) which uses cross-correlations on element data [5].

Another approach adapted from SAR is autofocus, which is a method for blind correction of image degradations using the complex synthetic aperture image as input.

The most common technique both in SAR and SAS is called phase gradient autofocus (PGA) [3], [6].

B. Interferometry

Interferometry means to determine the angular direction of an arrival signal, by means of the time delay between the arrival of the signal at spatially separated receivers [7], [2]. Below figure shows a simple sketch of a typical interferometric sonar. A single transmitter and two vertically separated receivers are used to determine the depression angle of the arriving echo.

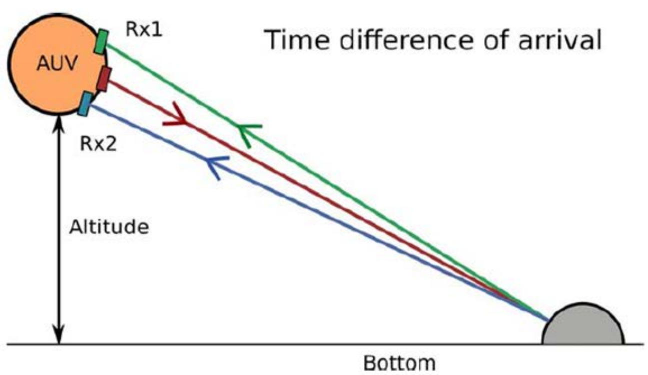

Fig. 10

The distance between the interferometric receivers is called the baseline. Usually, one assumes that the baseline, D is small relative to the range so the arrival wavefronts can be considered parallel [7]. The relative depth, z is then found from

$$z = r\left(\frac{C\tau}{D}\right) \tag{8}$$

where τ is the interferometric time delay between the arrival signals. The time delay is usually estimated from the phase-difference between the signals [7]. The precision of the time delay estimate is a function of SNR, and the estimate can thus be very precise for high SNR. However, the phase-difference is ambiguous modulo 2π [8]. A number of different approaches have been made to unwrap the phase. 2D phase unwrappers find the most likely phase assuming that the data are continuous [8], multi-receiver or multi-frequency systems use redundancy to resolve the ambiguities [7] and crosscorrelation based methods estimates the ambiguities at the expense of poorer horizontal resolution and increased processing time [9].

The accuracy of the time delay estimate is proportional to the baseline [7]. However, increasing the baseline to much will reduce the coherence between the signals [10] and also deteriorate the accuracy of the time delay estimate. Other limiting factors are

• Layover [2]. In layover regions, there is a mixture of signals arriving from different directions. The different directions cannot be resolved and the coherence drops.

• Shadow [2]. In shadow regions, there is a lack of signal energy and a time delay can not be estimated.

• Multipath [11]. Signals arriving from other directions than directly from the seafloor (e.g. via the sea surface or from an elevated object and via the seafloor) will deteriorate the time delay estimate.

In benign bathymetries, the interferometric performance is limited by baseline decorrelation at close range and SNR at long range [10]. In area with large bathymetric variations or with large man-made objects, layover, shadow and multipath will limit the interferometric performance.

C. Differences and similarities with radar

The principle of synthetic aperture radar and synthetic aperture sonar is the same, but there are fundamental differences [12]:

• For electromagnetic signals in air, the phase velocity is typically 3×10^8 m/s. For acoustic waves in seawater, $c \approx 1.5 \times 10^3$ m/s, which limits the forward velocity in SAS. In practice, it is difficult to make a stable SAS-platform with a low enough velocity. The solution is to use multi-element receiver arrays.

• The atmospheric attenuation of electromagnetic signals depends on the weather conditions, but is often considered a minor effect in SAR. In SAS, however, the seawater absorbs the acoustical signal energy through viscosity and chemical processes [9]. This limits the range for a given frequency, as the practical range is roughly constant measured in wavelengths.

• The phase velocity has to be known along the wave path. In SAR the speed of light is accurately known, but in SAS the speed of sound varies with depth [9]. In coastal waters, there are also local horizontal and temporal variations. The variation may be as high as 2% along the wave path. The effect is two-fold: An error in the average sound speed leads to defocusing of the SAS images, while an error in the sound speed profile also causes position errors [13].

