DE GRUYTER
OPEN

Reports on Geodesy and Geoinformatics vol. 100/2016; pp. 55-65 DOI:10.1515/rgg-2016-0006

Review article

THE PROBLEM OF THE INSTRUMENT STABILIZATION DURING HYDROGRAPHIC MEASUREMENTS

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Abstract

Performing any measurement on watercraft is connected with many additional difficulties caused by the sea-environment. The most important is the problem of spatial stabilization of measurement systems, which are usually fastened to craft body. As soon as usually these measurement are executed during the move of the craft additional question is the accuracy of execution the planed trajectory.
This is a problem for all investigators, especially when system use spatially configured beams of any antennas or other sensors, regardless is it receiving or transmitting one.
Different aspects of these question are the subject of research activity of Institute of Navigation and Maritime Hydrography of Polish Naval Academy. In this paper the review of works executed in last years are presented.

Keywords: *Hydrography, Measurements, Stabilization, Ship*

1. General information

Seas and oceans are covering 3/4 of the globe surface, however they are still insufficiently examined regardless of this how intense we use their in our everyday life.

A reason of this state are difficulties, on which we meet when performing such measurement. Except many technical reasons we are talking about difficulties of moving the ship along the planned trajectory, and also about problems which are a consequence of waved surface of the sea. Let us notice that each parameters of the movement which is talked about mean the vector of the movement of the ship when is treated as kinematic point. However do not mean his spatial orientation. In many cases, especially when it moves slowly, ship is oriented in different direction (Heading - HDG) than its vector of movement (Course Over Ground - COG) (see fig. 1).

Additionally we should take into account the orientation and movement of the hull as an result of the environment influence (see fig. 2).

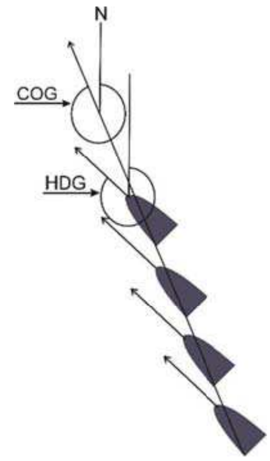

Fig. 1. Ship's orientation versus its movement.

We can divide it into two groups:

- lineal movements: heave, sway and surge;
- angular movements: yaw, pitch and roll.

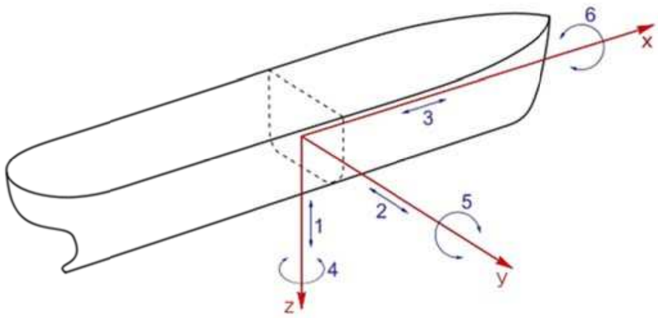

Fig. 2. Ship movements:

1 – heave, 2 – sway, 3 – surge, 4 – yaw, 5 – pitch, 6 – roll.

From among various cases of investigations performed aboard, in this paper we will consider only bathymetric, which are commonly executed in hydroacoustic domain. Measuring-systems available on market can be divided into main three groups: Single Beam Echosounder, Multibeam Echosounder and Side Scan Sonars. Movement of the ship will influence in different manner on each systems. Let we look on SBES and MBES only.

1.1 Single beam echosounders

Single beam echosounders (SBES) are the most common hydroacoustic devices used not only for bathymetric measurements. The most important characteristic of the SBES is a beam width, which is wide in fishing and navigation equipment and narrow in precise hydrographic one. Navigation or fishing devices are not sensitive on ship's hull movement, as width of the beam should be bigger than the angle of ship's motion in contrary to survey devices which are very sensitive for this.

