DOI: 10.17725/rensit.2021.13.377

Application of spectral and spatial processing methods to sonar images

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Received May 26.2021, peer-reviewed June 07.2021, accepted June 21.2021

Abstract: **The paper proposes the use of the method of renormalization with limitation (MRL) for suppressing the speckle noise of images obtained using sonar. The method is tested on real images obtained by the interferometric side-view sonar. The principal possibility of a significant reduction in the speckle noise level is found due to the fact that the MRL renormalizes the spectrum of the sonar image to the universal reference spectrum (URS) model, which is a model of the spectrum of a "good" quality grayscale image. To increase the overall sharpness of the image, after applying the MRL, it is proposed to use spatial brightness transformations. The study allows us to conclude that the application of MRL to sonar images can significantly reduce speckle noise.**

Keywords: **sonar, remote sensing, sonar images, image processing, speckle noise, method of renormalization with limitation.**

UDC 621.369

Acknowledgments: The work was performed within the framework of the state assignment of the Ministry of Science and Higher Education of the Russian Federation

For citation: Alexander V. Kokoshkin, Evgeny P. Novichikhin, Ilia V. Smolyaninov. Application of spectral and spatial processing methods to sonar images. *RENSIT*, 2021, 13(3):377-382. DOI: 10/17725/rensit.2021.13.377.

Contents

1. INTRODUCTION

Currently, sonar systems are extremely widely used to solve applied problems in a large number of applications. Such as: environmental monitoring, search for natural resources, archeology, emergencies, industrial and defense security. Sonar images are a special case of synthetic aperture radar (SAR) images. Such images are characterized by the presence of multiplicative speckle noise. It arises due to wave interference caused by multiple scattering from reflectors small relative to the resolution element. Speckle noise appears as bright spots and bright dots randomly scattered throughout the image field.

Unlike SARs used for sounding the Earth from space, in sonar systems, the change in the relief from point to point can be commensurate with the distance to the sounding object. This increases the likelihood that a signal will be reflected from targets at different angles of arrival at the same range. This leads to the averaging of signals reflected from different areas [1]. This feature increases the likelihood of additional speckle noise.

Speckle noise suppression techniques are aimed at freeing the image from parasitic artifacts, removing graininess, and defining the boundaries of areas and objects in the image. The fight against speckles is carried out in two directions. The first is to improve the design of sonars, i.e. the quality of visualization is improved with the help of various technical means. The second is the digital processing of an already obtained image.

This work is devoted to digital image processing. Frequently used methods of dealing with speckle noise are methods ranging from a simple locally averaging spatial filter and median filtering to Wiener, Kalman or homomorphic filtering algorithms applied to the entire image. Wavelet transforms or fractal coding are also used [2-5].

When testing the method of renormalization with limitation (MRL) on various types of images, in particular, a significant reduction in speckle noise was found [6,7]. Thus, the idea arose to apply MRL to sonar images in order to improve their quality. It is proposed to process the original acoustic images using the method of renormalization with limitation. It is assumed that after applying the MRL, on average, the axially symmetric (isotropic) part of the amplitude spatial spectrum of the studied images will correspond to the Universal Reference Spectrum (URS) model, i.e. models of the image spectrum of "good" quality [8,9]. It should be noted that the most significant information about the contours of regions and objects in the image is contained not in the amplitude, but in the phase part of the spectrum. Thus, while eliminating possible noise and distortions, all boundaries of the areas and the localization of objects in the images will be preserved. The aim of this work is to test the effect of suppressing speckle noise using MRL on real sonar images.

2. APPLICATION OF MRL TO SONAR IMAGES

The application of the renormalization method with limitation to sonar images is demonstrated by the example of **Fig. 1** - images of a fragment of the seabed with a sunken ship.