• The imaging geometry of existing SAS systems are very similar, with a swath reaching from nadir to roughly ten times the altitude. This geometry is very different from spaceborne SAR systems, which have a much more vertical geometry. The vertical geometry reduces the effect of shadowing, but increase the effect of foreshortening and layover [2]. An airborne SAR system usually has an imaging geometry somewhere between a SAS and an spaceborne SAR.

• To make a diffraction limited image, the sensor position has to be known within a fraction of a wavelength over the synthetic aperture. Satellite tracks are deterministic and accurately known within this limit, but on airborne SAR systems and SAS systems (which can't use GPS) the navigation is often a limiting factor.

While SAR, being available for decades, has reached a very high level of maturity, SAS has only recently become commercially available. This is partly due to the differences listed above. SAR interferometry is today very sophisticated, using techniques such as repeat-pass image collections over years and multi-baselines for tomographic (or 3D) imaging.

SAS interferometry has been demonstrated successfully at numerous occasions, but has yet to reveal its full potential. It is likely that advanced methods in interferometric SAR will be adapted by the SAS specialists.

Current technology trends in SAR interferometry are:

• Differential and repeat-pass interferometry for deformation monitoring, where multiple images are collected over a large time span (up to years). A major limitation is that the effect of the atmosphere has to be estimated and compensated for.

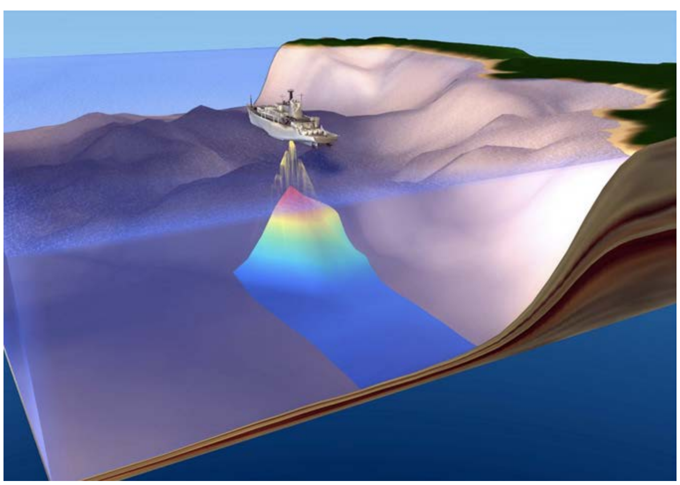

Fig. 11

• Multi-baseline SAR tomography for 3D imaging, e.g. used in forest mapping (to estimate the average height of the trees).

• Single pass multi-platform interferometric SAR for increased baseline and mapping accuracy using several platforms in formation flying.

• Bistatic SAR using one moving antenna and one stationary antenna, or two moving antennas.

• Multi-frequency and ultra wideband SAR for characterization of areas and targets.

• Multi-channel along-track interferometry for moving target indication.

III. Using bathymetry in Romanian projects

The Danube River is the major economic importance for Romania, is an important corridor for river navigation, an important source of water for irrigation in agriculture and industrial water supply, and fish resources are recovered. The Danube Delta also is a major natural economic resource, not only by the variety of wildlife, but is visited by many tourists is valuable for tourism revenues and travel on water with different types and sizes of boats.

Considering all the above is easy to guess that most of the projects where they applied and bathymetric investigations have focused on the Danube and the Danube Delta. Thus, by the 2000s they developed projects that have focused on the creation of an updated online support digital modern navigation on the Danube, noticing increased traffic of commercial ships and cruise touristic ships.

For navigation, in this section of Danube are critical points where the Danube between Calarasi and Braila is splits and flows on many valleys, some can not being navigable when water is low. For more accurate estimation of the situation campaigns were conducted bathymetric and geodetic measurements to create unique DTM, above water and under water on this zone of the Danube with meanders and several courses (valleys) .

