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Improved Performance of Multistage Lattice Vector Quantization with Hybrid Lattice Structure

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Abstract: Lattice vector quantization (LVQ) reduces computational load and design complexity due to its regular structure. In this letter, we introduce and analyze the performance of two hybrid combinations of two lattices i.e. the $A_nA^*_n$ and $A_nD^*_n$. Experiment results show that multistage LVQ with lattice A_nA^{*n} combination in four dimensional vector offers the least quantization errors with $p = 0.0098$ as compared to other single stage lattices or combination of lattices.

Key words: LVQ, Quantization error, Hybrid

INTRODUCTION

Vector quantization technique has been employed in applications related to multimedia communications (Gersho, A. and R.M. Gray, 1992). There have been many research efforts done regarding lattice vector quantization (LVQ) as presented in (Gersho, A. and R.M. Gray, 1992; Conway, J.H. and N.J. Sloane, 1999; Agrell, E., 2002). The main reason for the choice of this technique is due to its lower computational load and design complexity.

Servetto *et al.* (1999) uses multistage LVQ where a sublattice of order one is formed within the main lattice. This produces two descriptions of source data for transmission in wireless channel. The multistage LVQ has been also successfully employed in wavelet based image compression scheme as presented in (Bai, H., 2007; Mukherjee, D. and S.K. Mitra, 2002). The work in (Mukherjee, D. and S.K. Mitra, 2002) presents a successive refinement uniform Voronoi lattice VQ (VLVQ) algorithm using two stages A_2 lattice. Meanwhile in (Salleh, M.F.M. and J. Soraghan, 2007), the application of multistage LVQ (MLVQ) technique in video coding is presented.

A thorough performance analysis of single lattice has been well documented in (Conway, J.H. and N.J. Sloane, 1999) where Conway and Sloane have compared the performances of different lattices with several dimensions. Other works that compare the performance between lattices are presented in (Gao, Z., 1995; Postol, M.S., 2002). In Gao *et al.(1995)* compare the performance of specific lattices, Z, E_8, and leech lattice for Quantization of the transformed image in the form of generalized Gaussian distribution. The work in (Postol, M.S., 2002) compare the performance of E_8 and Leech lattice for motion estimation algorithm in video coding that reduce decoder computational complexity.

All of those lattice quantizer performance analysis in (Conway, J.H. and N.J. Sloane, 1999; Gao, Z., 1995; Postol, M.S., 2002) are based on single stage lattice. In this paper, the hybrid multistage LVQ (HMLVQ) technique that combines two types of lattices *i.e.* the (A_4 and A^*_4) and (A_4 and D^*_4) are proposed. Then, the performances of these quantizers are evaluated. Simulation results show that performance of HMLVQ with $A_4A^*_4$ combination outperforms others in term of Quantization errors (p) for various dimensions (n = 2, 3, 4 and E_8).

Multistage Lattice Vector Quantization (MLVQ):

The MLVQ technique consists of several lattices, where the size of the inner lattice is reduced by a certain scaling factor. Fig. 1 depicts a simple example of multistage LVQ in 2 dimensions lattice A_n. As explained in (Gao, Z., 1995), the essence of multistage LVQ is to generate a series of decreasing scale of zero-centered Voronoi lattice regions with maximum of three sublattice A_n as shown in Fig. 1a. Unlike in (Gao, Z., 1995), in this work we generate an *m-order* or stages of sublattices. The technique introduces the veronoi regions of

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having A_n lattice as indicated by $V_1(A_1,0)$, $V_2(A_2,0)$, ..., $V_n(A_n,0)$ where $V_1(A_1,0)$ as the main lattice. Each sublattice has a zero-centered voronoi region that has smaller scale from the main lattice.

The sublattices are arranged in such a way that no overlapping can be occurred as shown in Fig. 1. The scale down factor defines the size of sublattice given as $1/2^m$ of the main lattice. The order of sublattice or stage is indicated by the value of *m*. For example, the scale down factor is 1/8 ($r = 2^3 = 8$) and the order or stage is 3 as shown in Fig. 1a.

