

Dynamic region method for improving adaptive quantization during sonar data transmission

Hyunjae Song¹, Minho Kim¹, Youngsub Lim¹, and Youngsin Kim¹

¹Underwater Surveillance Technology Research and Development, LIG Nex1 Co., Ltd.

Contact author: Hyunjae Song

Address: (13488) 333, Pangyo-ro, Bundang-gu, Seongnam-si, Gyeonggi-do, South Korea

E-mail: hyunjae.song@lignex1.co.kr

Abstract: *Sonar system required massive amount of data on long period of time by receiving data repeatedly. There are many previous study for reduce data rate, sampling reduction, vector quantization. But these studies require to change exist systems. In this paper, I search adaptive quantization bit to fit sonar system and suggest dynamic region method that divide region along with characteristics of signal. Short-time Fourier transform (STFT) analysis and percentage error were conducted. there is less noise occurred from 5-bit re-quantization result. Dynamic interval region method (DIRM) has lower percentage error in every re-quantization bit, maximum percentage error difference is 22.61 % at 4-bit re-quantization result. We demonstrated that our proposed method is capable of effectively applying adaptive quantization method at sonar system and reduce data rate for improving quantization error. It is necessary that address to compare final image conducted rest of sonar signal processing providing to operator.*

Keywords: *Sonar, Adaptive quantization, Data rate, STFT, Dynamic interval region method*

INTRODUCTION

Sonar system conducts sampling and quantization ultrasound signal obtained from acoustic sensor. It transmits data to operator via cable or wireless communication. It requires too much data because it repeats transmitting and receiving. [1] Recently, high-end sonar systems, such as Sonobuoy or Multistatic, require more data because they use several, high frequency sensors simultaneous. But it is difficult to implement high data transfer rate system. Although research has been conducted on compression techniques applied to sonar images, such as a compression technique using the discrete wavelet transform technique [1], a technique using non-uniform quantization and noise-shaping feedback coding [2], and the SPIRT algorithm proposed to complement the weakness of being vulnerable to changes in the input signal [3, 4], a lossless compression technique using the data reordering technique to remove redundancy in data, and a Deflate/inflate algorithm [5, 6]. These are studies on compression techniques applied to sonar images, such as reduce the sampling rate methods to reduce the data rate [7, 8, 9], vector quantization [10, 11], subband partitioning based on Quadrature Mirror Filter (QMF) and methods applying linear prediction coding and entropy coding techniques [12] These methods have been proposed, but changes to the existing system are required.

Recently, adaptive quantization research has been conducted in the field of ultrasound imaging to reduce the amount of data transmitted while using the existing system. [13] This method divides data already quantized into M-bits into regions with equal intervals and obtains the local maxima of each region. It is a technology that re-quantizes the data into N-bits smaller than the initial quantization M-bits, transmits the data, and then multiplies the local maxima to restore the signal. The adaptive quantization method reduces the amount of transmitted data by re-quantizing using only 3 bits, which is less than the 14-bit ADC used in the existing ultrasound imaging system, but signal loss occurs. Since medical ultrasound provides the results as images, the results of evaluating the ultrasound image loss and CNR show that the loss is small and can be applied to ultrasound imaging systems.

In this study, we propose a method to minimize signal loss by reducing the amount of transmitted data and dynamically dividing the regions according to the characteristics of the signal to perform adaptive quantization as the first attempt to apply adaptive quantization to the existing sonar system. To verify this study, we compared the signals restored by the existing equal interval region method (EIRM) that divides the regions into equal intervals using data collected from the currently operating sonar system and the proposed dynamic interval method. As a result, the DIRM proposed in this study can reduce the amount of data transmitted by 6-bits re-quantization to a 16-bits existing sonar system and has a maximum 22.61% lower error rate than the EIRM, which is expected to allow the simultaneous operation of higher frequency acoustic sensors.

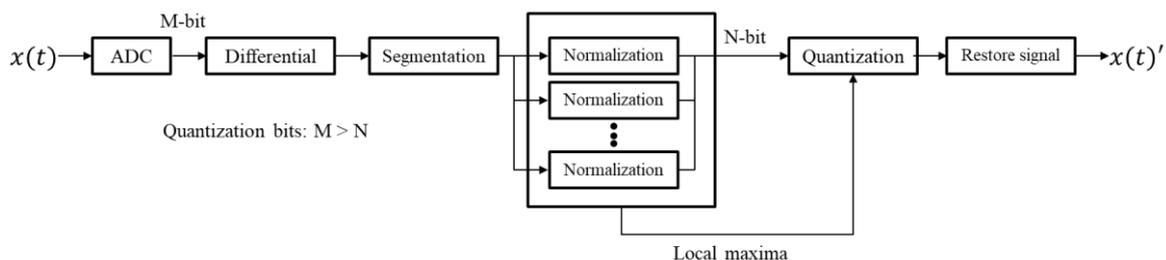


Fig. 1: Proposed Adaptive quantization block diagram with DIRM

METHODS

A. Data

The acoustic signals used in the study were transmitted for 0.2 seconds at 2 second intervals from a circular array sensor and received by an acoustic sensor with a center frequency of 80 kHz and a bandwidth of 50 kHz. Since the transmitted signal is included in the received acoustic signal, it was removed before use.

