Side Scan Sonar Stereo Survey

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SUMMARY
At the interpretation of the bottom surface images received by Side Scan Sonar (SSS) is frequently useful an information received by other means. It is obvious that these means should be, whenever possible, compatible with SSS relative to methods of their use and the cost of such investigations. On the one hand, bottom surface stereo surveying with using the SSS can be represent an independent problem which decision would allow to determine a bottom relief within boards of the surveyed strip. On the other hand, it can be used for the identification of a target with relief roughness. It was carried out the comparative analysis of various variants of the stereo surveying with using the SSS antennas disposed in a vertical and horizontal directions. It is marked the perceptivity of using a stereo surveying variant in that the SSS antennas are established, accordingly, with a tilt on a stern and on a nose of the research ship. Anaglyph acoustical stereo images of the bottom are presented that synthesized on the base of the SSS image and bathymetrical data received during of the inspecting the Sajano-Shushenskaja Hydroelectric Power Station.

1.INTRODUCTION.

The purpose of this report is to attract an attention to the problem of obtaining sea-bottom stereo images by acoustic methods.

At the first, our interest in this problem was due to our desire to obtain the additional information about the objects revealed on acoustic images of a bottom surface, received by the side scan sonar (SSS). During the interpretation of such images in many cases the information obtained by acoustical profiler or echo sounder was extremely useful. It is explain of the fact that said means are compatible in many respects with the methods and costs for their use. It is possible to assume that results of bottom stereo surveying by SSS will be extremely useful, first of all, for the identification of three-dimensional objects on the bottom surface and effective presentation of acoustical data obtained by sonar.

On the other hand the stereo survey data may be useful for the identification of the bottom relief within the limits of the bottom site surveyed by this method.

2. THE PROBLEMS OF THE SSS STEREO SURVEYING.

In spite of these arguments we cannot find in the literature the references containing information about the successful realization of the said method in practice. Mean while there are well known results of Earth surface stereo surveying obtained by radar. Also the results of stereo surveying by optical methods are well known. As an example of such results it is possible to indicate the results obtained with useful Canadian satellite RADARSAT-1.

In our opinion it is possible to explain this fact by a number of factors among those the main thing is vary small resolution of convenient SSS when compared with the means mounted on satellites. Really, the optical and location systems angular resolution is determined by a relationship $\lambda/\mathbf{D}$, where λ - wave length of used radiation and **D** - the size of the location system aperture. Therefore in an optical range where the wavelength is about $5\ 10^{-8}$ m, the resolution is limited, as a rule, not by the sizes of the aperture of the optical device but by the properties of environment and is in order of angular second. In

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the radiolocation field, where waves in order of a cantimetric and decimeter range are usually used, the problem of obtaining the high resolution for a long time have been solved by using of antenna with synthesized aperture. As for hydrolocation field there are a number of the reasons in that SSS antenna sizes, as a rule, do not exceed 100 wavelengths.

More over the real resolution of the most SSS do not exceed the physical size of its antenna. But it appears insufficient for direct realization of the methods, which are similar to those that are used at Earth surface stereo surveying by using radar with the synthesized aperture. The simplest method to improve resolution is to use SSS working at more high frequency. However it caused the essential decreasing surveying range from hundredth meters at the frequencies about 100 kHz up to tenth meters at the frequencies about 1 MHz. More complicated method consist of using a large antenna with dynamic focusing on range or an antenna with synthesized aperture which are similar to those that used in radiolocation field.

It is necessary to note that, besides low resolution, the realization possibility of bottom stereo surveying by the SSS may be greatly affected by well known effects which take placed in the case of radar. There are such effects as foreshortening, pseudo shadowing, layover and shadowing that will be considered below.

3. VARIANTS OF THE SSS STEREO SURVEYING.

Let's consider various possible scheme of bottom surface stereo surveying by the SSS in more detail. First of all, it is necessary to note, that, as shown in **fig. 1,** relief displacement in the case of a bottom surveying by the SSS occurs in a opposite direction to the relief displacement that takes place in optical systems. Actually, it means that for correct stereo perception of the acoustic stereo pair it is necessary to change them by their places, at least, or to change the signs of the relief displacements.