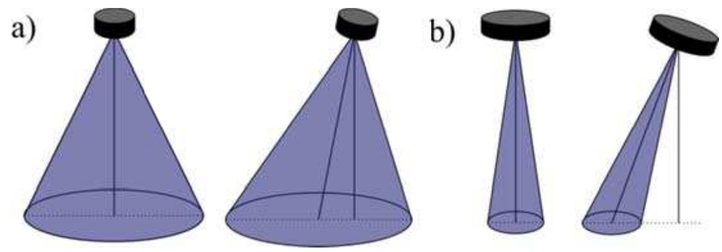

Fig. 3. The correspondence between beam width and transducer pitch/roll impact:
a) Roll is compensated by beam width. b) The difference between measured and true depth (Dijkstra et all, 2013).

1.2 Multibeam echosounders

Multibeam echosounders (MBES) are the newest tendency in hydroacoustic survey and are still more and more common. The idea of this kind of hydroacoustic devices is based on a use of two orthogonally arranged transducers, one as transmitting and second as receiving one. The transmitting transducer generates an acoustic beam wide in the plane perpendicular to the direction of the craft and narrow in a plane parallel to it. The second one can receive an acoustic signal reflected from the bottom within a narrow angle in a plane perpendicular to the survey line (Fig. 4) [Multibeam Sonar, 2000]. Finally MBES can provide measurements in many individual points of the sea bottom as combination of transmitting and receiving beams create a "virtual" beams by sweeping the wide receiving sector. This is performed by technics of phase steering each element of receiving antenna. Different MBES can generate from tens to hundreds of receiving beams.

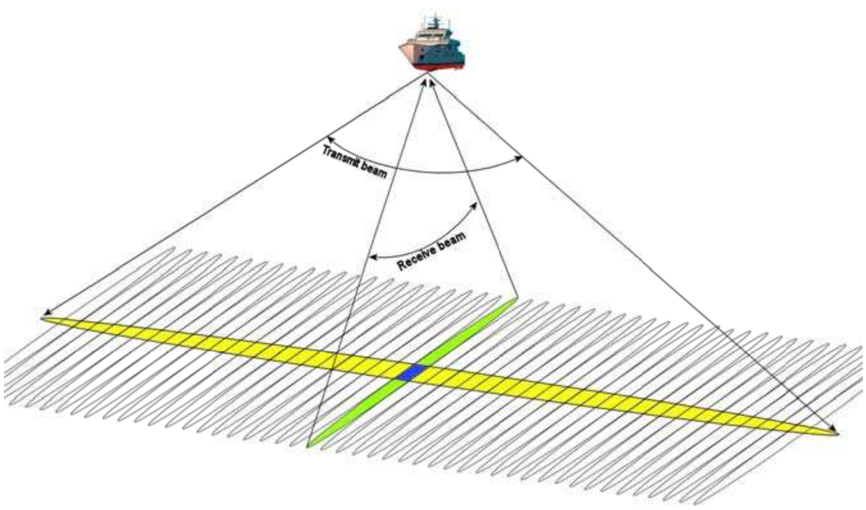

Fig. 4. Multibeam echosounder principle.
(Source: http://www.amloceanographic.com/CTD-Sound-Velocity-Environmental-Instrumentation-Home/Multibeam-Overvew, access 22.04.2016)

A large number of beams determine the high efficiency of data acquisition. Bathymetric data from MBES echosounder are characterized by high horizontal and vertical accuracy. However similar to SBES this system is sensitive on craft motion and commonly are equipped in motion compensation devices.