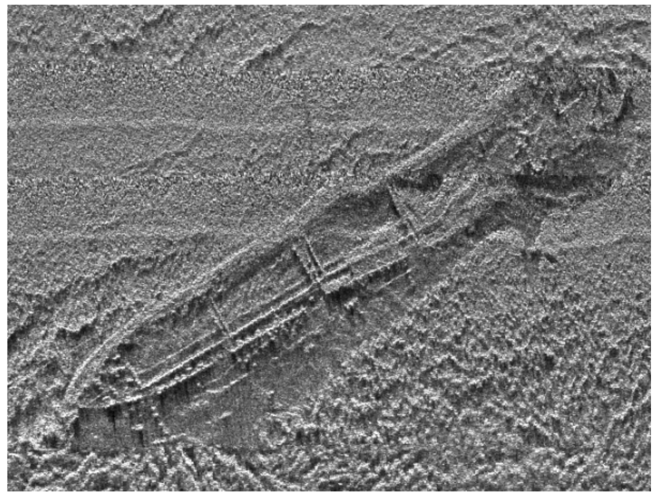

Fig. 1. *Original sonar image.*

The image with a size of 668 by 512 pixels, shown in Fig. 1, was obtained using the interferometric side-scan sonar (ISSS), which is part of the AGKPS 100 multifunctional sonar complex and has the following technical characteristics [10]:

1. The resolution of the ISSS in the direction of movement is 1.5 degrees. Slant range resolution - 0.03 m.
2. The working frequency of the ISSS is 450 kHz.
3. The root-mean-square error of measuring the depths of the ISSS in the swath up to 3 depths is not worse than 1% of the depth of survey, the sensitivity to changes in the coefficient of backscattering of soils is not less than 10%.
4. Band of survey (overview) ISSS up to 300 m on one side.
5. Probing signal is pulsed with linear-frequency modulation.

The multifunctional sonar complex AGKPS 100 also included additional sensors:

1. Satellite navigation receiver.
2. Trim roll and vertical displacement sensors.
3. Gyrocompass.
4. Sound speed meter in water.

The sonar survey was carried out while the vessel was moving in parallel directions (tacks) at a distance of 20 meters between them. Acoustic images obtained on parallel tacks are applied to a geographic map, taking into account the

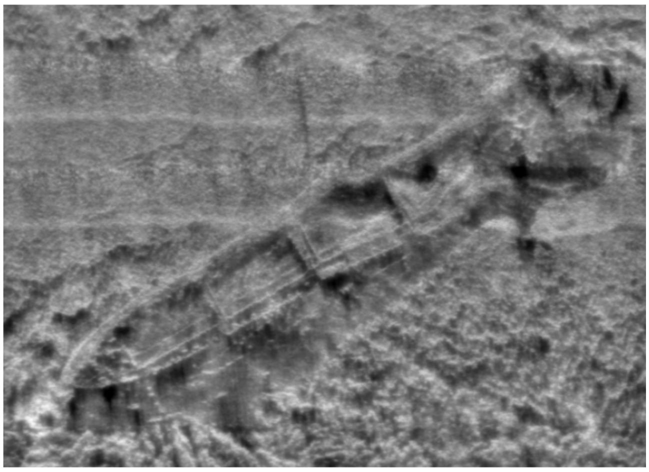

Fig. 2. *Applying the MRL to the image Fig. 1.*

indications included in the complex of sensors [11]. The peculiarity of the map construction is that the images from the adjacent tacks do not overlap (the images from the adjacent tracks are not averaged).

Shown in Fig. 1, the sunken ship has a length of 40 m and lies at a depth of 17 m.

We use the renormalization method with restriction in our "classical" version, i.e. the same as it was presented in [8,9] and registered in the certificate of state registration of a computer program [12]. Since it is assumed that the original image was not subjected to any blurring, the distorting hardware function is assumed to be “needle-like” (much less than one pixel wide). **Fig. 2** shows the application of the MRL to the image Fig. 1.

