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Karolina Zwolak[1]

UNDERWATER OBJECTS' DETECTION SYSTEM CHOICE FOR HARBOR SURVEILLANCE PURPOSES

ABSTRACT

The paper presents an analysis of various hydrographic systems, in order to find the most suitable set of equipment for hydroacoustic harbor surveillance system. Singe beam and multibeam echosounders, sweep systems, sidescan sonars, scanning sonars, interferometric sonars and underwater vehicles were analyzed in terms of their usefulness for mentioned purpose. The preferred hydroacoustic systems were chosen based on the analysis results.

Key words:
harbor surveillance system, hydroacoustic systems, hydrographic equipment.

INTRODUCTION

The importance of maritime transport in the modern economy causes the strong need of ensuring an appropriate harbors' security level. This includes an access control to the harbor areas, not only from land, but also from waterside. The second option may be really problematic. Surface vessels' traffic is closely controlled; any suspected activity can be relatively easily detected. Successful underwater surveillance is much more difficult to achieve.

Surveillance systems available on market are focused on the possibility of detecting a diver or underwater vehicle trespassing to the port area of. This, however, does not guarantee complete protection from the threat from below a water

[1] Hydrographic Support Squadron of the Polish Navy, Rondo Bitwy pod Oliwą Str., 81-103 Gdynia, Poland; email: karolina.zwolak1@gmail.com

surface. For example, an object which may pose a threat (for example an improvised explosive device) can be placed at the bottom of the harbor basin from the deck of a vessel that has already entered the port. The potential impact of such an event is described in [4].

The concept of a harbor surveillance system, based on a comparison of sonographs obtained at different points of time was established in Polish Naval Academy [5]. This would allow detecting new objects of an unknown origin at the harbor basin bottom, which can be dangerous.

The important stage of the system development is a choice of data gathering equipment. This requires the analysis of modern survey equipment capabilities and the conditions in which the developed system will work. Relatively small depths of harbor areas must be taken into account. The boundary between a shallow and deep water reservoir is not strictly defined. In the context of the paper the shallow water means a depth range of a few to about 20 meters.

The paper presents an overview of the hydrographic survey systems in the context of their suitability for the detection of potentially dangerous objects in hydroacoustic harbor surveillance system.

MULTIBEAM ECHOSOUNDERS

Multibeam echosounders (MBES) recently dominated the modern hydrography. The idea of this type of devices is based on a use of two orthogonally disposed transducers. The transmitting transducer generates an acoustic beam wide in the plane perpendicular to the direction measuring unit and narrow in a plane parallel to it. The receiving transducer, placed perpendicularly to the transmitting one can receive an acoustic signal reflected from the bottom within a narrow angle in a plane perpendicular to the survey line (fig. 1) [12]. A single acoustic beam is actually a ‘virtual’ beam formed by the emitter and receiver [6]. The use of carefully selected phase delays for individual transducer elements causes the effect of ‘sensitivity’ of the receiver for the signal reflected from a specific direction. A single set of delays applied to the signal received by the individual transducer elements generates a depth value for the specified ‘virtual’ beam. Depending on the model, the echosounder generates from tens to hundreds of beams. With this configuration, the reception of a single acoustic pulse (after taking into account the information about the sound speed profile in the water column) results in obtaining a number of depth values arranged approximately along a line perpendicular to the survey line. The exact layout of the soundings depends on the algorithms used for motion compensation [11].