1.3 Influence of craft motion on bathymetric data

Every object when moving must be supported with the information about the spatial orientation. In case of water craft the question is easier than in case of airplane, as usually water object has natural tendency to take horizontal position. However still decision concerning the direction of the movement can be taken only on the basis of some azimuthal information. For many hundreds years we use magnetic compasses for this, although now many users even does not know that their electronic device is in reality a magnetic compass. This is very complex question, especially in the context of magnetic deviation taking into account. For this see (Felski, 1999a, 2007a, 2007b, 2007c, 2008, 2014; Felski & Przepióra, 1999; Przepióra, 1998).

In turn on sea-going ships for last hundred years such role play gyroscopic compass. Research led in PNA prove that present compasses capabilities, both magnetic and gyro ones, became problematical. The course error of the magnetic compasses beside of their construction is about 1^0, because of accuracy of the deviation and magnetic declination information. As well, the gyrocompasses have similar accuracy, but the course error is an effect of the ship's movement. Its amplitude is variable, particularly after end of ship maneuvers.

In addition to mentioned before, nowadays so-called GPS-compasses becomes more and more popular. This aspect will be discussed later. However all kind of compasse at the moment characterize themselves with the accuracy about 1 deg.

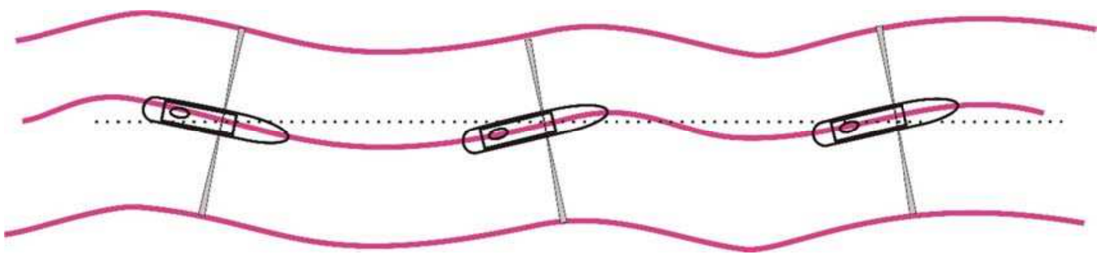

Fig. 5. Influence of compass oscillation on path of the ship and on shape of zone monitored by means of Multibeam echosounder.

Such accuracies are enough for controlling the movement of the ship down the planned trajectory, however dynamical properties of the standard gyrocompass, in fact its long period of own oscillations (84 min) take effect of sinusoidal, not straight move. This fact can be corrected by frequent correction of the craft position.

More complex problem gets out of space orientation of the craft. Pitch and roll of the craft take effect of error in measured depth because of wrong direction of the measure, but also give us distance to different point on the bottom, not this one which is situated vertically under the watercraft. From this point of view surveying craft should be stabilized, but it is impossible.

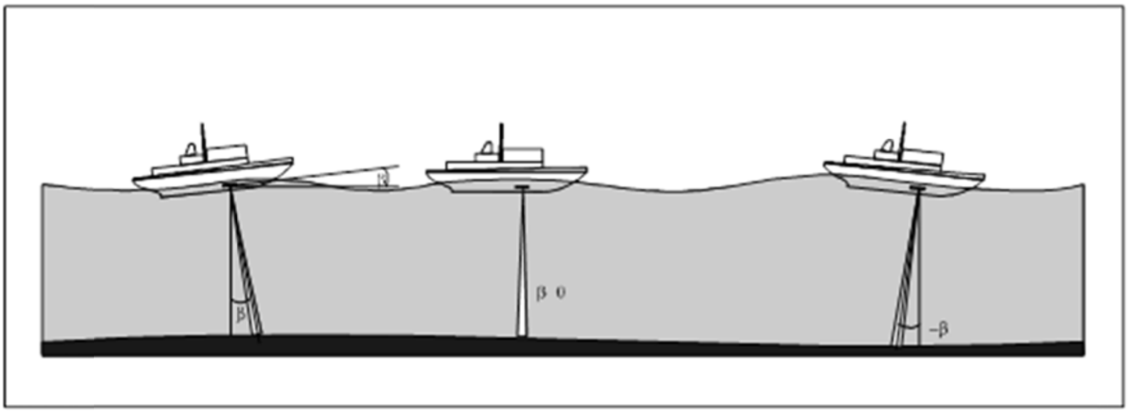

Fig. 6. Influence of pitch on accuracy of bathymetric measurements.

