IMAGE ENHANCEMENT USING STOCHASTIC RESONANCE

Qinghua Ye (1)(2), *Haining Huang* (1) *and Chunhua Zhang* (1)

(1) Institute of Acoustics, Chinese Academy of Sciences, Beijing, 100080
(2) Graduate School of Chinese Academy of Sciences, Beijing, 100039
Email: qinghua_ye@pku.org.cn, drhhn@263.net

ABSTRACT

This paper presents an image enhancement method using stochastic resonance (SR) and provides two applications to sonar image processing, i.e. side-scan sonar image and bearing-time record. Simulated and real data are tested and the results show that the proposed method is suitable to noisy images with very low signal-to-noise ratio (SNR), when the texture of the object is not subtle, and the region where the object lies in is not too small compares to the minimal region coverage that SR works. We also show that an additional amount of noise besides the noise of the image itself may be helpful to enhance the image.

1. INTRODUCTION

Many image formation systems work in bad environments and have to deal with the strong random noise. A typical example is a sonar system to detect targets from far away. This paper intends to exploit the potential utilization of noise and extract information from it for image enhancement.

We use stochastic resonance (SR) as a fundamental tool for our purpose. Roughly speaking, SR can be viewed as a noise-induced enhancement of the response of a nonlinear system to a weak input signal [1-5]. Because of the noticeable advantage in weak signal enhancement, SR seems to play a growing role in many diverse fields. Recently Hongler *et al.* found that far from being a drawback, the ubiquitous presence of random vibrations in vision systems can advantageously be used for edge detection [2]. Marks *et al.* studied the SR of a threshold detector in image visualization, wherein an optimal noise level produces a better visual representation than when other noise is used [3]. Ye *et al.* presented a SR-based Radon transform to extract weak lines from noise images [4]. These studies imply the potential use of SR in image processing. In this paper a region enhancement method based on SR is presented and used as a model for some image enhancement applications.

2. STOCHASTIC RESONANCE- AN OUTLINE

We consider an overdamped motion of a Brownian particle in a bistable potential in the presence of noise and periodic forcing [1]

$$\dot{x}(t) = -V'(x) + A_0\cos(\Omega t+\varphi)+\xi(t), \tag{1}$$

where A_0 is the signal amplitude and Ω is the modulation frequency. Here, we assume that the noise $\xi(t)$ is zero-mean, Gaussian white noise with an autocorrelation function given by $\langle\xi(t)\xi(0)\rangle = 2D\delta(t)$. $V(x)$ denotes a symmetric bistable potential $V(x) = -\frac{a}{2}x^2+\frac{b}{4}x^4$. The potential minimas are located at $\pm x_m$, with $x_m=\sqrt{a/b}$. The height of the potential barrier between the two minimas is $\Delta V = \frac{a^2}{4b}$.

Ref. [5] provided a method to select the parameters a and b when the signal frequency Ω_1 and the noise intensity σ_1 are known for a fixed discrete simulation of Eq. (1).

To obtain the maximum output SNR, the optimal a and b have the following relationship

$$\frac{a}{b} = \left(\frac{\sigma_1}{\sigma_0}\right)^2, \tag{2}$$

where

$$\sigma_0 = f(\Omega_0) \approx M\left(-\frac{1}{2\log(\sqrt{2}\Omega_0)}\right)^{\frac{1}{2}}, \tag{3}$$

and

$$\Omega_0 = a\Omega_1. \tag{4}$$

In a fixed discrete simulation, $f(\Omega_0)$ can be measured using experimental method. M is a constant.

The output SNR *vs.* parameter a when parameter b has been selected as the optimal value using Eq. (2) can

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be written as

$$SNR = \frac{4a}{\sqrt{2}(\sigma_0\sigma_1)^2}\exp(-\frac{a}{2\sigma_0^2}) \cdot \quad (5)$$

Given the signal frequency Ω_1 and the noise intensity σ_1, to obtain the optimal output the parameter a is determined by Eq. (5) and b is determined by Eq. (2).

The relationship between the response of the SR system and the variation of the signal frequency and the noise intensity shows that low frequency signals have higher output SNR when the noise intensity is optimized. The output SNR is maximized when the input is a direct current (DC) signal, and we have used this property to enhance weak lines in noise images [4].

When a DC signal is applied to the SR system, the output signal is restricted in one of the potential wells in the steady response case and the output signal is also a DC signal.