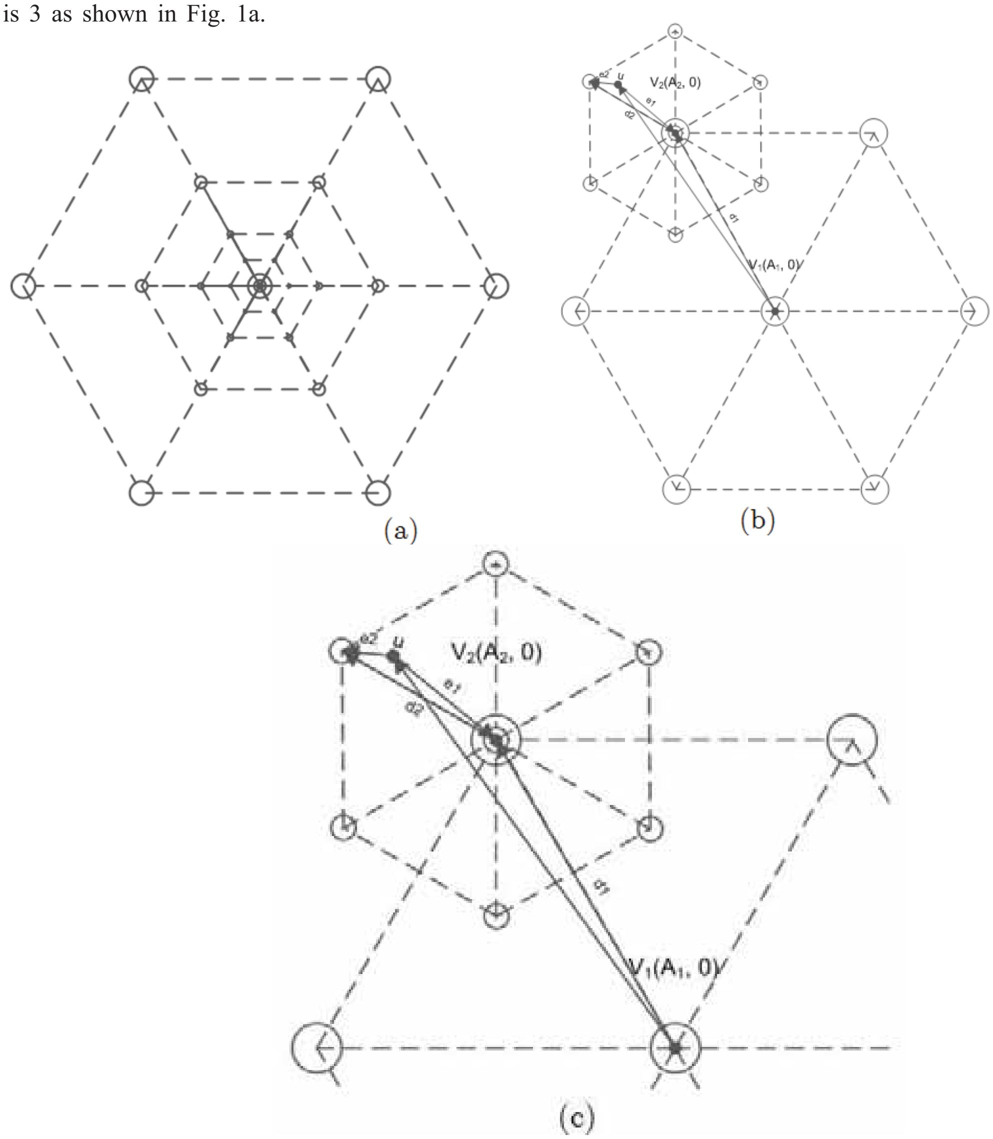

Fig. 1: 2-dimension Multistage Lattice Vector Quantization, a) 3th order of MLVQ scaling the points until 8 times, b) 1st order of MLVQ and vector operation c) Sublattice of 1st orde of MLVQ.

The process of finding the closest point in multistage LVQ can be seen in Fig. 1b. First, the vector *u* is quantized by $V_1(A_1,0)$ lattice with radius d_1 (top left corner of lattice V_1). The Quantization error e_1 is given by $e_1 = u - d_1$. After that, the zero-centered lattice $V_2(A_2,0)$ is constructed as shown in Fig.1c. The size of $V_2(A_2,0)$ is reduced by ½ of lattice V_1 and the center coordinate of V_2 is subtracted by radius d_1 and becomes the origin of V_2 lattice.

Next, vector *u* is quantized using $V_2(A_2,0)$ sublattice. This results vector *u* to be rounded to the point at the top left corner of sublattice $V_2(A_2,0)$. The Quantization error e_2 is given by $e_2 = d_2 - e_1$. Thus, the quantization error e_2 is smaller than e_1 due to smaller size of sublattice as shown in Fig. 1c.

Hybrid Multistage Lattice Vector Quantization:

The idea of hybrid multistage lattice vector Quantization is to combine two different lattices to form a multistage process. The propose method uses the first lattice as *A*-type and the sublattice or the next stage lattice as different type with higher density.