Only, what can be made is to perform the measurements when the sea is not waved, however this is not always possible. So there were undertaken attempts to stabilize echosounder transducers mechanically, but it need the complicated mechanism and a lot of energy. More convenient is analytical method which consist in measuring pitch and roll angles and correcting the measurement analytically.

Space orientation of a sounding craft can be described by different parameters: space orientation angles, Euler's angles, direction cosines, quaternions, Cayley-Klein's parameters and pitching and rolling angles. The last one are the most natural for vessels and they are the most frequently used. Nowadays hydrographic ship or underwater vehicle is equipped with additional inertial device which can be called on the different manner. The most common are: Motion Reference Unit (MRU), Inertial Measurement Unit (IMU) or Attitude Heading & Reference Unit (AHRS). Sometime the term "Inertial Navigation System" is in use, however this is more complex device which can present to the user information not only about spatial orientation of the craft, but in addition craft position coordinates in Earth system.

The commonly used MRU are built on the basis of laser gyros and can measure Roll and Pitch angles with accuracy of 0,01-0,08 deg. and Heavy with accuracy in 5cm. Unfortunately they cost very much, so still exist interest to find out some new devices.

2. Satellite technologies in fixing the spatial orientation.

The idea of using the GPS data to acquire heading information appeared in end of eighties. It was presented already (Schenke & Wubena, 1992) during scientific research in polar areas with MBES. We should remember that in polar area none of compass' types works properly. Investigation of that type of solution was accomplished also in Polish Naval Academy (Felski, 1998, 1999b; Felski & Męsikowski, 1999, 2000) partly in cooperation with Warsaw University of Technology (Felski et al. 2000). One of the investigated aims was a trial of preparing an inexpensive frame of reference to investigate the ship's compasses' parameters in dynamic conditions.

The basic idea of this kind of measurements is based on appointing at least two points that are distributed on the ship. Such positioning information enable to calculate the direction of vector that joins both antennas and if its arrangement in relation to the hull of the ship is known, possibility of hull's orientation is easy to recognize. It was proved that using a base not smaller than 5m it is able to obtain accuracy in measured angles about $0{,}05^0$. Lately also were acted tests of the use EGNOS to such assignments (Nowak & Naus, 2014). According to official information accuracy of EGNOS system is about 3m. During sea trials we have difficulties in establishing some reference points, however in case of multi-points experiments (more than one receiver on the ship) precise information about distances between antennas can serve as cross reference information. For example this distances can be measured in advance with laser technique. So differences between distances calculated on the basis of EGNOS fixing can be use as indicator of quality of calculated directions.

Experiments on board of the ships shows that accuracy of relative position fixed with the same type of EGNOS receiver give us enough accurate distances, so the same will be with directions. In the fig. 7 example of such results is presented when distance between antennas was 33m. During 53000 sec only few single occurrences was observed when relative positions was differ more than 10 cm and mean error of direction computed on this basis was no more than 0,2 deg.