In Eq. (1) the sinusoid signal $A_0\cos(\Omega t+\varphi)$ is replaced by A_0, and Eq. (1) can be written as

$$\dot{x}(t) = SR(A_0 + \xi(t)) = ax(t) - bx^3(t) + A_0 + \xi(t) \cdot \quad (6)$$

3. REGION ENHANCEMENT METHOD USING STOCHASTIC RESONANCE

3.1. Model

We consider an image in which a square object is located in region R_5 (Fig. 1a) and the image is corrupted by strong noise (Fig. 1b). For region $R_i, i=1,2,\cdots,9$ we form a vector $x_j, j=1,2,\cdots,M$. The pixels order is arranged by some rule and M is the number of pixels in region R_i,

$$x_j = A_0 + n_{0j}, \text{ for region } R_5, \quad (7.a)$$

$$x_j = n_{0j}, \text{ for other regions.} \quad (7.b)$$

A_0 is a constant and n_{0j} is the noise (the noise distribution is not confined). For a desired region, by inputting vector x_j to the stochastic resonantor one obtains

$$y_j = SR(x_j) \quad (8)$$

and forms the enhanced output image region R' with the same pixels arrangement rule.

For a DC signal (frequency $\Omega_1 = 0$) and the noise intensity σ_1, using the method described in the previous section one can obtain the values of parameters a and b. To avoid the denominator in Eq. (3) being zero, Ω_1 in Eq. (4) can be chosen to be a very small value, and it achieves enough precision for our short data record enhancement issue. In one of our numerical simulation, for example, the output SNR as a function of parameter a is depicted in Fig. 2. Thus we choose the best value $a = 0.02$.

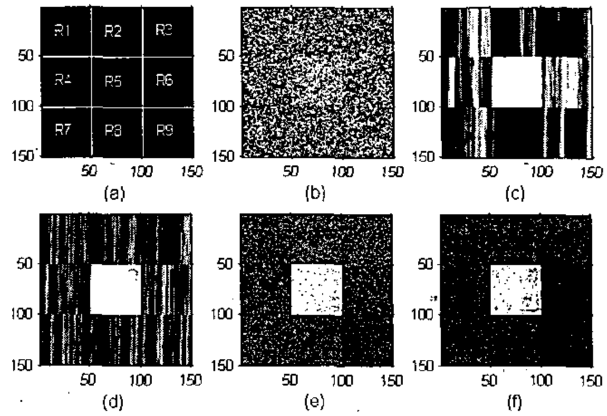

Figure 1: Image enhancement model. (a) Illustration of the processing regions; (b) image subjected to strong noise; (c) processed by SR directly; (d) additional noise is mixed in and repeated by 100 times; (e) the output sequence for each region is arrangement by random order; (f) random input sequence for each region.

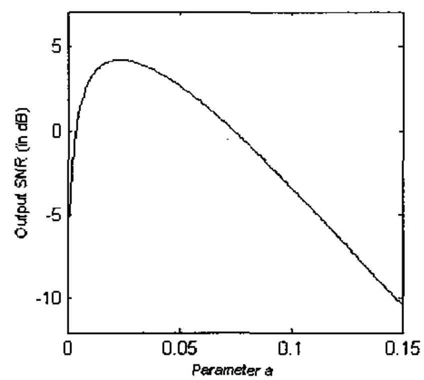

Figure 2: Output SNR *vs.* parameter *a*.

The above procedure is the principle of the region enhancement method using SR. Contrary to the regular image enhancement methods where noise is seen as a nuisance, this one uses noise. To adequately make use of the SR property of transition from noise energy to signal energy, we mix an additional noise (may be much stronger than the noise of the image itself) to the image and repeat this processing for K times (for each time the additional noise is regenerated) then Eq. (8) becomes

$$y_{kj} = SR(x_j + n_{kj}) = SR(A_0 + n_{0j} + n_{kj}), \; k = 1,2,\cdots K \cdot \quad (9)$$

The output sequence is

$$y_j = \frac{1}{K}\sum_{k=1}^{K} y_{kj} \cdot \quad (10)$$

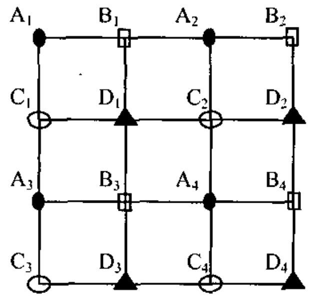

Figure 3: A simple example of the image enhancement method using SR. A*i*, B*i*, C*i*, D*i*, *i*=1, 2, 3, 4 are four overlapping processing regions.

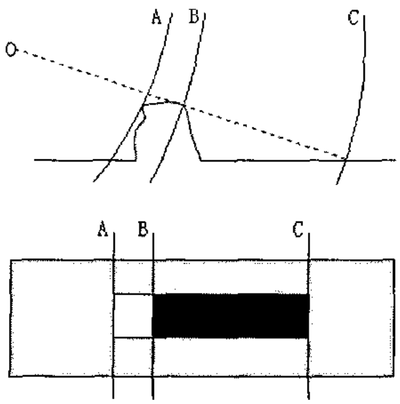

Figure 4: The formation of object in side-scan sonar images.

The average value computation of above also makes the output image smoother. If x_j is a new random sequence from image region R_i for each k, the initial condition effect will be eliminated and the enhancement performance will be better (Fig. 1f).

