HYBRID DIFFERENTIAL PULSE CODE MODULATION IN WAVELET DOMAIN AND LOSSLESS METHODS FOR IMAGE COMPRESSION

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Abstract

Digital images are widely used in computer applications. Uncompressed digital images require considerable storage capacity and transmission bandwidth. Efficient image compression solutions are becoming more critical with the recent growth of data intensive and multimedia-based web application.

In this paper, Hybrid Differential Pulse Code Modulation (DPCM) in wavelet domain and lossless methods (Huffman and Run length code) for image compression is investigated. The image signal is composed into four scales (approximate, horizontal, vertical and diagonal coefficients). The energy level of approximate is different from that of detail information; therefore, the approximate is quantized alone and horizontal and vertical are quantized alone by using the differential pulse code modulation (DPCM). In all simulations the diagonal coefficients are discarded. Two types of coding are used, Huffman code and run length coding (RLC) techniques. The results show that truncate horizontal and vertical coefficients using hard threshold gives best performance than soft threshold with gain about 3 dB to get the same compression ratio (CR). The wavelet based image compression using Huffman code gives CR about 77% compared with RLC that gives CR about 71% with suitable peak signal to noise ratio (PSNR).

Key words: image compression, discrete wavelet transforms (DWT), differential pulse code modulation (DPCM), Huffman code and run length code (RLC)

الخلاصة

تستعمل الصور الرقمية على نحو واسع في تطبيقات الحاسبة، والصورة الرقمية غير المضغوطة تتطلب سعة خزن كبيرة ومساحة انتشار واسعة. ومع النمو الاخير لبيانات تطبيقات الصورة الرقمية أصبح من الضروري ضغط الصورة الرقمية. في هذا البحث تم التطرق الى ضغط الصورة باستخدام الدمج بين التشكيل التفاضلي النبضي المرمز (DPCM) في مجال تحويل المويجة مع طرق الضغط بدون خسائر (Huffman and RLC). تم تحليل اشارة الصورة الى أربع معاملات (التقريبي , الافقي, العمودي والقطري). بما ان مستوى الطاقة للمعاملات التقريبية تختلف عنه في المعاملات الاخرى لذلك تم تكميم المعاملات التقريبية لوحدها والمعاملات الافقي والعمودي لوحدهما بأستخدام تقنية (DPCM) . تم أهمال معاملات القطرية من كل الحسابات. كما تم أستخدام نوعين من التشفير هما شفرة Huffman و شفرة RLC . أوضحت النتائج ان تقليم المعاملات الافقية والعمودية بأستخدام تقليم (hard) اعطى تمثيل أفضل من تقليم (soft)بربح مقداره (3 dB) لنفس نسبة الضغط(compression ratio). ان ضغط الصورة بأستخدام شفرة (Huffman) أعطت نسبة ضغط بمقدار 77% مقارنة مع تقنية (RLC) التي تملك نسبة ضغط حوالي 71% مع (PSNR) مناسب.

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1-Introduction

With the continuous growth of modern communication technology, demand for image transmission and storage increases rapidly. Advance in computer technology for mass storage and digital processing has paved the way for implementing advanced image compression techniques to improve the efficiency of transmission and storage of images. Image compression is very important because it reduces the volume of data by exploiting spatial, statistical, spectral and temporal redundancies and by eliminating the data that can not be displayed suitably by the associated display or imaging devices.

There are two types of image compression methods, the first type is called lossless methods because no data are lost, and the original image can be recreated exactly from the compressed data. The most commonly lossless techniques are Huffman code, run-length coding (RLC), and arithmetic coding [1, 2]. The second type of compression is called lossy because they allow a loss in the actual image data, so the original uncompressed image cannot be created exactly from the compressed file. The most commonly lossy techniques are differential pulse code modulation (DPCM) [3], discrete cosine transform (DCT) [4] and wavelet transform [5]. The lossy methods provide higher compression ratios, and, therefore, they are often applied in image compression.

The wavelet transform plays substantial role in a multiresolution analysis (MRA) technique particular in the last ten years, where it was used in image processing. In discrete wavelet transform the image will be transformed in each of decomposition to a one low information image and three details image in horizontal, vertical and diagonal axis images, also the low information images can be decomposition into another four images. This approach of decomposition process provides us a number of unrealizable features in the original image which appear in their levels after the application of the transformation. Due to this reason, the wavelet transform is a very good choice for image compression [6]. In this paper the image compression technique using discrete wavelet transform (DWT), differential pulse code modulation (DPCM), run-length code (RLC), and Huffman code will be investigated.