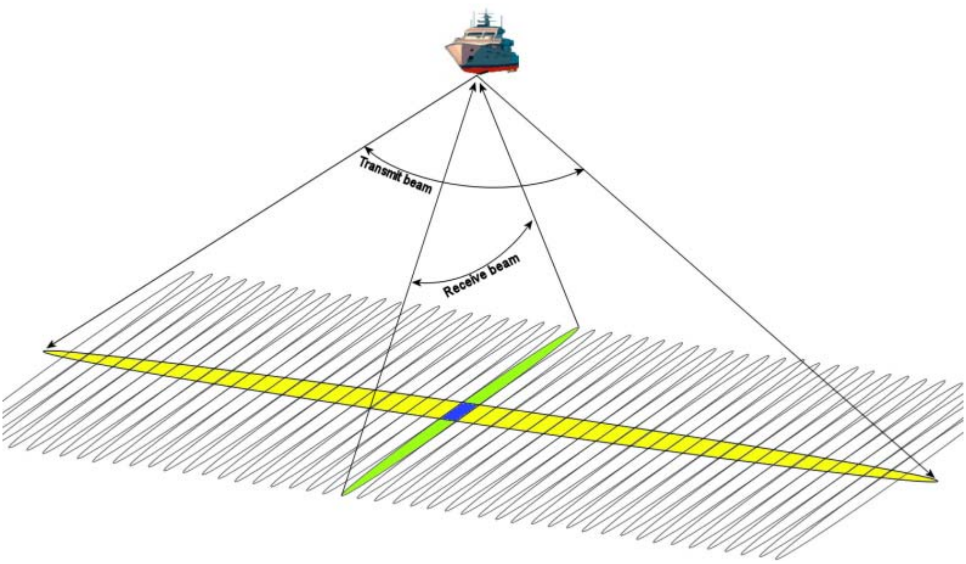


Fig. 1. Multibeam echosounder principle

Source: http://www.amloceanographic.com/CTD-Sound-Velocity-Environmental-Instrumentation-Home/Multibeam-Overvew, [access 23.11. 2013].

A large number of soundings obtained from each acoustic pulse determine the high efficiency of multibeam data acquisition. Bathymetric data from multibeam echosounder are characterized by high horizontal and vertical accuracy, mostly because of a use of motion compensation as well as a distribution of the sound speed in the process of depth calculation. Models available for measurement errors estimation, implemented in hydrographic software allows estimating values of uncertainties for depths obtained by multibeam echosounder [6].

Can be then MBES called 'a perfect device'? First of all, because of an advance technology and the system complexity, they are relatively expensive. Therefore they are not easily available for some institutions. In addition, MBES survey requires an access to the additional equipment for measuring the sound speed profiles. Moreover, vessel motion parameters must be accurately measured, recorded and analyzed in the echosounder system in a real time.

The sonar swath is a function of water depth; the lower the depth, the narrower area is ensonified during a single pass on the survey line. The use of a multibeam echosounder in very shallow water in this situation is questionable. The risk of the expensive equipment damage at very shallow water may be not balanced by the profit of survey efficiency compared to the single beam echosounder.

Multibeam echosounder is designed for surveying generally in deeper waters. Can it be used for the small objects detection in shallow waters? The size of objects in relation to the density of data points is essential here.

Figure 2 shows a three-dimensional model created based on the bathymetric data obtained using Kongsberg EM2040 multibeam echosounder, in the Atlantic Ocean off the coast of New Hampshire, USA. Measurements were carried out during the 'Summer Hydrography Field Course 2013', the practical part of the 'Postgraduate Certificate in Ocean bathymetry' course under the 'GEBCO and Nippon Foundation Training Project'. The survey was carried out on the waters with a depth of approximately 12 m. The area is used by local fishermen to catch lobsters using traps, similar to those shown in figure 2. They are usually placed in straight lines. The metal structure of such a trap generates strong acoustic echo. The length of this type of trap is generally higher than 1 m, so they are quite large in the context of objects, which should be detectable by the hydroacoustic surveillance system.

Figure 2 presents regularly arranged objects, which are clearly visible on the flat area of the sea bed. In this case, a multibeam echosounder easily detected objects on the bottom. However, horizontal resolution of multibeam bathymetric data decreases with increasing depth, while at shallower depths the use of multibeam echosounder encounter difficulties, as mentioned above (low efficiency and the risk of damage).

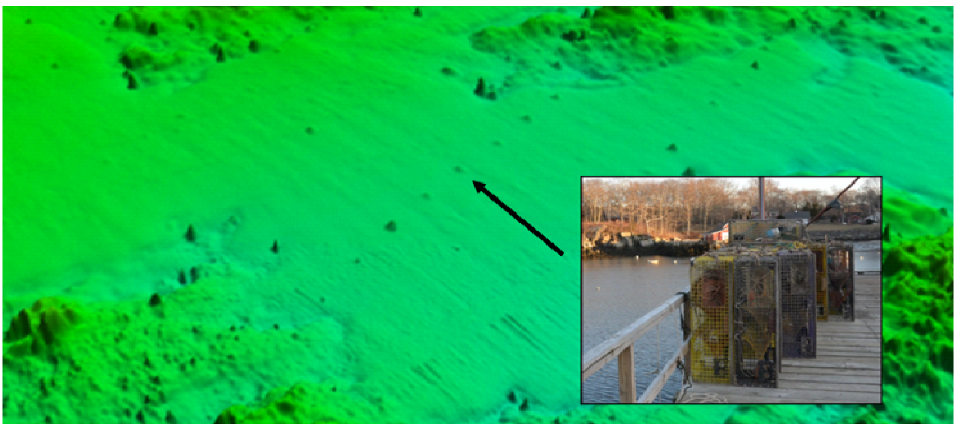


Fig. 2. 3D sea bed visualization with 5-times vertical exaggeration used; regularly arranged objects are clearly visible on the flat area of the sea bed

Source: bathymetric data [7], picture by author.