B. Dynamic interval region method

Since the adaptive quantization technique performs normalization by region, it can minimize signal loss when the dynamic range of each region is set small. The existing EIRM does not consider the characteristics of the signal, so there are large dynamic range regions, but the proposed DIRM differentiates the signal and divides the region when it exceeds the threshold, so it minimizes the dynamic range of each region.

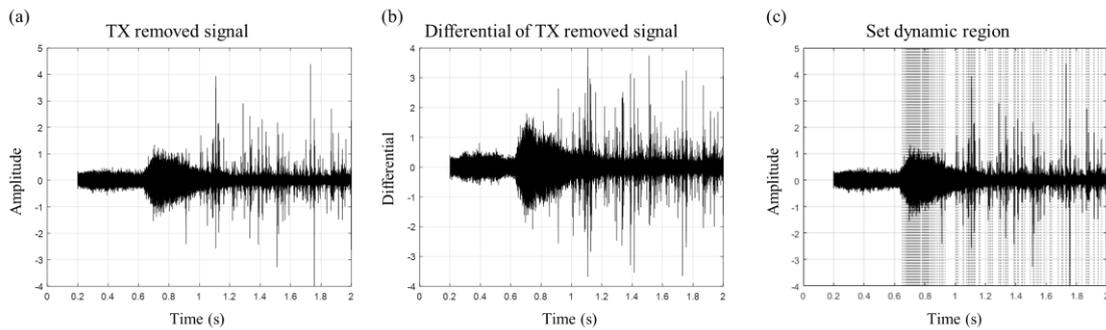


Fig. 2:TX removed signal (a), Differentiation of the signal (b) and the region divided into DIRM (c). The boundaries of the region set according to the change threshold are indicated by dots

The threshold was arbitrarily set to an absolute value of 1, and the boundaries of adjacent regions were set to the same region. The number of regions divided was 196. Normalization was performed for each region divided, and local maxima were calculated. Local maxima are used to restore data re-quantized to low bits.

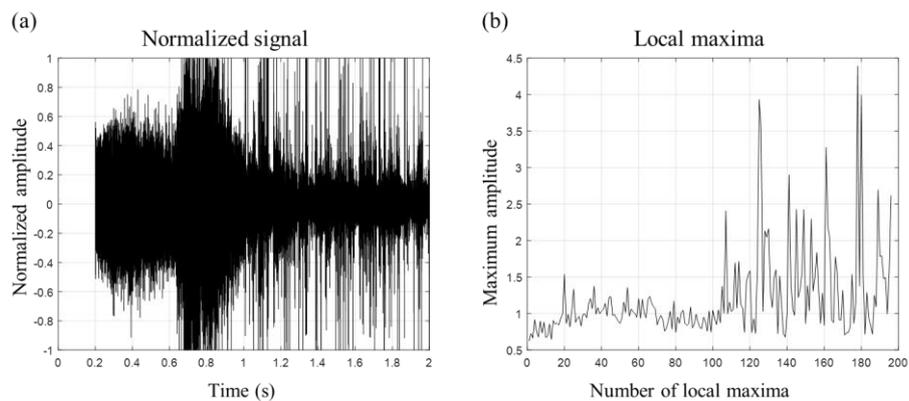


Fig. 3:(a) Normalization was performed by dividing the area by the change threshold (Fig. 2b), and (b) the local maxima, which is the maximum value for each area, was obtained.

C. Short Time Fourier Transform (STFT)

STFT is a method of analysing received acoustic signals according to time and frequency axes, used for target identification and detection in sonar systems. Since acoustic signals are randomly received and statistical characteristics of long-term signals change over time, Fast Fourier Transform (FFT) of the entire signal cannot identify the characteristics of the changing signal. If it is assumed that the characteristics of the signal change relatively slowly and are stationary in a short period of time, it can be analysed using STFT, which divides it into short segments and then performs FFT on each short segment

D. Percentage error rate

The percent error rate is a method of measuring how close two values are. It is essential to evaluate how much of the original data is restored after the signal is re-quantized to a lower bit to reduce the amount of data to be transmitted. The percent error rate was calculated using the STFT Magnitude of the restored signal and the original signal and used for quantitative evaluation. Here, $x(t)$ is the original signal and $x'(t)$ is the quantized restored signal. The threshold was arbitrarily set to an absolute value of 1, and the boundaries of adjacent regions were set to the same region. The number of regions divided was 196. Normalization was performed for each region divided, and local maxima were calculated. Local maxima are used to restore data re-quantized to low bits.

$$\text{Percentage error} = \frac{\sum_{t=1}^N |x(t) - x'(t)|}{\sum_{t=1}^N |x(t)|} * 100 \tag{1}$$

RESULTS

A. Qualitative evaluation

For qualitative evaluation, we performed STFT for each re-quantization bit. The normalized data by region was re-quantized to 1–15 bits, which is smaller than the 16 bits of the existing sonar system's quantization bits, and only the results for re-quantization 6-bit where the difference from the original is visible to the naked eye, are presented. When comparing the STFT results, the background noise gradually disappeared as the bit increased, and from the 6-bit re-quantization result, the noise components of the restored signal began to differ visually (red arrow) when DIRM (Figure 4b) was performed rather than EIRM (Figure 4a).