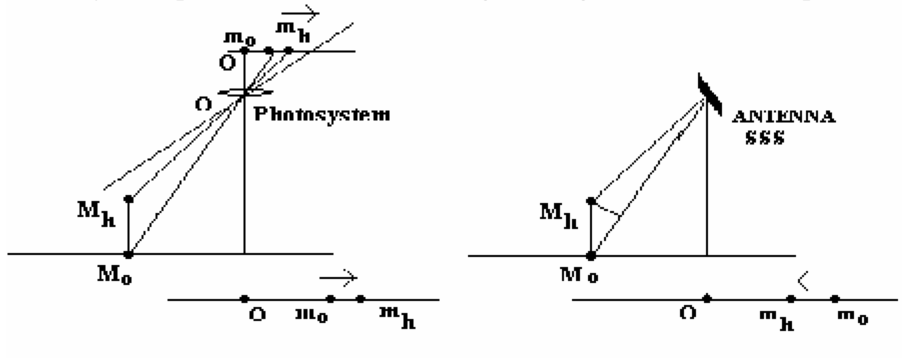

Figure 1: Scheme showing that relief displacements in the images take by camera and by the SSS is directed to the different directions.

The similar situation takes place with the mentioned above effects. So the said foreshortening and pseudo-shadowing effects, can cause, respectively, reduction and increasing sizes of slopes, depending on what its side they are directed according to the SSS antenna **(fig. 2).**

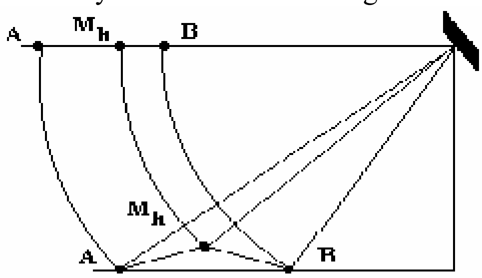

Figure 2: Scheme illustrating foreshortening and pseudo shadowing effects.

The layover effect having as a result an ambiguous readout of image coordinates can take place in the situation when the sternness of the slope directed forward to the antenna, exceeds some critical angle. At the same time in a similar situation the side of a slope, directed backward to the antenna, can appear completely in shadows **(fig. 3)**. The said effects can cause the difficulties of the stereo pairs stereo perception of the acoustic images, first of all, on the sites of a bottom with the crossed relief where application of stereo surveying is especially perspective.

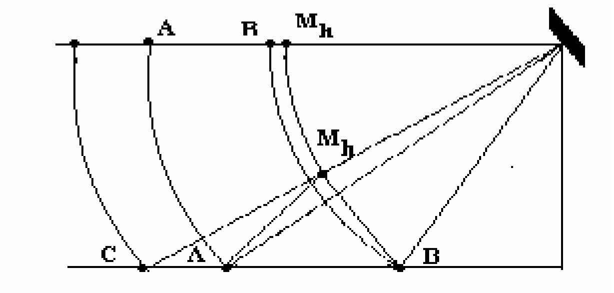

Figure 3: Scheme illustrating layover effect when steepness of the slope exceeds critical angles.

Let's consider now the basic schemes of bottom surface stereo surveying by the SSS. In the case if the point M situates on the flat bottom surface with depth **H**, slant range up to it, $\mathbf{R_M}$, is determined by expression:

$$R = \sqrt{X^2 + H^2} \quad (1)$$

Let us assume that condition $\mathbf{h_M} \ll \mathbf{H}$ is satisfied, where $\mathbf{h_M}$ is a difference between the depth in a point M and the some reference depth **H**, from expression (1) it can be obtained an estimation for the value of relief displacement δ**R**:

$$\delta R \approx \frac{\partial R}{\partial h}\delta H = \frac{Hh}{\sqrt{X^2 + h^2}} = \frac{Hh}{R} = (2)$$

For an estimation of the parallax of a point **M**, p_M that is determined as a difference of relief displacements for the "left" and the "right" images, at horizontal displacement of antennas of the left and right channels on size ***x*** **(fig. 4)** it is possible to differentiate the expression (2) on **x** (in the assumption, that displacement value $x \ll X$), were **X** is horizontal range. Then

$$p_M \approx \frac{HXhx}{R^3} = (3)$$

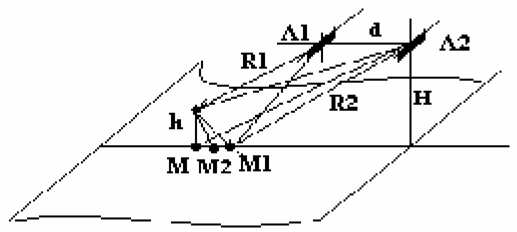

Figure 4: Scheme illustrating stereo surveying of the bottom surface by the SSS in the case of horizontal displacement of the SSS antennas.