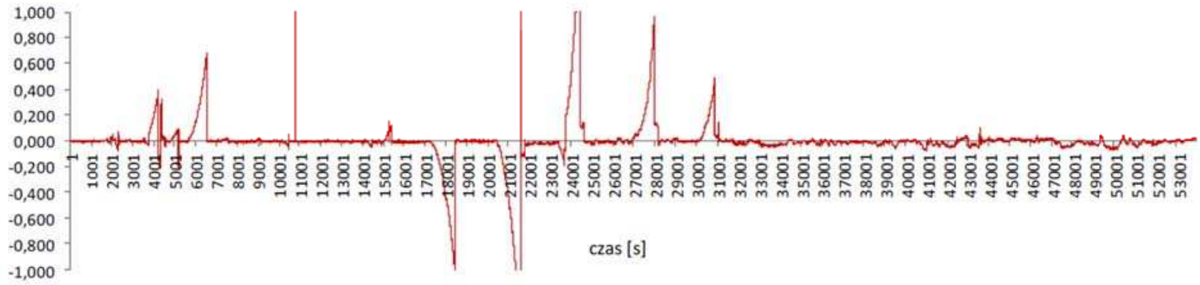

Fig. 7. Example of differences (in meters) between distances calculated on the basis of EGNOS fixes versus measured with laser (Nowak & Naus, 2014).

It should be stressed that if error of computed heading is proportional to the GPS error, especially important is information, that the frequency of its changes is rather high and is similar to GPS fixes behavior. So conclusion from this investigation is, that the method of calculating the spatial orientation of the object on the basis of GPS fixes should be supported by filtration algorithm.

This idea became developed as the satellite compass which is more and more often in use on small surveying crafts. The satellite compass is a specific set of GPS-RTK receivers which basing on phase measurement, computing the vector connecting both antennas of the device. Usually they are into the common casing which is in the permanent manner fasten aboard, so mark heading of the ship. The most common solutions appear with two antennas, however happen also solutions of three, and even four-antennas. The system of two antennas makes possible the settlement of two degrees of the freedom of the vector (the heading and the pitch or roll), depending on the manner of fastening of the antenna to the ship. More antennas makes possible the settlement of full information about the angles of spatial orientation.

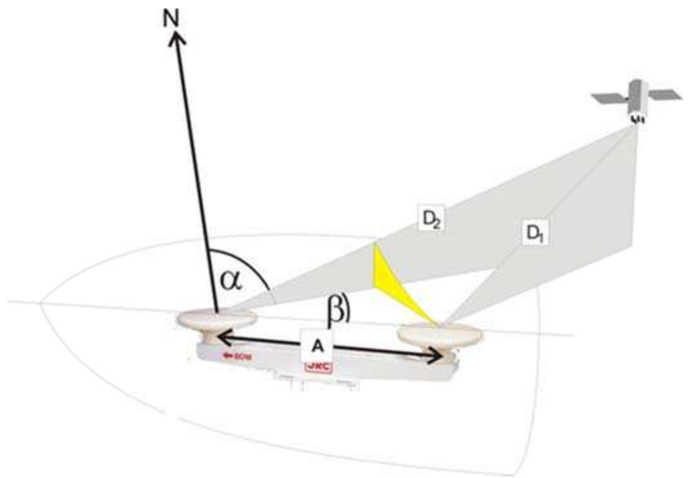

Fig. 8. The idea of measurement with the satellite compass (Różański & Felski, 2013).

Let us found that the signal from the satellite is received by two antennas situated in the line which is parallel to the plane of watercraft symmetry. The difference of the pseudo-distance from antennas to the satellite *(D2-D1)* when we know length of the base *(A)* gives the possibility to count the angle (*β)* between diametrical line of the watercraft and the projection of the difference (D2-D1) on the surface of the horizon (Różański & Felski, 2013). In the reality receiver makes similar calculations in relation to many satellites and makes settlements so calculated values. Some compasses are additionally equipped with the inertial sensor permitting to count also the amplitude of moving the antenna in the vertical direction.