Fig. 12

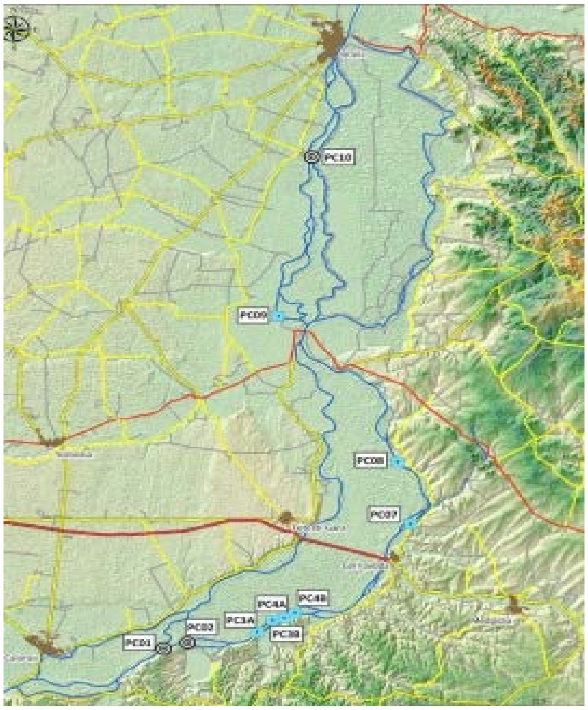

Fig. 13

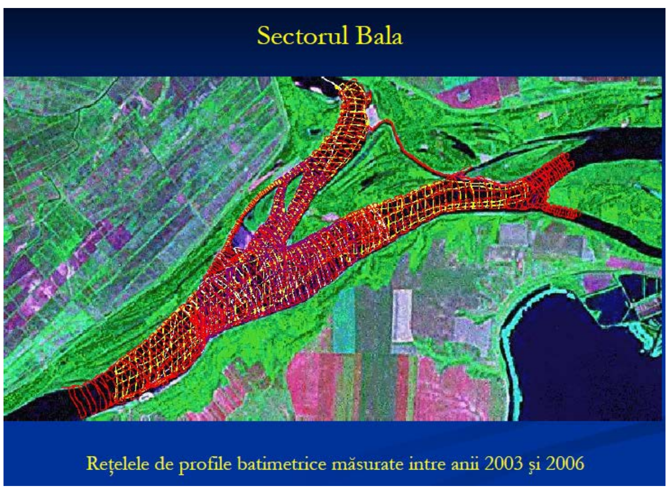

Fig. 14

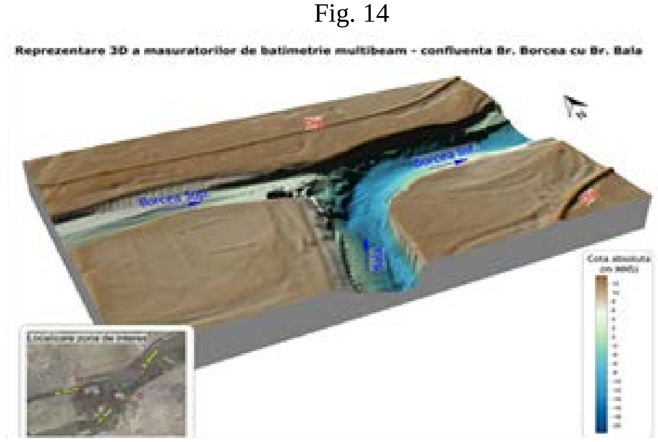

Fig. 15

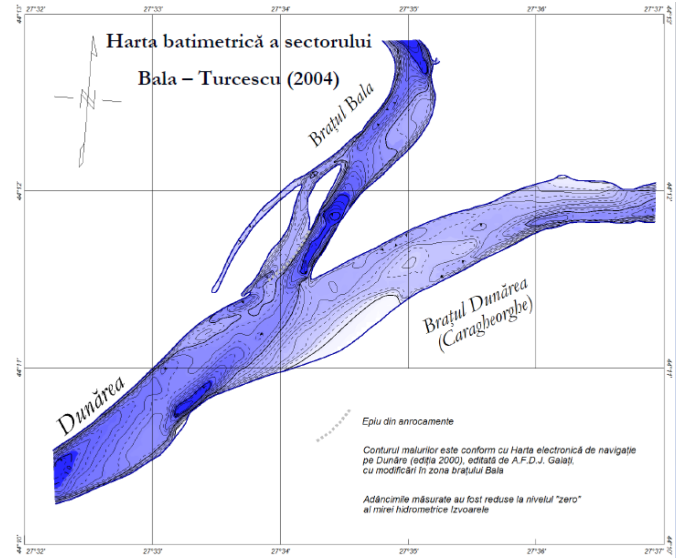

Fig. 16

In the Danube Delta, fairway of the Sulina branch is checked regularly because the alluvial deposits can create bathymetric changes in depth, unwanted movement of large ships.

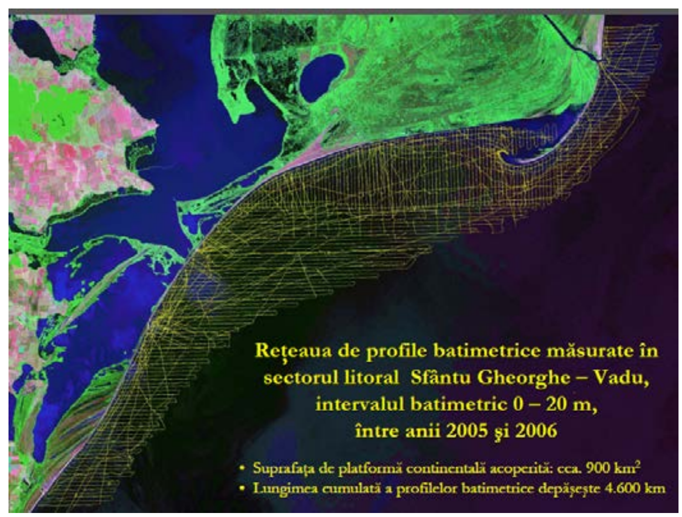

Fig. 17

At the mouth of the Danube to the Black Sea, the maritime landscape evolves according to prevailing sea currents and the volume of sediment dischargedon the 3 arms of the Danube Delta.

Therefore, was periodically investigat bathymetric, the continental platform of Black Sea coast between Sfantul Gheorghe and Vadu, an area where there is and the complex of lakes Razelm – Sinoe.