SINGLE BEAM ECHOSOUNDERS

Single beam echosounders are the most common hydroacoustic devices used for bathymetric measurements. They are available in different types. One of the most important characteristic is a beam width, which is wide in affordable amateur fishing echosounders and navigation equipment and gets narrow in precise hydrographic sonar (replaced by multibeam echosounders, with reservations previously discussed). In some sources, oceanographic or special purpose echosounders are mentioned as a separate type of echosounders [10].

If a vessel is not equipped with motion parameters registration system, an impact of roll and heave may be significant in case of narrow beam. In most cases, it is considered that the roll angle is compensated by the beam width, which is true for most navigational echosounders, but rather not for survey equipment (fig. 3a) [6].

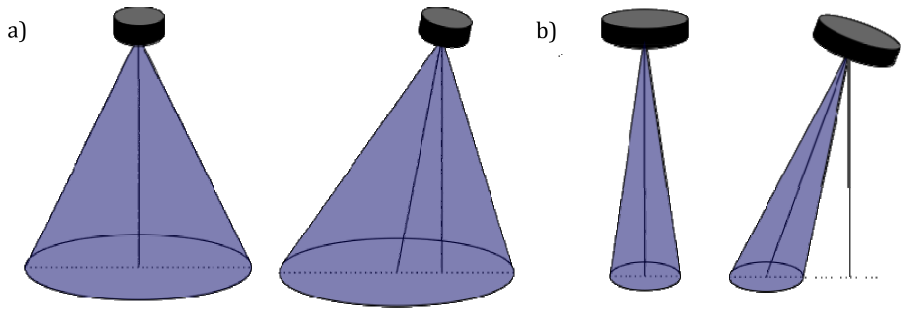


Fig. 3. The correspondence between beam width and transducer roll impact:
a) roll is compensated by beam width, b) the difference between measured and true depth is caused by roll impact not compensated by beam width [6]

Single beam echosounder does not allow to determine the exact direction of the reflected acoustic wave; therefore, it is not possible to determine if the indicated. Depth value corresponds with the point directly below the transducer. Single beam echosounder, by acoustic wave two way travel time measurement, indicates only the smallest depth within an emitted beam. The device operates in some way a lowpass filter, not recording deeper areas within an acoustic footprint [6]. It is not a problem from a navigational point of view because the shallow areas detection is essential. However, the device's principle of operation does not allow detecting small objects on the bottom.

SWEEP SYSTEMS

The problem of low efficiency of hydrographic measurements in shallow waters has been addressed by the introduction of the so-called sweep systems. They are series of single beam echo sounders placed on a structure perpendicular to the movement direction of the survey vessel.

While such a solution provides a large swath width regardless of depth, the assumptions of the system generate a lot of problems. First of all, this system requires an installation of a structure to mount echosounders, which significantly impedes the maneuverability and makes the vessel very sensitive to higher sea states. In addition, the fact that a single echosounder records the smallest depth within its footprint, can lead to a situation in which several adjacent sonars actually captures the same depth, which makes the results very difficult to interpret.

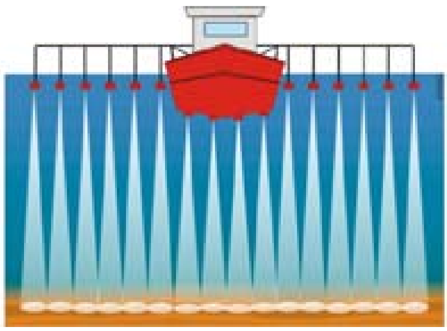


Fig. 4. Sweep system's principle

Source: http://www.km.kongsberg.com/ks/web/nokbg0240.nsf/AllWeb/531E2BBCC30DDDD4C1256 DFA004CBB1D?OpenDocument.

SIDE SCAN SONARS

Some geologists and geophysicists consider an opinion that the side scan sonars are no longer necessary, since there are multibeam echosounders available. Side scan sonar data used to evaluate the bottom type can be replaced by the backscatter level from multibeam echosounders, providing also the bathymetric data. Does such an opinion can be shared by a hydrographer, whose main purpose is to detect obstacles to navigation or small objects on the bottom of the harbor basin?

The requirements of the American National Ocean Service [13] suggest side scan sonar survey with 100% or 200% coverage, in addition to the multibeam bathymetric measurements. Side scan sonar takes an advantage from optimal signal geometry, obtained because of the proper sonar height above the sea bed. It also provides a high-resolution data increasing a probability of detecting objects on the sea bed. This type of data is particularly valuable during bathymetric survey with single beam echosounder, providing information about the bottom between survey lines. It can also be used in addition to multibeam survey to verify data or for object identification [13].