It is apparently from (3) that, in the case of horizontal antenna displacement of the left and right channel the, parallax of the point **M** with height **h**, is small value of the second order. More over that value decreases as inverse proportional value of slant range **R**. It may shown that the similar situation takes place also at vertical antennas displacement. It is necessary to note that by using antennas of the left and right channels which scan a surveyed strip from two different sides **(fig. 5)** the parallax p_M represents the double value of relief displacement. This scheme is more favorable than the schemes considered above with horizontal and vertical displacement antennas. The essential disadvantage of this variant is as difficulty of its practical realization and influence on a stereo perception of the acoustical stereo pairs the mentioned above effects such as foreshortening and layover effects.

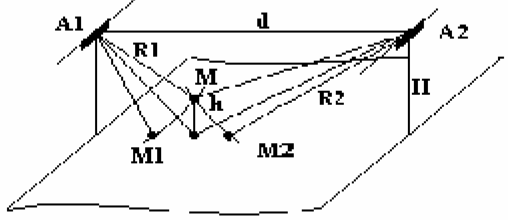

Figure: 5. Scheme illustrating stereo surveying of the bottom surface by the SSS in the case of horizontal displacement of the SSS antennas from both side of observed bottom side.

So, the stereo surveying variant is inserting in which antennas are mounted, accordingly, with a trim to the nose and to a stern of a research ship. As it shown in **fig. 6**, in the case of a rectilinear trajectory of antennas SSS, the specified method allow to obtain an acoustic stereo pair on which the longitudinal relief displacements equal in value and are directed to the opposite sides. At the same time transversal relief displacements are equal in value and coincide with the direction. It facilitates the overlapping stereo images on view it, as is known, it is necessary that the vertical component of a parallax was minimal. The stereo surveying configuration in that the radiation channel is used in a traditional mode and two receiving antennas are displaced, respectively, forward and back and oriented forward to illuminated bottom strip seems to be especially perspective. In this case the mentioned above effects are appeared in the images of a stereo pair in an equal measure and do not influence its stereo perception.

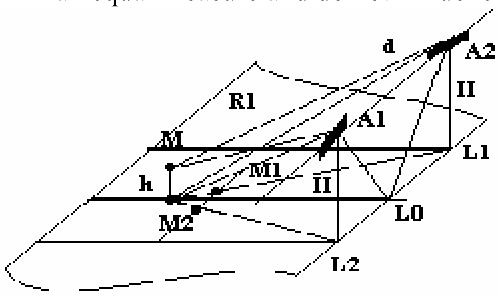

Figure 6: Scheme illustrating stereo surveying of the bottom surface by the SSS in the case when antennas are mounted with a tilt forward to nose and stern of research ship.

There is a question what to do further with such stereo pairs. It is obvious that the using radar grammometry methods such stereo pairs would allow determine the relief of a surveyed bottom site. But such method is beyond the frame of the given work.

Now it is more interesting for us a more simply method, when the data is transformed into a stereo pair so that it could overlook without any problems in a stereoscope or is represented as anaglyph stereo image. The main condition for such transformation is that real resolution of the SSS images must be essentially more than the expected parallax value for the bottom sites with the minimal height.

It is necessary to note that as a rule the inspection of a bottom by the SSS is carried out simultaneously with ordinary or multibeam echo sounder. In some cases the bathymetrical surveying can be made with the help of the SSS modifications such as a phase SSS or interferometer that obtain not only tone image but also a relief map. In this case, the stereo pair images can be synthesized on the basis of the acoustic image received by the SSS and the data of the bathymetric surveying. As an example of such method, we can show the stereo images received in the USA under the program of the U.S. Eenvironment Protection Agency and U. S. Geological Survey **(fig. 7).**