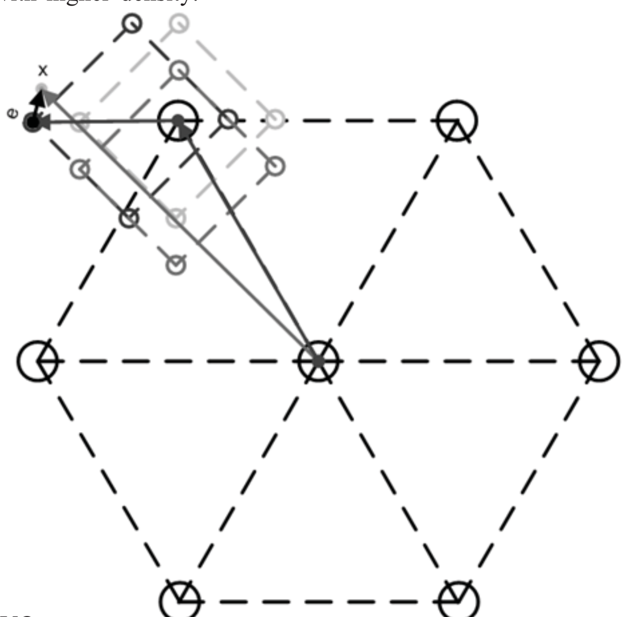

Fig. 2: Hybrid A_2D^{*2}MLVQ

Fig. 2 shows an example of Hybrid MLVQ using A_2 as the main lattice and D^*_2 as the sublattice. First, the data or vector x is quantized by A_2. Then, x is quantized again using D^*_2. The process is exactly the same as the MLVQ process as explained in section 3. The difference is that the sublattice used here is denser than main lattice. The other combination is using A_2 as the main lattice and A^*_2 as the sublattice as shown in Fig. 3.

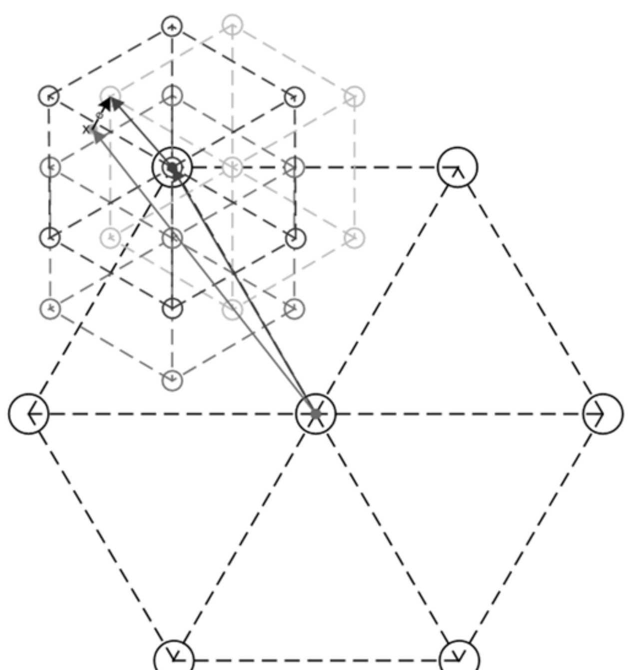

Fig. 3: Hybrid A_2A^{*2}MLVQ

RESULTS AND DISCUSSION

The Gaussian distribution source is used in simulation to obtain the performance of various lattice combinations. Fig. 4 shows the overall performances of several lattices with dimension 2, 3, 4 and 8 (for *E* type lattice). From that Figure, the performance of vector quantizer improves as the dimension of lattice increased. Secondly, comparing the performance of A_2A_2 multistage LVQ with $A_2A^*_2$ quantizer, the former offers better performance. This is because the density of the subsequent lattice is higher than first lattice. Comparing the performances of hybrid combinations using 4 dimensions lattice reveals that the combination of $A_4A^*_4$ offers the best performance.

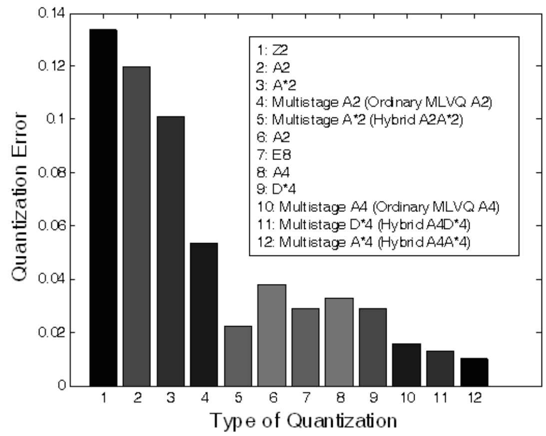

Fig. 4: Comparison of LVQ with several types of lattices.

Conclusion:

This paper proposes various hybrid lattice combinations for multistage quantizer. The performance comparison of various single lattice quantizer as well as with multistage lattice quantizers has been conducted. The best performer is given by the hybrid combination of $A_4A^*_4$.

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