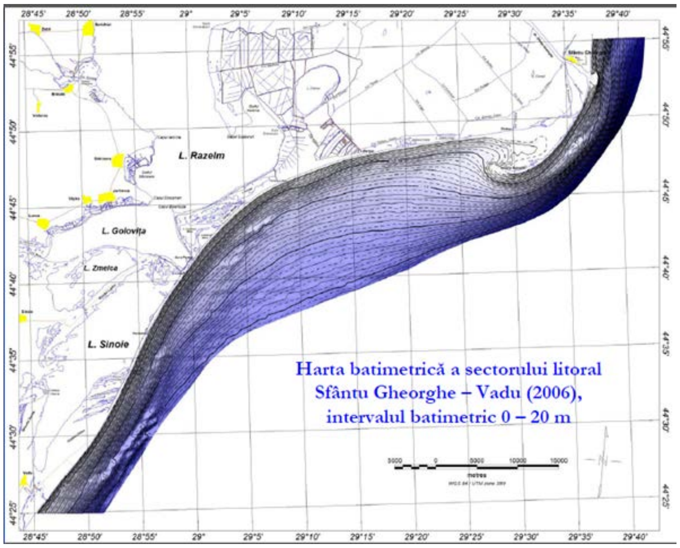

Fig. 18

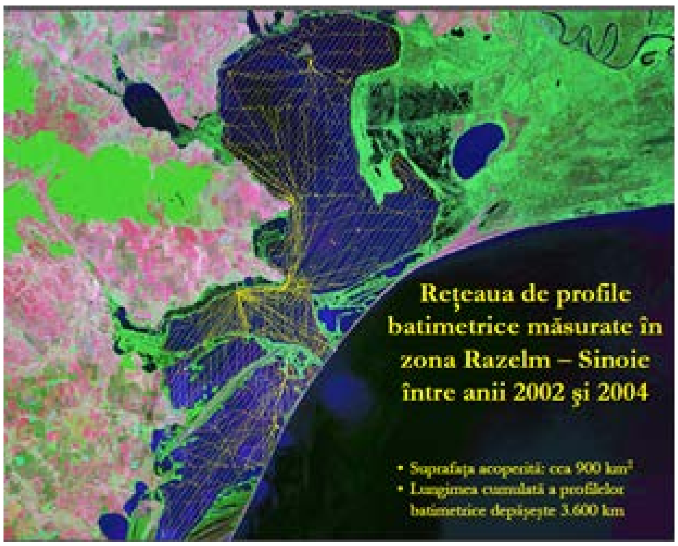

Fig. 19

Investigation of clogging to the port area or berths of commercial ships were made measurements of scans to bottom water correlated with precise GPS measurements and terrestrial laser scans in the construction areas of port, resulting accurate estimates of the dredging interventions or recovery of the immersed shipwrecks.

IV. CONCLUSIONS

The interferometry principle makes it possible to reconstruct the subsea bottom with an acceptable performance and a simple implementation to multibeam systems. Commercial MBES are already proposing high-density modes for which more than one sounding per beam can be produced, but they do not generally exceed 5 soundings per beam.

Sidescan sonars can also take advantage of in situ beam forming to solve some of the difficulties related to phase ambiguity. And processing based on the properties of the correlation coefficient permits sorting out relevant samples to reach the interesting bathymetry.

Interferometry is clearly an interesting technique that can provide high quality bathymetric data. The approach, with lengthening baselines and an increasing number of ambiguities, can reach its physical limits due to decorrelation.

To reach their potential, interferometers must be correctly designed according to the SNR level. This also suggests that largely unexplored approaches such as advanced wide band signals, nonstationary array processing, and synthetic array processing have genuine promise as ways to improve detection accuracy.

REFERENCES

[1] C. de Moustier, (1998a), “Fundamentals of echo-sounding II.” 1998 Coastal Multibeam Sonar Training Course, Darmouth, N. S., April 20-24. Lecture Notes #4. Ocean Mapping Group, Department of Geodesy and Geomatics Engineering, University of New Brunswick, Fredericton, N.B.

[2] G. Franceschetti and R. Lanari, ”Synthetic aperture radar processing”, CRC Press, 2000 Corporate Blvd. Boca Raton, FL 33431, USA, 1999.

[3] J. C. V. Jakowatz, D. E. Wahl, P. H. Eichel, D. C. Ghiglia and P. A. Thompson, ”Spotlightmode synthetic aperture radar: A signal processing approach”, Kluwer Academic Publishers, P. O. Box 17, 3300 AA Dordrecht, The Netherlands, 1996.

[4] M. P. Bruce, ”A processing requirement and resolution capability comparison of side-scan and synthetic-aperture sonars”. IEEE J. Oceanic Eng., 17(1): 106–117, 1992.

[5] A. Bellettini and M. A. Pinto, ”Theoretical accuracy of synthetic aperture sonar micronavigation using a displaced phase-center antenna”, IEEE J. Oceanic Eng., 27(4): 780–789, 2002.

[6] W. G. Carrara, R. S. Goodman and R. M. Majewski, ”Spotlight synthetic aperture radar: Signal processing algorithms”, Artech House, 685 Canton Street, Norwood, MA 02062, USA, 1995.

[7] R. F. Hanssen. ”Radar interferometry: Data interpretation and error analysis”, Kluwer Academic Publishers, P. O. Box 17, 3300 AA Dordrecht, The Netherlands, 2001.

[8] D. C. Ghiglia and M. D. Pritt, ”Two-dimensional phase unwrapping: Theory, algorithms, and software”, John Wiley & Sons, 605 Third Avenue, New York, NY 10158, USA, 1998.

[9] X. Lurton, ”An introduction to underwater acoustics: Principles and applications”, Springer Praxis Publishing, Chichester, UK, 2002.