The specificity of side scan sonar surveying is described in detail in numerous publications. Mosaicing process is presented in [2]. Side scan sonar tests in a harbor basin, in an unusual configuration were presented in [9]. Sonar was fixedly attached to the hull of the vessel. Considering quite shallow depths, the geometry of the system was acceptable, despite the limited possibilities of adjusting the height of the sonar above the bottom. The results presented in this publication are the evidence of a possibility of successful use of side scan sonar in shallow, limited waters of dock areas.

Figure 5 shows examples of the sonar images obtained in the area of Gdynia marina using towed side scan sonar EdgeTech 272-TD. Because of high resolution of obtained images and a presence of acoustic shadows, carrying information about the shapes of objects, sidescan sonar seems to be a preferable device for sea bed objects detection.

a) b) c)

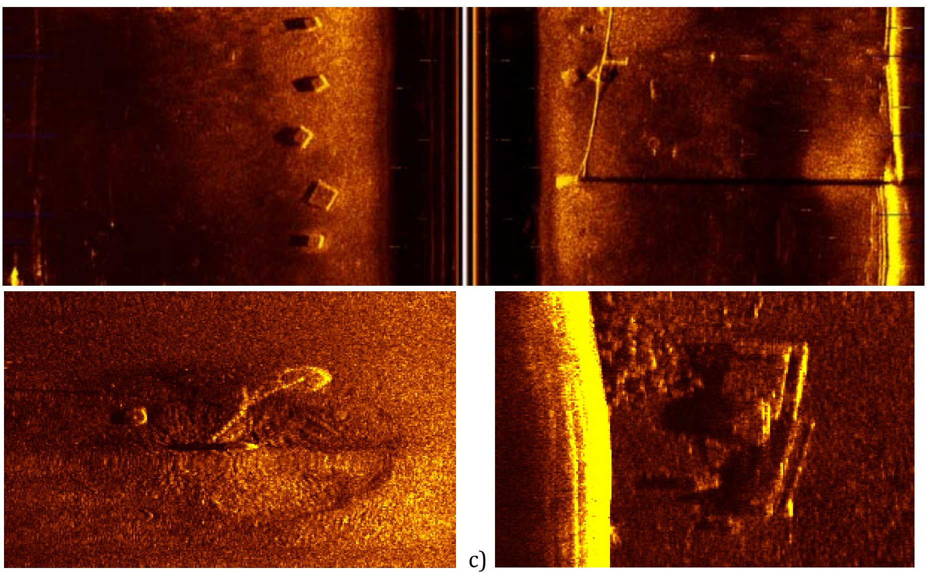
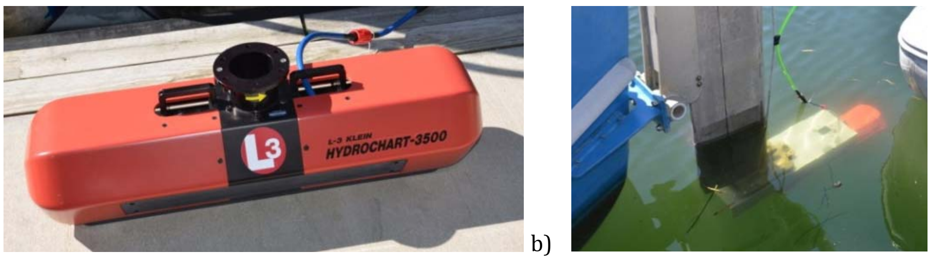


Fig. 5. Examples of side scan sonar: a) pier construction elements in Gdynia marina, b) buoy an chor, c) an object close to the breakwater

INTERFEROMETRIC SONARS

Interferometric sonar is a device combining the advantages of sidescan sonar (obtaining high-resolution sonographs) with the ability to measure depths, providing data in some way comparable with multibeam echosounder measurements. The phenomenon of interferometry (measuring the phase difference of signals received by a series of three parallel arranged transducers) is used in this kind of equipment. An example of the interferometric sonar (Hydrochart-3500 from L3) is shown in figure 6.



a) b)

Fig. 6. Interferometric sonar Hydrochart-3500 onshore (a) and on the vessel bow frame (b)

Reliable measurements of depth values exclude the possibility of towing sonar behind a vessel. It is necessary to attach the device to a hull, which in case of larger water depths may cause the poor signal geometry. Use of the construction which allows making adjustments of the sonar draft (similar to this presented in fig. 6b) enables enhancing system geometry. It may not be sufficient in shallow waters, but the adjustment range is still smaller than in the case of towed sonar.