2- Discrete Wavelet Transform (DWT)

The discrete wavelet transform (DWT) is a powerful signal processing tool to perform multi-resolution analysis. The decomposition consists of observing the signal at different resolution levels and different versions of a “mother” scaling and wavelet functions. Time localization is achieved by projecting the signal onto a subspace spanned by contracted versions of the wavelet function (high frequency), while frequency localization is achieved by implementing the same procedure using dilated (low frequency) versions of the mother scaling function.

Wavelet based coder leads to interesting performance compared to standardized compression algorithms and because of the good time and frequency localization of the wavelet function, the wavelet function is well suited for image compression.

Two dimensional DWT is realized as a cascade of two one-dimensional wavelet transform operations. The first wavelet transform operates in horizontal direction and the second wavelet transform operates in vertical direction. A one level of two-dimensional wavelet decomposition and reconstruction is depicted in Fig. (1) and Fig. (2) respectively [6,7]. After each one stage two dimensional wavelet decomposition, the two dimensional input signal is projected onto four subspace of low-low (LL), high-low (HL), low-high (LH), and high-high (HH) band frequencies. The coefficients h(r) and g(r) are low pass and high pass FIR filter coefficients respectively. The scaling coefficients (g(r)) are related to wavelet coefficients (g(r)) by:

$$h(r) = (-1)^r g(R - r)$$
(1)

where R is a finite odd length of quadrature mirror filter.

The symbols ↓2 and ↑2 are down-sampler (decimator) and up-sampler respectively.

3- Wavelet Thresholding

There are two ways in which threshold can be applied:

a-Hard-Thresholding

Hard-thresholding also called (kill/keep) strategy, which is the simplest method and can be stated mathematically as [6]:

$$T(t,x)=\begin{cases} x & ,|x| > t \\ 0 & ,|x| \le t \end{cases}$$
(2)

where T(t,x) represents the output value after thresholding the wavelet coefficient, x is the input image and t represents the value of threshold.

$$t = \sigma\sqrt{2\log(N)}$$
(3)

where σ is standard deviation of the N wavelet coefficients.

b- Soft-Thresholding

Soft-thresholding is alternative scheme of hard-thresholding and can be stated mathematically as [6]:

$$T(t,x)=\begin{cases} \operatorname{sign}(x)(|x| - t) & ,|x| \ge t \\ 0 & ,|x| < t \end{cases}$$
(4)

4- Differential Pulse Code Modulation (DPCM) [8]

Fig. (3) shows differential pulse code modulation (DPCM) encoder scheme. In this system the input to the quantizer is the difference between the unquantized input sample (x(n)) and the prediction of the input sample ($\tilde{x}(n)$).

$$d(n)=x(n)-\tilde{x}(n)$$
(5)

The predicted value is the output of the predictor system (P), whose input is a quantized version of the input signal, x(n). The quantized difference signal can be represented as:

$$\hat{d}(n) = d(n) + e(n)$$
(6)

where e (n) is the quantization error. The quantized difference signal is added to the predicted value to produce a quantized version of the input, i.e.:

$$\hat{x}(n) = \tilde{x}(n) + \hat{d}(n)$$
(7)

Fig. (4) involves a decoder to reconstruct the quantized difference signal from which the quantized input is reconstructed using the same predictor as used in encoder.

The predictor P, is linear predictor, where $\tilde{x}(n)$ is a linear combination of the past quantized value.

$$\tilde{x}(n) = \sum_{k=1}^{p} a_k \hat{x}(n-k)$$
(8)

where a_k is predictor coefficients and p is order predictor.

One method can be used to find the optimum value of predictor coefficients is Levinson Durbin algorithm [8].

4-Huffman Coding

This is the most popular statistical data compression technique for removing coding redundancy. It assigns the smallest possible number of code symbols per source symbol and hence reduces the average code length used to represent the set of given value. The general idea is to assign least number of bits to most probable (or frequent) values occurring in an image. The Huffman algorithm can be described in five steps [9, 10]:

1- Find the gray-level probabilities for the image.
2- Order the input probabilities from smallest to largest.
3- Combine the smallest two by addition.
4- Repeat step 2, until only two probabilities are left.
5- By working backward along the tree, generate code by alternating assignment of 0 and 1.

5- Run Length Coding (RLC)

Run Length Coding (RLC) is an image compression that works by counting the number of adjacent pixels with the same gray level value. This count, called the run length, is then coded and stored.