3.2. A simple example

We assume the texture of the image is not subtle, and the region where the object lies in is not too small compares to the minimal region coverage that SR works. As a simplest example the original image subjected to noise is divided into overlapping rectangular regions (Fig. 3, region A*i*, B*i*, C*i*, D*i*, *i*=1, 2, 3, 4), and each is processed using the previous method in order. These processed regions are combined to form the output image at last.

4. APPLICATONS TO SONAR IMAGE PROCESSING

In order to address the image enhancement issue using SR, a simple image enhancement model in Sec. 3 was presented. To employ the method we must consider the practice situation and accordingly modify the method. Next we give two types of sonar image and show in brief how the image enhancement method using SR works.

4.1. Side-scan sonar image

Mine detection and classification using side-scan sonar is a critical technology for mine counter measures (MCM) [6]. The geometrical situation of side-scan sonar image is pictured in Fig. 4. As the object is denser or has a higher reflectivity than the background, the return from the object surface (points A–B) is much stronger than the background. The sonar shadow (points B–C) is produced due to the object effectively blocking the sonar waves from reaching this region of the seabed.

Due to several classes of mines (cylinders, spheres, manta, sigeel, rockan mines), associated prototype templates are used. The original side-scan sonar image is enhanced to detect the object-highlight regions, and then the image complement (reverse black and white) is enhanced to detect the shadow regions. The output image is combined by these two enhanced images.

4.2. Bearing-time record

In sensor array processing, the bearing-time record (BTR) is used for data postprocessing. This display system has a "waterfall" effect: the most recent line of data is placed at the top of the display and, to maintain a constant display size, the oldest line is removed from the bottom. To deploy the proposed method in such a 'real-time' system, the processing regions are updated by new coming data at each time. Because regular far-field targets don't move fast, we can select the processing regions as strait rectangles.

Fig. 5 is a simulated real-time BTR. The signal-to-noise ratio is −20dB. We only used Eq. (8) not Eqs. (9) and (10) (i.e. the additional noise wasn't mixed in) to reduce the computational requirements. Real BTR data in Fig. 6a are adopted from Ref. [7]. A strong noise is mixed in it (Fig. 6b) and the output image using the proposed method (mixing additional noise and repeated by 100 times) is pictured in Fig. 6c.

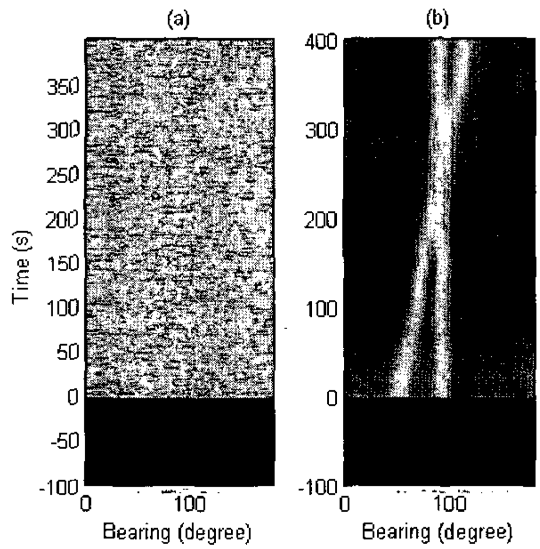

Figure 5: (a) Bearing time record by a real-time sonar system; (b) the proposed method is integrated in the sonar system.

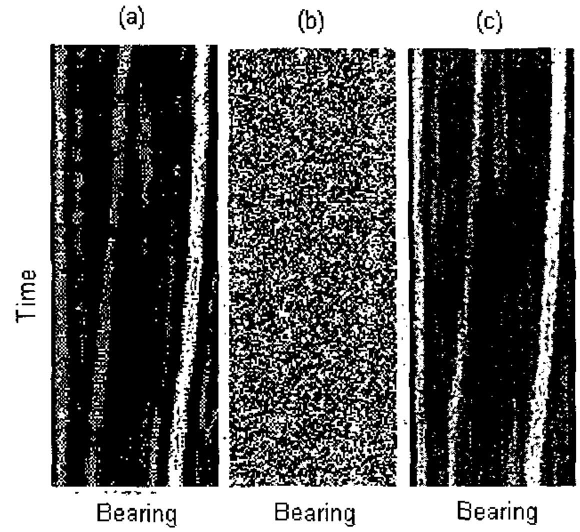

Figure 6: (a) Original BTR image; (b) noise corrupted image; (c) enhanced image.

5. CONCLUSION

In this paper, we present an image enhancement method using stochastic resonance and provide two applications to sonar image processing. Comparing to Marks' method [3], the proposed one is suitable to enhance an image with very low SNR when the texture of the object is not subtle. This work is the development of Ref. [4] which only enhances lines, and this work also shows that an additional amount of noise besides the noise of the image itself may be helpful to enhance the image.

6. ACKNOWLEDGEMENT

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7. REFERENCES

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