Signal Processing 120 (2016) 129–140

Contents lists available at ScienceDirect

Signal Processing

journal homepage: www.elsevier.com/locate/sigpro

Two forward adaptive dual-mode companding scalar quantizers for Gaussian source

Jelena Nikolić *, Zoran Perić, Aleksandra Jovanović

Faculty of Electronic Engineering, University of Niš, Aleksandra Medvedeva 14, 18000 Niš, Serbia

ARTICLE INFO

Article history:
Received 3 February 2015
Received in revised form
26 August 2015
Accepted 27 August 2015
Available online 6 September 2015

Keywords:
Dual-mode companding
Scalar quantizer
Forward adaptation
Gaussian source
Optimal compressor function
Piecewise linear compressor function

ABSTRACT

In this paper we propose a novel model of piecewise linear companding scalar quantizer (PLCSQ) having the piecewise linear compressor function determined by minimizing the mean-squared error between the optimal compressor function and the piecewise linear compressor function for the Gaussian source subject to the constraint of the equal number of cells per segments. We show that with the increase of the number of segments, the difference between the optimal compressor function and the novel piecewise linear compressor function decreases, which implies that the novel PLCSQ, having a simpler design and implementation procedure compared to the one of optimal companding scalar quantizer (OCSQ), can be used as a good alternative for OCSQ. We also consider the implementation of these two quantizers in the forward adaptive dual-mode quantization scheme. The numerical results presented in the paper indicate that the proposed quantizers are worth implementing not only in view of flexibility in the bit rate choice, but also in view of the significant gain in signal to quantization noise ratio (SQNR) achieved over the one forward adaptive unrestricted companding scalar quantizer. Also, the numerical results indicate great possibilities for application of the proposed quantizers in high-quality quantization of Gaussian source signals.

1. Introduction and motivation

In ordinary fixed-rate scalar quantization, a unit bit rate decrease results in an approximately 6 dB decrease in the quality of the quantized signal, which can be unfavorable [1]. Although fixed-rate scalar quantizers (SQs) are simplest to design, they generally do not offer sophisticated compression as it is the case with high-dimensional vector quantizers [1]. Since the application of vector quantizers is often complexity-restricted, more sophisticated compression models based on fixed-rate SQs providing the quality-rate slope smaller than 6 dB/1 bit have become essential and have been recently proposed in [2,3]. In models from [2] and [3], the input signal, modeled by the Laplacian probability density function (PDF), has been processed in frame by frame manner, where the frame refers to the sequence of samples of a certain finite length. In particular, in [2] and [3], for each frame procession, the selection has been made between the two available forward adaptive nonlinear companding SQs designed for the Laplacian PDF, i.e. between the restricted quantizer and the unrestricted one. In both models, the restricted quantizer has been used when all the amplitudes of the samples within the frame belong to its support region. Otherwise, the second remaining quantizer, named unrestricted quantizer, having an equal number of quantization levels, the same form of the compressor function and a wider support region, has been used. As the restricted quantizer is designated for quantization of the frames of samples having the amplitude dynamic that ranges within its support region, it introduces only the granular distortion, where its overload distortion equals zero. By utilizing this convenience and by frequently selecting the

* Corresponding author. Tel.: +381 18529213; fax: +381 18588399.
E-mail addresses: jelena.nikolic@elfak.ni.ac.rs (J. Nikolić), zoran.peric@elfak.ni.ac.rs (Z. Perić), aleksandra.jovanovic@elfak.ni.ac.rs (A. Jovanović).

http://dx.doi.org/10.1016/j.sigpro.2015.08.016
0165-1684/

restricted quantizer, the total distortion has successfully been decreased, i.e. the signal quality has successfully been increased, in comparison to the one of the unrestricted quantizer with an equal number of quantization levels. This has allowed the decrease of the bit rates of the restricted and the unrestricted quantizer, where the high quality of the Laplacian source signals has still successfully been achieved with this solution. In particular, it has been shown that compared to the one unrestricted quantizer, the models from [2] and [3] provide high quality of the Laplacian source signals at about 1 bit/sample lower bit rate, which is beneficial from the compression point of view.

Unlike [2] and [3], where the quantizer models are composed of SQs with an equal number of quantization levels, the models proposed in [4,5] are composed of SQs with an unequal number of quantization levels. To provide the highest possible quality of the quantized signal, given fixed bit rate, the support region thresholds of SQs observed in [2–5] have been optimized. The importance of the support region optimization has been shown in a number of papers addressing this topic [6–10]. Along with the optimization of the support region thresholds, for the given bit rate, the optimization of the number of quantization levels has been performed in [5]. The optimization procedure described in [5] is rather complex because of the fact that both, the signal quality and the bit rate, depend on the number of quantization levels and on the support region thresholds.

