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Hadamard transform based fast codeword search algorithm for high-dimensional VQ encoding

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Abstract

An efficient nearest neighbor codeword search algorithm for vector quantization based on the Hadamard transform is presented in this paper. Four elimination criteria are derived from two important inequalities based on three characteristic values in the Hadamard transform domain. Before the encoding process, the Hadamard transform is performed on all the codewords in the codebook and then the transformed codewords are sorted in the ascending order of their first elements. During the encoding process, firstly the Hadamard transform is applied to the input vector and its characteristic values are calculated; secondly, the codeword search is initialized with the codeword whose Hadamard-transformed first element is nearest to that of the input vector; and finally the closest codeword is found by an up-and-down search procedure using the four elimination criteria. Experimental results demonstrate that the proposed algorithm is much more efficient than the most existing nearest neighbor codeword search algorithms in the case of problems of high dimensionality.

Keywords: Vector quantization; Image coding; Fast codeword search; Hadamard transform

1. Introduction

Vector quantization (VQ) is a block-based lossy compression technique, which has been successfully used in image compression [5,22], image filtering [6] and speech coding [14]. The main idea of VQ is to exploit the statistical dependency among the vector components to reduce the spatial or temporal redundancy and obtain a high compression ratio. VQ can be defined as a mapping from k-dimensional Euclidean space R^k into a finite subset C of R^k called the codebook: $C = \{\boldsymbol{y}_1, \boldsymbol{y}_2, \ldots, \boldsymbol{y}_N\}$, where $\boldsymbol{y}_i$ is a codeword and N is the codebook size. There are two key problems involved in VQ, i.e., codebook design and codeword search. The task of codebook design is to generate the N most representative codewords from a large training set that consists of M training vectors, where $M \gg N$. One well-known codebook design method is LBG algorithm or GLA [14]. The task of

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Nomenclature

C	codebook
$\boldsymbol{y}_i$	spatial codeword
R^k	Euclidean space
N	codebook size
M	number of training vectors
x	spatial input vector
k	vector dimension
X	transformed input vector
$\boldsymbol{Y}_i$	transformed codeword
S_x	sum of spatial input vector
S_i	sum of spatial codeword
m_x	mean of spatial input vector
m_i	mean of spatial codeword
v_x	deviation of spatial input vector
v_i	deviation of spatial codeword
V_X	deviation of transformed input vector
V_i	deviation of transformed codeword
$\|\boldsymbol{X}\|$	norm of transformed input vector
$\|\boldsymbol{y_i}\|$	norm of transformed codeword
X_1	first element of transformed input vector
Y_{i1}	first element of transformed codeword
$d_{\min}$	current minimum distortion
$\boldsymbol{H}_n$	the Hadamard matrix
VQ	vector quantization
FS	full search
IFS	improved full search
PDS	partial distortion search
TIE	triangular inequality elimination
ENNS	equal-average nearest neighbor search
EENNS	equal-average equal-variance nearest neighbor search
IENNS	improved equal-average nearest neighbor search
IEENNS	improved equal-average equal-variance nearest neighbor search
EEENNS	equal-average equal-variance equal-norm nearest neighbor search
SVEENNS	sub-vector equal-average equal-variance nearest neighbor search
WTPDS	wavelet transform based PDS
HTPDS	Hadamard transform based PDS
NOS	norm-ordered search
TNOS	transform-domain norm-ordered search

codeword search is to find the best-match codeword from the given codebook for the input vector. That is to say, the nearest codeword $\boldsymbol{y}_j = (y_{j1}, y_{j2}, \ldots, y_{jk})$ in the codebook C is found for each input vector $\boldsymbol{x} = (x_1, x_2, \ldots, x_k)$ such that the distortion between this codeword and the input vector is the smallest among all codewords. The most common distortion measure between $\boldsymbol{x}$ and $\boldsymbol{y}_i$ is the Euclidean distance as follows:

$$d(\boldsymbol{x}, \boldsymbol{y_i}) = \sum_{l=1}^{k} (x_l - y_{il})^2 \quad (1)$$

From the above equation, we can see that each distortion computation requires k multiplications and $2k - 1$ additions. For an exhaustive full search (FS) algorithm, encoding each input vector requires N distortion