[10] X. Lurton, ”Swath bathymetry using phase difference: Theoretical analysis of acoustical measurement precision”, IEEE J. Oceanic Eng., 25 (3): 351–363, 2000.

[11] L. Brekhovskikh and Y. Lysanov, ”Fundamentals of ocean acoustics”, volume 8 of Springer Series in electrophysics. Springer-Verlag, Berlin, Germany, 1982.

[12] R. E. Hansen, H. J. Callow, T. O. Sæbø and S. A. V. Synnes, ”Challenges in seafloor imaging and mapping with synthetic aperture sonar”, InProceedings of the Eighth European conference on synthetic aperture radar. Aachen, Germany, June 2010a. CDROM (ISBN 978-3-8007-3272-2).

[13] Ø. Hegrenæs, T. O. Sæbø, P. E. Hagen and B. Jalving, ”Horizontal mapping accuracy in hydrographic AUV surveys”, In Proceedings of the IEEE Autonomous Underwater Vehicles 2010. Monterey, CA, USA, September 2010.

[14] J. C. Novarini, and J. W. Caruthers (1998), ”A simplified approach to backscatter from a rough seafloor with sediment inhomogeneities”, IEEE Journal of Oceanic Engineering.

[15] J. E. Hughes Clarke, B. W. Danforth and P. Valentine (1997a). “Areal seabed classification using backscatter angular response at 95 kHz.” In High Frequency Acoustics in Shallow Water, Eds. N.G. Pace, E. Pouliquer, O. Bergen, and A. Lyons. Proceedings of SACLANT Conference, Lerici, Italy, 30 June to 4 July.

[16] I. Tolstoy and C. S. Clay, 1987, “Ocean Acoustics: Theory and Experiment in Underwater Sound” (The American Institute of Physics for the Acoustical Society of America).
[17] R. O. Nielsen, 1991, ”Sonar signal processing” (Artech House).
[18] R. E. Hansen, 2012, ”Introduction to sonar” (Course material to INF-GEO4310, University of Oslo).
[19] C. D. de Jong, G. Lachapelle, A. Skone and I. A. Elema. ”Hydrography”. Series on Mathematical geodesy and positioning. VSSD, Leeghwaterstraat 42, 2628 CA Delft, The Netherlands, 2002.
[20] L.Wang, A. Bellettini, R. Hollett, A. Tesei, M. Pinto, S. Chapman and K. Gade.” InSAS’00: Interferometric SAS and INS aided SAS imaging”. InProceedings of Oceans 2001 MTS/IEEE, pp. 179–187. Honolulu, HI, USA, November 2001.

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From his scientific work may be mentioned:

a) Books:

Special Topographical Surveys - CONSPRESS Publishing House, Bucharest, ISBN 978-973-100-031-2.

Topography – Course, Practical applications - CONSPRESS Publishing House, Bucharest, ISBN 978-973-100-099-2.

b) Papers:

Mathematical Models Used in Processing Measurements Made By Terrestrial Laser Scanning Technology - WSEAS & NAUN CONFERENCES - AMCME SESSION: Simulation and Modelling - Rhodes Island, Greece, July 16-19, 2013.

Displacement And Deformation Measurement Using Ground Radar Interferometry Technique - JOURNAL OF APPLIED ENGINEERING SCIENCES-Vol. 1/2013-University of Oradea Publishing House, ISSM/ISSN-L 2247-3769/e-ISSN 2284-7197, indexed by Copernicus, Ulrichsweb, INSPEC, DRJI.

Dam deformation measurements using terrestrial interferometric techniques - RevCAD 2012 - Journal of Geodesy and Cadastre, ISSN 1583-2279, "1 Decembrie 1918" University of Alba Iulia, Romania, indexed by SCIRUS, COPERNICUS.

c) Projects:

Geodesy Surveying Consultancy for the "Flood hazard maps and plan for prevention, protection and diminish the effects floods in hydrographic area Dobrogea-Seaside".

Geodesy Surveying Consultancy for the "Hazard maps and flood risk in the river system Prut-Bārlad".

Monitoring SFT (Sludge Fermentation Tanks) structures from the wastewater treatment plant Glina-Bucharest by topographic and geodetic activities.