The use of interferometric sonar for small objects detection (or use it as a side sonar) is objectionable because of the limited possibility of ensuring sonar optimum height above the bottom. However, from the point of view of data acquisition for scientific purposes, the possibility of obtaining various data types using a compact unit is extremely valuable. Interferometry technique is still being developed. Interferometric devices provide more and more accurate bathymetric measurements combined with the acquisition of sonograms, which probably will strengthen the position of the interferometric sonars in near future.

SCANNING SONARS

The principle of operation of scanning sonars is similar to the sidescan sonars, but its design, based on a rotating acoustic transducer, gives radar-like looking sonographs. The whole device does not move during measurement, excluding rotating transducer array. Examples of data obtained by scanning sonar can be found in [3].

High-frequency scanning sonar, working on relatively small ranges, allows obtaining very high resolution images, which can be used for objects identification. Lower surveying efficiency, caused by the fact that scanning is performed in one stationary point at one time, speaks for choosing rather towed sidescan sonar, as a prime data acquisition device in the hydroacoustic harbor surveillance system.

UNDERWATER VEHICLES

Underwater vehicles in modern hydrography perform a number of functions. The traditional classification distinguishes two main groups of underwater vehicles:

- AUVs (Autonomous Underwater Vehicles) — carrying out programmed functions without operator intervention;
- ROVs (Remotely Operated Vehicles) — submersible vehicles externally powered and controlled by an operator from the onshore or a vessel.

In [1] UUVs (Unmanned Untethered Vehicles) are listed as a third category of underwater vehicles. They are characterized by its own power supply, but requiring operator intervention during the execution of the task. Other sources, however, treat the UUVs as a wide a group of underwater vehicles, especially in military applications, explaining the abbreviation as Unmanned Underwater Vehicles.

This division takes into account mainly the method of control during an operation. Classification according to the implemented functions may be not so clear. Underwater vehicle can be understood as a carrier for data acquisition devices. The change of installed devices is available in some models, and thus the change of functions. A modular underwater vehicle GAVIA can be an example. It can be alternatively equipped for example with sidescan sonar, interferometric sonar or sub bottom profiler [8].

Underwater vehicles, depending on their technical characteristics, can be used in various depth ranges, from shallow waters to the depths of the oceans. Kaiko 7000II from Japan Agency for Marine-Earth Science and Technology (JAMSTEC) is dedicated to work at depths of up to 7000 m. In the testing phase in 1995, at the Challenger Deep, Kaiko dived to a depth of 10 911.4 m [14]. However, from the surveillance system point of view, installed devices, not the high operation depth, is crucial for the system choice decision.

Underwater vehicle equipped with high-resolution sidescan sonar and precise navigation system could be used in hydroacoustic harbor surveillance system for images acquisition and subsequent detection of potentially dangerous objects. However, the methodology of underwater vehicle use in surveillance harbor system must be elaborated.

Underwater vehicles are usually equipped with a camera, which provides a perfect solution for flawless object identification, but its range (depending on the optical properties of water) is usually significantly smaller than the range of hydroacoustic device.

SUMMARY

Side scan sonar is chosen as a preferred data acquisition system for hydroacoustic surveillance system purposes. It should maximize the possibility of object detection on the bottom of controlled harbor area. The geometry of the system ensures the optimal acoustic beam use, dedicated to obtaining sonographs, ensuring the possibility of object detection and recognition.

Scanning sonar and underwater vehicle may be used as tools for detected object identification, creating a complete hydroacoustic surveillance system.

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WYBÓR SYSTEMU DETEKCJI OBIEKTÓW PODWODNYCH DLA POTRZEB HYDROAKUSTYCZNEGO SYSTEMU KONTROLI DNA AKWENÓW PORTOWYCH

STRESZCZENIE

W artykule przedstawiono analizę różnorodnych systemów hydrograficznych pod kątem możliwości ich wykorzystania w hydroakustycznym systemie kontroli dna akwenów portowych. Analiza obejmuje echosondy jedno- i wielowiązkowe, systemy wieloprzetwornikowe, sonary boczne i skanujące, sonary interferometryczne oraz pojazdy podwodne. W oparciu o ich charakterystykę i sposób użycia wskazano systemy hydroakustyczne preferowane do detekcji obiektów w ramach kontroli dna akwenów portowych.

Słowa kluczowe:
ochrona portu morskiego, systemy hydrograficzne, urządzenia hydrograficzne.