In a comparative analysis Fig. 1 and Fig. 2, it can be noted that, together with the suppression of speckle noise, there is a slight decrease in the

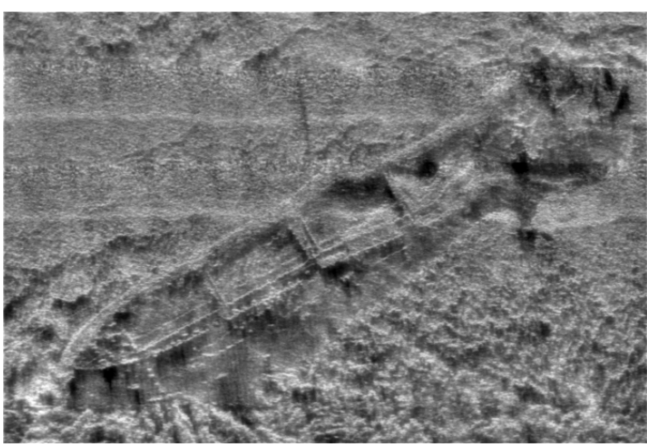

Fig. 3. *The result of applying the Laplacian to the image in Fig. 2.*

Fig. 4. *The result of applying median filtering to the image in Fig.1.*

overall contrast of the image. Therefore, as an additional step, we will sharpen Fig. 2 using the Laplacian [13]. The result of this operation is shown in **Fig. 3**.

For comparative analysis, as an alternative method for combating speckle noise, we use the commonly used median filtering with a square kernel of 3 by 3 pixels. The processing result is shown in **Fig. 4**.

Volumetric views of spatial brightness for images of Figures 1-4 are shown in **Fig. 5**.

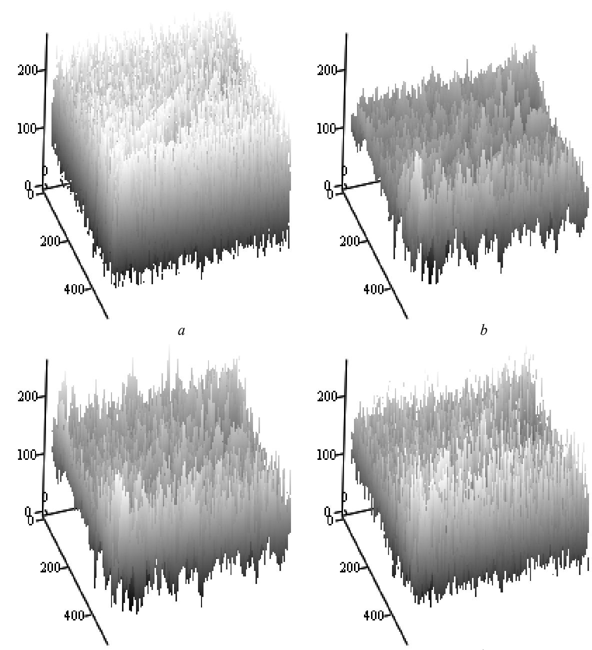

Fig. 5. *Volumetric view of the corresponding spatial brightness of the original sonar image (Fig. 1) - (a); original image processed by MRL (Fig. 2) - (b); original image processed by MPL and Laplacian (Fig. 3) - (c); original image after median filtering (Fig. 4) - (d).*

Along the vertical axis, the values of pixel brightness are plotted in grayscale (from zero - black, to 255 - white). The two remaining axes of the volumetric Fig. 5 show the coordinates of the brightness pixels on the image field. Fig. 5*b* - the result of using the MRL, clearly demonstrates a significant decrease in the level of speckle noise relative to the initial sonar image - Fig. 5*a*. This can be seen in the structure of the volumetric drawings. The original image is noisy with speckles all over the field, while the MRL processing, removing bright spots, leaves the contours of the sunken ship and the bottom topography intact. **Table 1** shows the statistical characteristics of the spatial brightness of the images. The root mean square deviation (RMSD) of the brightness in the image of the processed MRL is equal to 29, which is significantly less than the RMSD of the original one which is 49.