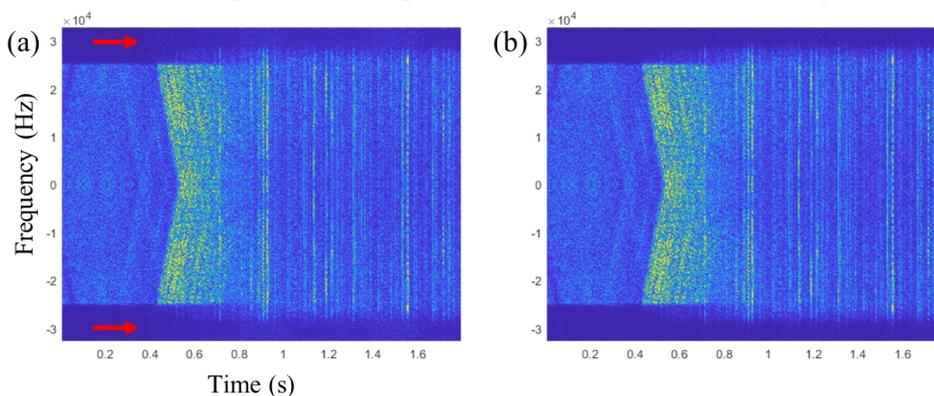


Fig. 4: STFT result of EIRM (a) and DIRM (b)

B. Quantitative evaluation

The error rates of the signals restored after re-quantization with the two methods were measured using Equation 1. When EIRM was performed, the error rates were 31.73%, 16.47%, and 8.20% at 5, 6, and 7 re-quantization bits, respectively, while the DIRM results showed low error rates at all re-quantization bits, at 13.99%, 6.89%, and 3.43%. The largest error rate difference occurred at 4 re-quantization bits, and the DIRM result showed more than twice the error rate up to 5 re-quantization bits compared to EIRM, showing greater similarity to the original signal.

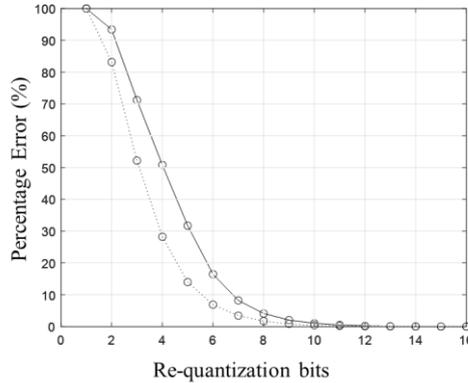


Fig. 5: Error rate according to re-quantization bit when DIRM (dot) and EIRM (line) are used

Re-quantization bit	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Error rate of Equal interval region (%)	100	93.39	71.21	50.85	31.73	16.47	8.20	4.10	2.03	1.02	0.51	0.25	0.13	0.06	0.03	0.02
Error rate of Dynamic interval region (%)	100	83.19	52.17	28.24	13.99	6.89	3.43	1.71	0.85	0.42	0.21	0.11	0.05	0.03	0.01	0.01
Difference of error rate (%)	0	10.21	19.04	22.61	17.74	9.57	4.77	2.39	1.18	0.60	0.30	0.15	0.07	0.04	0.02	0.01

Table 1: Error rate of EIRM and DIRM according to re-quantization bit

DISCUSSIONS & CONCLUSION

In this paper, we first applied adaptive quantization technique to the sonar system under study to reduce the transmission amount with minimizing data loss. We proposed a DIRM to reduce signal loss compared to the EIRM used in adaptive quantization, and proved it quantitatively and qualitatively. From the result of 5-bit re-quantization by DIRM, it was confirmed that less noise occurred in the restored signal even with the naked eye. In addition, when the error rate of the restored signal for each re-quantization bit was calculated, the DIRM had a lower error rate than the EIRM for all re-quantization bits, and the maximum difference was 22.61% at 4 bits.

There are still many aspects that need to be addressed to ensure the practicality of this method. The scope of this study does not yet include sonar images provided to the operator, and the change threshold was arbitrarily set to half of the maximum change threshold. Instead, the error rate was evaluated by focusing on the reduction of signal loss in the existing adaptive quantization. The author's future research will study whether there is a difference from the original signal when performing signal processing up to detection and identification of the restored signal after re-quantization.

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