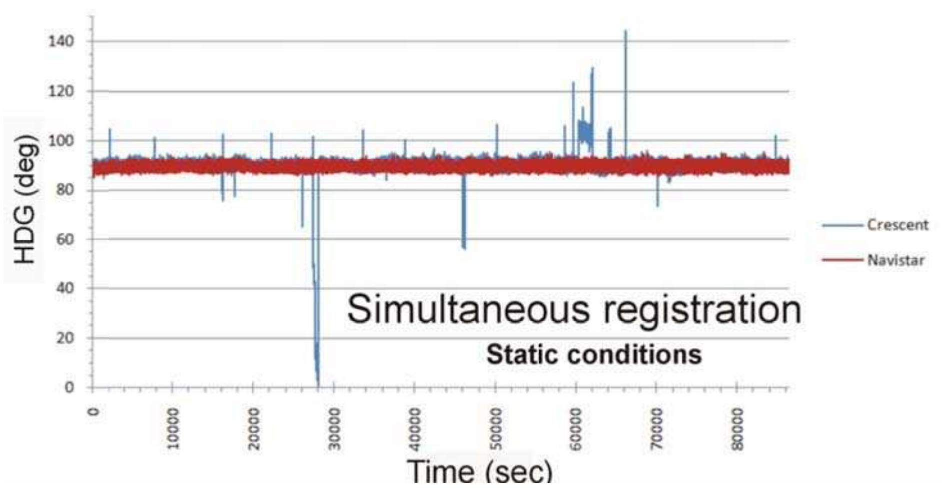

Fig. 9. The idea of measurement with the satellite compass (Felski, 2011).

For the radio-technique the occurrence of disappearances of the signal is characteristic what in the case of the satellite compass can lead to the inadmissible discontinuity in marking of the heading. Different types of GPS compasses has different solutions and example of this can be seen in fig. 9, when some registration performed in static condition with two different devises is presented. In that case the decision about the choice of the suitable device should be preceded with exhaustive analysis.

3. Visual technologies in fixing the spatial orientation.

In recent years image recognition and its use as a primary source of information about the environment is the subject of numerous studies especially in the field of photogrammetry and robotics – interdisciplinary field of knowledge, acting on the contact mechanics, automation, electronics, cybernetics and computer science. Doubtless this is the result of the development of the technology of cheap Charge Coupled Device (CCD) cameras. For Navigation particularly noteworthy are studies on active visual information analysis and examination of the use of omnidirectional camera for positioning. Simultaneously is driven works over the measurement of angles of watercraft inclination basing on the camera CCD image.

It was mentioned before, that usually the value of pitching and rolling angles is measured using accelerometer methods. Research effected in PNA showed that cameras CCD attributes will permit to build the suitable system. This system should detect edges on the camera picture, however if the noise is extracted before. The presented method is the new one and can be alternative in the future with relation to methods used nowadays.

The system consists of measuring unit (formed by two video cameras) and video processing one (formed by PC computer with the dedicated software). For proper work the system should be placed on the vessel in such manner, that optical axes of cameras should be located in vessel's construction planes (symmetry plane and midship one) and they should be directed to the horizontal line. In the prototype application two models of processing the picture have been used. Extracting of noise from the picture is carried out using modified version of the Gauss' filter (Naus & Makar, 2005). Detection of edges is carried out using the differential (gradient) method, which works on the basis of the vertical component of the picture (value of the particle derivate). Determination of the value of the gradient only in this direction has been done for elimination vertical edges and emphasis horizontal one (or nearly horizontal), among of witch the horizontal edge was located.

Determination of the direction of the horizontal line is obteined in folloowing steps:

- Searching in the processed picture the set pixels, which create the line and which sum of values is the highest;
- On the basis of them, the angle between the found line and the horizontal edge is determined.

For the stern camera the angle fulfills rolling and for the beam camera the angle fulfills pitching of the vessel.