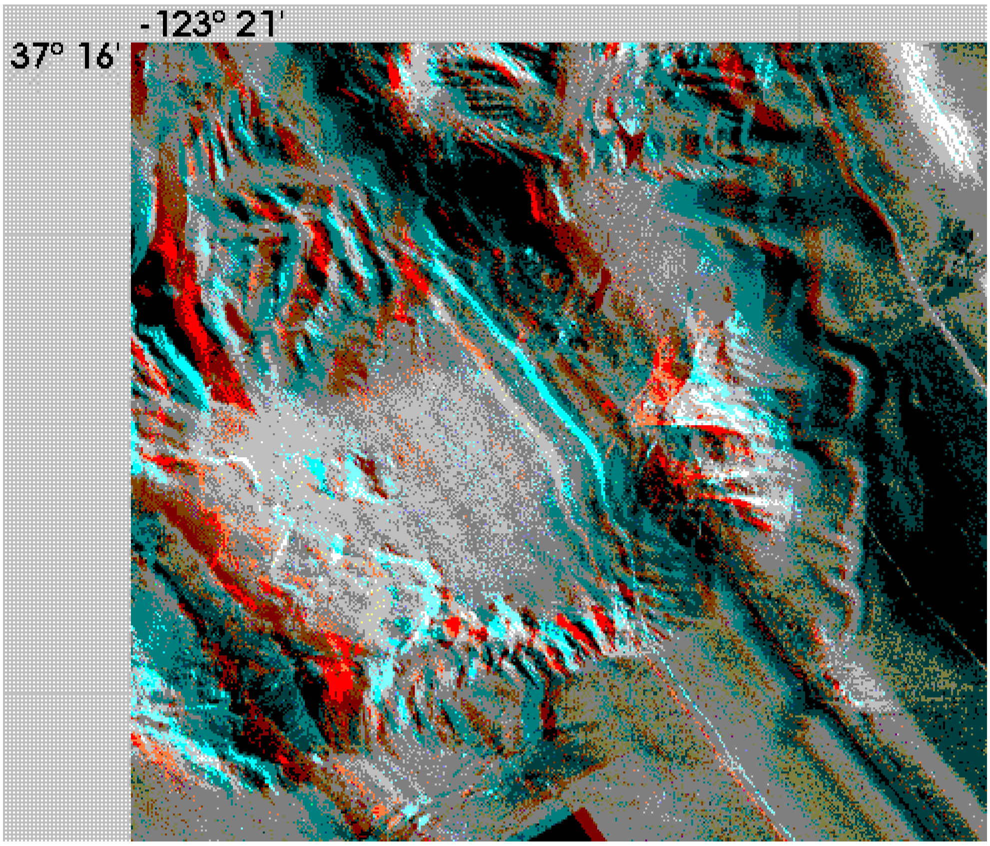

Figure 7: Anaglyph stereo image of sea bottom that was synthesized from the SSS images and bathymetrical data according to program of the U.S. Environment Protection Agency and U. S. Geological Survey.

4. SYNTHESIS OF ACOUSTICAL STEREO IMAGES.

We have been realized the similar method when processing the data, received inspecting Sajano-Shushenskaja Hydroelectric Power Station dams. The typical images of the surveyed site received by the SSS are shown on **fig. 8**. SSS worked at a frequency of 240 kHz and provided the resolution about of 0.5 m. Simultaneously with SSS the echo sounder was used. As a result of its using was the bathymetric map which is shown in **fig. 9**.