Unlike [2–5], where Laplacian PDF has been assumed in designing SQs, in this paper we assume Gaussian PDF, which is a more realistic PDF for the short-term statistic of speech signals [1]. We point to the fact that in designing the optimal companding scalar quantizer (OCSQ) for the Gaussian PDF, it is difficult to determine the inverse optimal compressor function, which is not a case in designing OCSQ for the Laplacian source [2]. Also, for the assumed Gaussian PDF, OCSQ should perform complex numerical integration and solving integral equations [1,7,11]. Eventually, from the aspect of hardware, it is hard to pair the characteristics of nonlinear elements that are used for the implementation of a nonlinear compressor and an expandor, which are two basic blocks of each companding quantizer [11]. Accordingly, when the Gaussian PDF is assumed, there is an evident need for simplifying the design and implementation procedure. One of the manners to achieve this goal is based on the linearization of compressor functions and the resulting quantizers are known as piecewise linear companding scalar quantizers (PLCSQs). This has motivated the research presented in this paper.

In PLCSQ, the support region consists of several segments, each of them containing several uniform quantization cells and uniformly distributed representation levels [1]. The fact that these quantizers are piecewise linear and hence, simpler from the aspect of design and implementation than the nonlinear SQs [1], justifies their widespread application. For instance, in the contemporary public switched telephone networks high-quality quantized speech signals is provided by the PLCSQ specified by the G.711 Recommendation [12]. Some novel propositions of the PLCSQ design have been recently reported in [11, 13–15]. In [11], the novel method for designing the PLCSQ based on the mean-square approximation of the first derivative of the optimal compressor function has been proposed. In [13], the robustness conditions of the PLCSQ based on a piecewise linear approximation to the optimal compressor function have been analyzed. This analysis has been extended in [14], where signal to quantization noise ratio (SQNR) behavior in the wide range of variances has been analyzed for the forward adaptive PLCSQ designed for a Laplacian source according to the piecewise linear approximation to the optimal compressor function. Unlike the forward adaptive PLCSQ proposed in [14], where the number of cells has been assumed to be constant per segments and where the segments have been determined by the equidistant partition of the optimal compressor function, the number of cells per segments has been optimized in [16,17]. Similarly to [16,17], in the PLCSQ model from [15], which is based on the approximation of the first derivate of the optimal compressor function at the points in the middle of the segments, the number of cells per segments is unequal. This resulted in SQNR increase, but in a more complex encoding/decoding procedure.

In this paper we perform an analysis of two different quantizer models. In both models, for processing of each frame of samples, forward adaptation of the two available companding SQs designed for the Gaussian PDF is performed and the selection is made between the forward adaptive restricted quantizer and the unrestricted one. Since the proposed quantizers can select one of the two quantization modes, we named them dual-mode companding SQs. Specifically, we observe the forward adaptive dual-mode optimal companding scalar quantizer, as well as the forward adaptive dual-mode piecewise linear companding scalar quantizer. Unlike the OCSQ, which is implemented in the first dual-mode quantization scheme mainly for the comparison purposes, the novel PLCSQ, which we propose and implement in the second dual-mode quantization scheme, is developed to overcome the difficulties observed in designing and implementing the first dual-mode quantizer.

In particular, in this paper we have three goals. The first one is to optimize the OCSQ in the dual-mode quantization scheme for the Gaussian PDF. We intend to provide a fair performance comparison with the model from [2], where OCSQ is optimized for the Laplacian PDF. Note that the similarity of the models from [2] and [3] and these which we propose follows from the same methodology applied in selecting the restricted quantizer or the unrestricted one. However, due to different compressor functions of the companding quantizers, resulting from the different assumed PDFs, the optimization procedure of the models from [2] and [3] rather differs from the one described in this paper. The second goal is to propose a novel PLCSQ and to analyze how close performances of the OCSQ and the novel PLCSQ are. Eventually, the third goal is to determine the minimal bit rate of the proposed dual-mode companding SQs at which high-quality quantization is achieved.

The novel PLCSQ model has the piecewise linear compressor function determined by minimizing the mean-squared error (MSE) between the optimal compressor function and the piecewise linear compressor function for the Gaussian source subject to the constraint of the equal number of cells per segments. As in PLCSQ model from [14], an equal number of cells per segments is assumed for simplicity reasons. However, unlike PLCSQ model from [14], where the segment thresholds are a priory defined, in the PLCSQ model