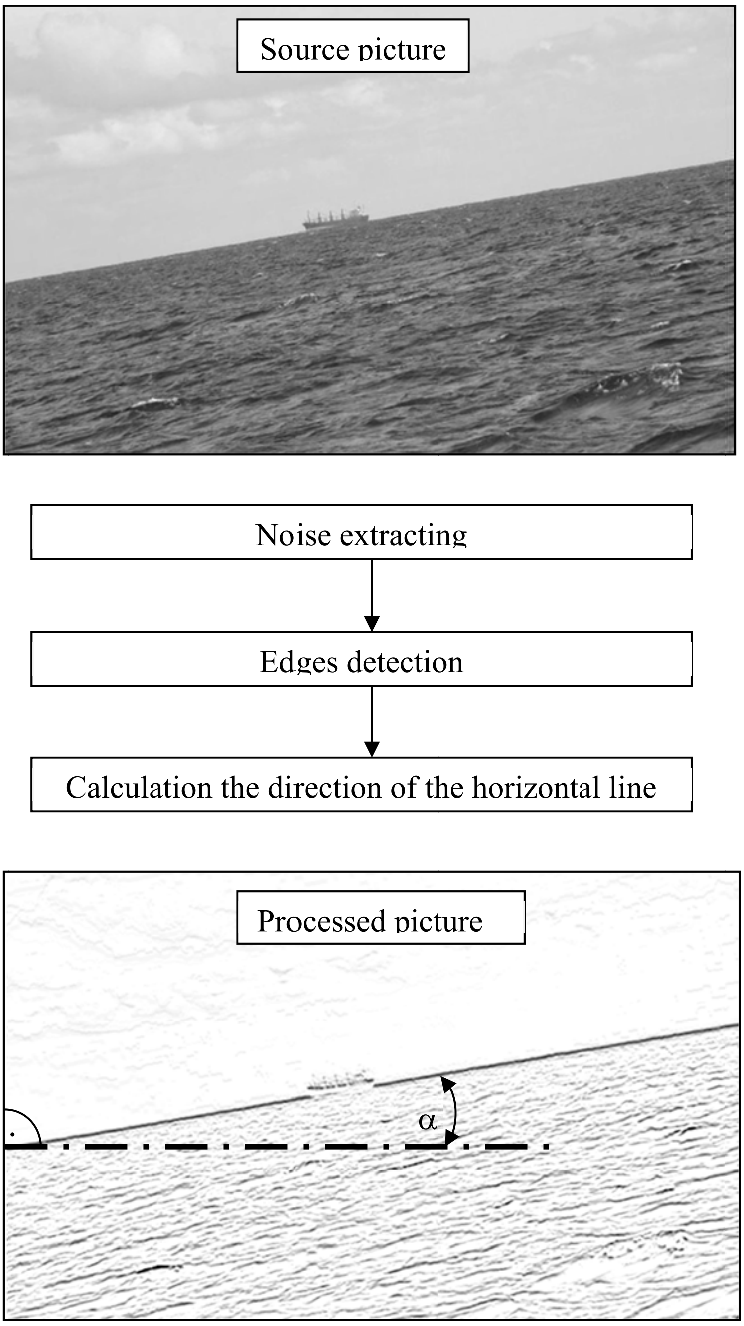

Fig. 10. The idea of Pitch\Roll calculation on the basis of the picture (Naus et al., 2012).

4. Closing remarks

Research over systems and methods allowing to measure data describing angular and lineal movement of the ships is conducted in Polish Naval Academy from about 20 years. These research refer different techniques: magnetic, gyroscopic, inertial, satellite and also visual lately. Research prove that still cannot be indicated one measurement system which fulfils expectations of all users. This results from various expectations with reference to accuracy, but also such features as required power of the power supply, dimensions and the weight of the device.

In this paper only hydrographic needs are discussed, however it should be mentioned, that now big interest to small unmanned vehicles can be observed. In many times this vehicles need not to accurate, but firstly small and light weight devices. This can be accomplished with flux-gate magnetic sensors. From the other side satellite technology cannot be applied on underwater vehicles.

Acknowledgements
Authors express satisfaction that they could perform presented research which were financed by the Committee Of Scientific Research, the National Centre of Research and Development within the framework of different projects and by Polish Naval ACademy within the framework of statutory research.

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