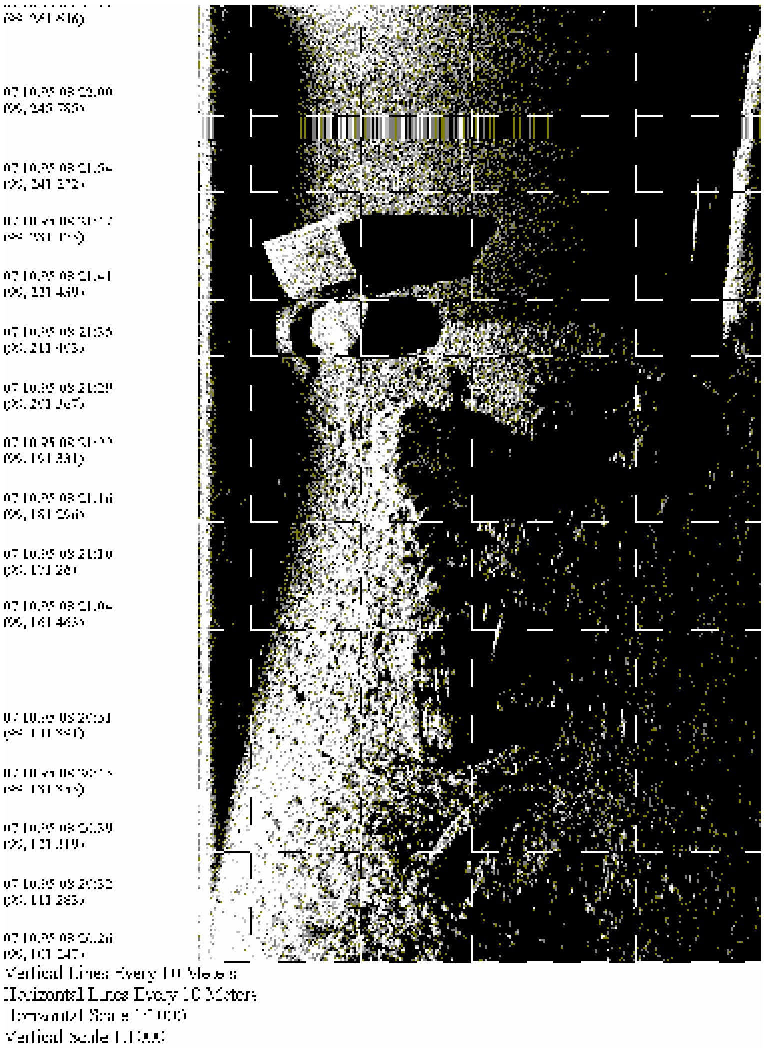

Figure 8: The typical acoustical image obtained by the SSS during of inspection of Sajano-Shushenskaja Hydroelectric Power Station dams (left view).

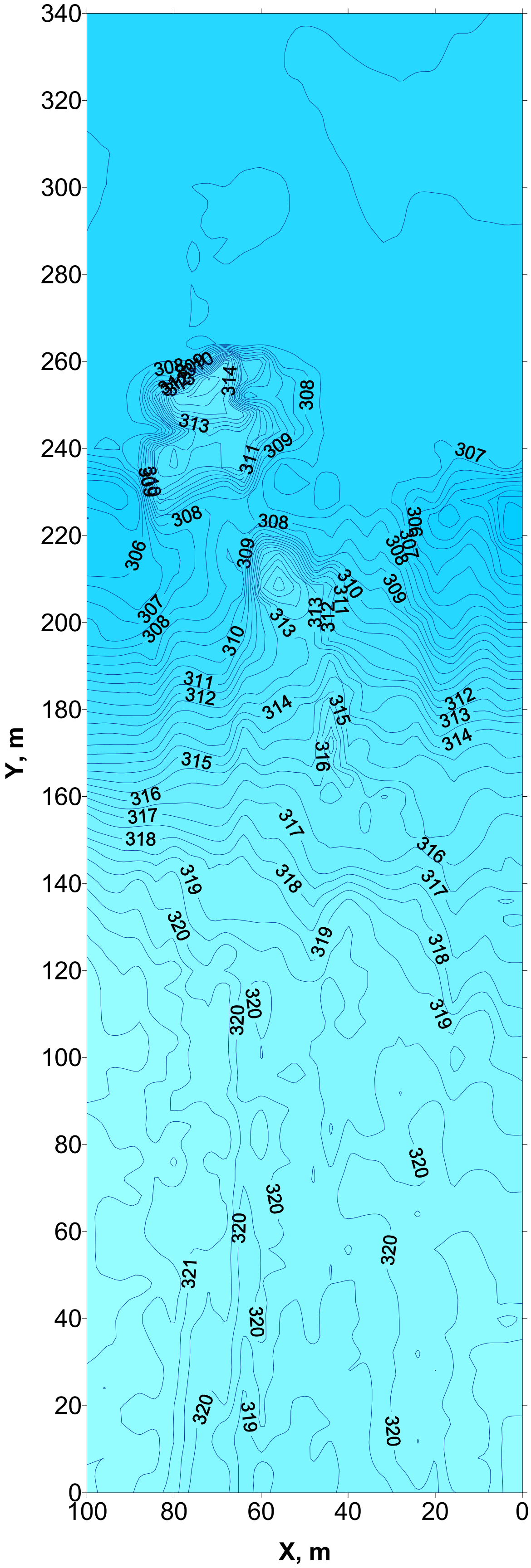

Figure 9: Bathymetric map obtaining on the base of the echo sounder data.