Fig. 5*c* is the action of the Laplacian in Fig. 5*b*. As mentioned above, this improves the sharpness after applying MRL to the original sonar image. Table 1 shows that the statistical characteristics of the MRL processing plus the Laplacian (Fig.5*c*) are very close to the alternative method - median filtering (Fig.5*d*) of the initial sonar image. The standard deviations are, respectively, 33 and 34. However, the use of median filtering is less preferable, since this procedure, together with speckles, can remove useful information [6,13].

Table 1

Statistical characteristics of spatial brightness in images

	Original sonar image	Sonar image, MRL processing	Sonar image, MRL processing and Laplacian	Sonar image, Median filter processing
Average brightness value	117	118	117	113
Root mean square deviation of Brightness	49	29	33	34

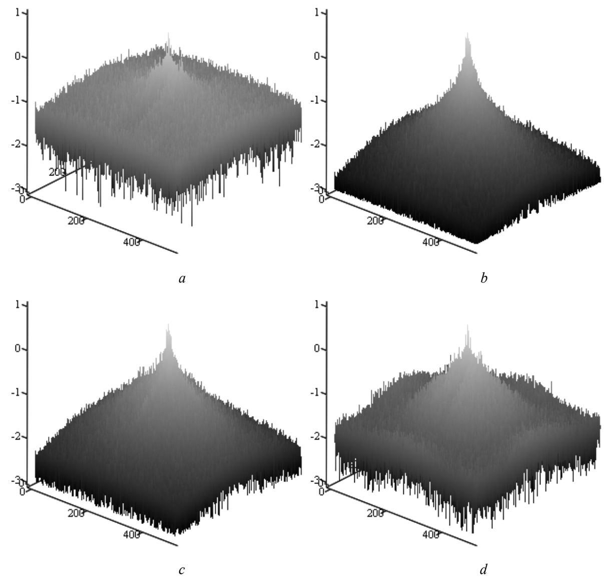

Fig. 6. *Amplitude spatial spectra on a logarithmic scale corresponding to the volumetric images in Fig.5. Spectra: initial sonar image (Fig. 1) - (a); the original image of the processed MRL (Fig. 2) - (b); the original image processed by MRL and Laplacian (Fig. 3) - (c); original image after median filtering (Fig. 4) - (d).*

Fig. 6 shows in a logarithmic scale the amplitude spatial spectra of the studied images with a size of 668 by 512 pixels. The indexing of Fig. 6 corresponds to the letters of Fig. 5.

The spectrum of the original image of the processed MRL (Fig. 6*b*), within the framework of the technique, was renormalized to the model of the universal reference spectrum (URS), i.e. to a model of the spectrum of a "good" quality grayscale optical image [8,9]. And, since sonar images are very different in structure from optical images, then as a "payment" for noise reduction, as a result of applying the MRL to the original figure 1, the effect of "fogging" or "blurring" of the image appears - Fig. 2. On the spectra, this can be seen as a decrease in the level of high frequencies in Fig. 6*b* relative to Fig. 6*a*. To increase the overall sharpness of the image, the Laplacian was then applied, which caused some increase in high frequencies - Fig. 6*c*. The spectrum after median filtering turns out to be slightly modulated (Fig. 6*d*), which may indirectly indicate possible undesirable changes in the image structure.

3. CONCLUSION

This article is devoted to testing the application of MRL to sonar images in order to improve their quality. It was found that the application of MRL to sonar images significantly reduces speckle noise. This is because the method of renormalization with limitation, by definition, renormalized the sonar image spectrum to a universal reference spectrum (URS) model, which is a model of the spectrum of a "good" quality grayscale image [8,9]. Due to the fact that sonar images in their structure differ significantly from optical images, as a "payment" for suppression of speckle, as a result of the use of MRL, the effect of "fogging" or slight "blur" of the image appears. To increase the overall sharpness of the image, it is proposed to use luminance transformations (for example, Laplacian) [13]. The use of median filtering in this problem is less preferable, since this procedure, together with speckles, can also remove useful information. All of the above allows us to conclude that the application of MRL to sonar images can significantly reduce speckle noise.

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