In order to obtain the acoustic stereo images of observed site the said data has been transformed according to the below-mentioned operations.

1) The tone acoustic images were transformed into bmp-files.

2) The said bmp-files were transformed into matrix A_{ij} by using **MathCAD** program. Dimensions of this matrix are determined by pixel quantity in horizontal and vertical directions in the image and the values of their elements a_{ij} correspond to the values of image pixels brightness.

3) The bathymetric map was transformed into a similar matrix $\mathbf{B_{ij}}$ by using **Surfer** program. Their elements $\mathbf{b_{ij}}$ correspond to depths values of the corresponding pixels.

4) Then the elements a_{ij} were displaced by using **MathCAD** program in longitudinal directions in order to create a longitudinal parallax. The values of this displacmentes dependent on the values of $\mathbf{B_{ij}}$ and the supposed point of view of the stereo images.

5) This obtained stereo pair was transformed into anaglyph stereo images. Last operation made by using **Photoshop** program. This program allows imposing the left image (in red color) and the right stereo the image (in green color). It is necessary to note, that the displacements values of each element of the tone images are function both of the height of a corresponding point over the some "reference" depth and of the desirable point of viewing of anaglyph. According to this remark, it is possible to simulate a stereo images with the various points of view, such as, for example, "top view", "front view", etc.

As result of the making such method, the anaglyph acoustical stereo images were obtained similar to which are shown fig. **10.**

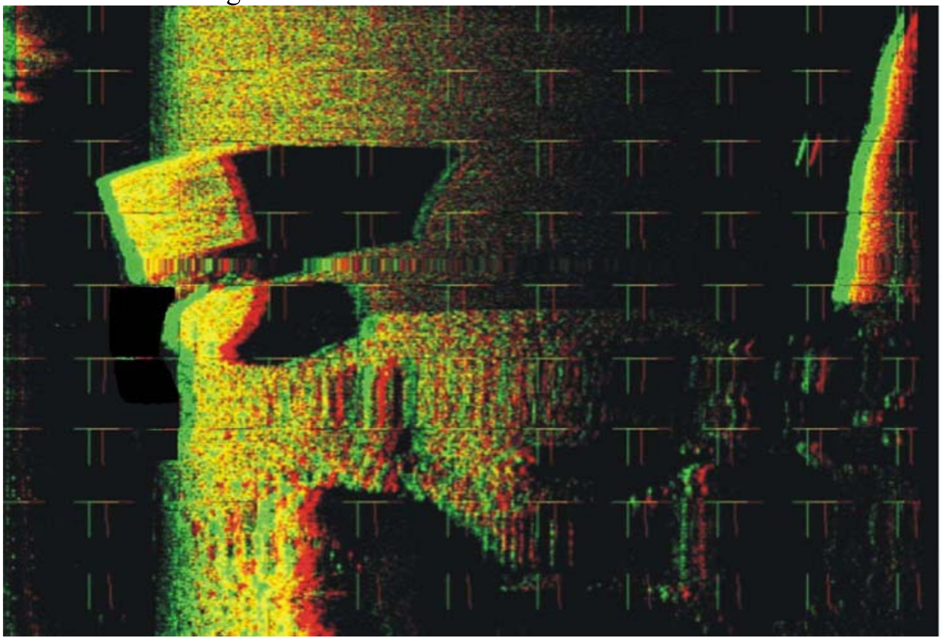

Figure 10: Anaglyph acoustical stereo image of the river bottom synthesized on the base of the SSS image and bathymetrical data received during of the inspecting the Sajano-Shushenskaja Hydroelectric Power Station.

5. CONCLUSION.

So the method which represents the stereo images in form of anaglyph seems to be convenient and effective method of presenting the information about a bottom relief. Actually, in this case we have pseudo stereo images in which the tone (brightness) resolution can be essentially higher than the relief resolution, which is determined by a quality of the bathymetrical surveying. It is obvious that in the case of successful realization of methods which directly obtain an acoustical image stereo pairs the above-mentioned technique can be modified, as the bottom relief information can be directly obtained from the acoustic images stereo pair. Accordingly, the relief image resolution becomes the same, as a brightness image resolution.