RLC developed to perform on gray level images to include the gray level of a particular run as part of the code. Here, instead of various values in the each run can be used only two values (L,G) to represent the run. Each run can be encoded by two values: first one for the length of the run (L) and the second one for the approximate gray level value of the run (G) [1].

6-Wavelet Based Image Compression Techniques

6-1 Image Compression Technique Using RLC

Procedure

1. Obtaining wavelet transform decomposition of the input image using different types of wavelet family.
2. Obtaining the approximate (LL band), horizontal (LH band), vertical (HL band) and discarding the diagonal coefficients (HH band).
3. Filtering the vertical and horizontal coefficients using hard and soft threshold.Encoding the approximate coefficients using DPCM.

4. Using RLC (Encoder) for compressing the vertical and horizontal coefficients.
5. Using RLC (Decoder) for decompressing the vertical and horizontal coefficients and using DPCM decoder to decode the approximate coefficients.
6. Performing the IDWT to reconstruct the image again.

6-2 Image Compression Technique Using Huffman Code

Simulations of image compression using discrete wavelet transform are carried out. Compressions are made on the calibrated 256 × 256 woman image. Woman image is an academic model in the image processing community for testing the efficiency of various algorithms. Fig. (7) Shows flowchart of image compression using RLC and Fig. (8) Shows flowcharts of image compression using Huffman code.

Procedure

Encoding process is performed by the following steps:

1. Obtaining wavelet transform decomposition of the input image using different types of wavelet family.
2. Obtaining the approximate (LL band), horizontal (LH band), vertical (HL band) and discarding the diagonal coefficients (HH band). Filtering the vertical and horizontal coefficients using hard and soft threshold.
3. Applying DPCM for approximate, vertical and horizontal coefficients.
4. Obtaining the output code for the compressed image depending on Huffman code table.

Decoding is performed by the following steps:

1. Applying the Huffman decoding for the compressed image.
2. Applying DPCM decoding for approximate, vertical and horizontal coefficients that is reconstructed from the previous step.
3. Performing the IDWT to reconstruct the image.

7- Experimental Results

The image was subjected to one level DWT using different types of wavelet family (db1, db2, db4, and db8). The approximate coefficients are kept without thresholding and the horizontal and vertical coefficients are thresholding using both hard and soft threshold. In all simulations the diagonal coefficients are discarded because very small effect of this coefficients on the reconstructed image.

he compression ratio (CR) factor for RLC technique is calculated as:

$$CR = 1 - \left(\frac{(L_h + L_v) * n_d + L_a * n_a}{L_o * 8} \right) *100\% \qquad (9)$$

where L_h is the size of horizontal coefficients.

L_v is the size of vertical coefficients.

L_a is the size of approximate coefficients.

L_o is the size of original image signal.

n_a is the number of bit required for approximate coefficients

n_d is the number of bit required for horizontal and vertical coefficients.

The compression ratio factor for Huffman code technique is calculated as:

$$CR = 1 - \left(\frac{(L_h + L_v) * \ell_d + L_a * \ell_a}{L_o * 8} \right) *100\% \quad (10)$$

where ℓ_d is the average code length of the vertical and horizontal coefficients.

ℓ_a is the average code length of the approximate coefficients.

The original image and reconstructed image for RLC technique with hard threshold and db2 is shown in Fig. (9).

Table (3) shows image compression using Huffman code technique with

The original image and reconstructed image for Huffman code technique with

Table (4) shows image compression using Huffman code technique with soft

The average number of bits per pixel (Length) in a Huffman code is:

$$\ell = \sum_{i=1}^{N} n_i p_i \quad (11)$$

where n_i is length in bits of the code for i_{th} gray level

p_i is probability of the i_{th} gray level.

Table (1) shows image compression using RLC technique with hard threshold and different types of wavelet family.

Table (2) shows image compression using RLC technique with soft threshold and different types of wavelet family.

hard threshold and different types of wavelet family.

hard threshold and db8 is shown in Fig. (10).

threshold and different types of wavelet family.

Conclusions

The following points are concluded from the simulation results:

1. Wavelet based Image compression using Huffman code technique gives higher CR compared with RLC technique with gain compression about 8 %.
2. For image compression using RLC code, Hard threshold gives best performance than soft threshold with gain about 3 dB in PSNR to get the same compression ratio (CR).
3. Increase Daubechies order decrease the compression ratio (CR).
4. There is optimization between CR and PSNR any increase in CR will affect PSNR.
5. Image compression using Huffman code and soft threshold gives highest PSNR (42.424 dB) with CR about 74.897 % in db6. And the highest CR (77.239 %) with PSNR (27.82 dB) in db1.

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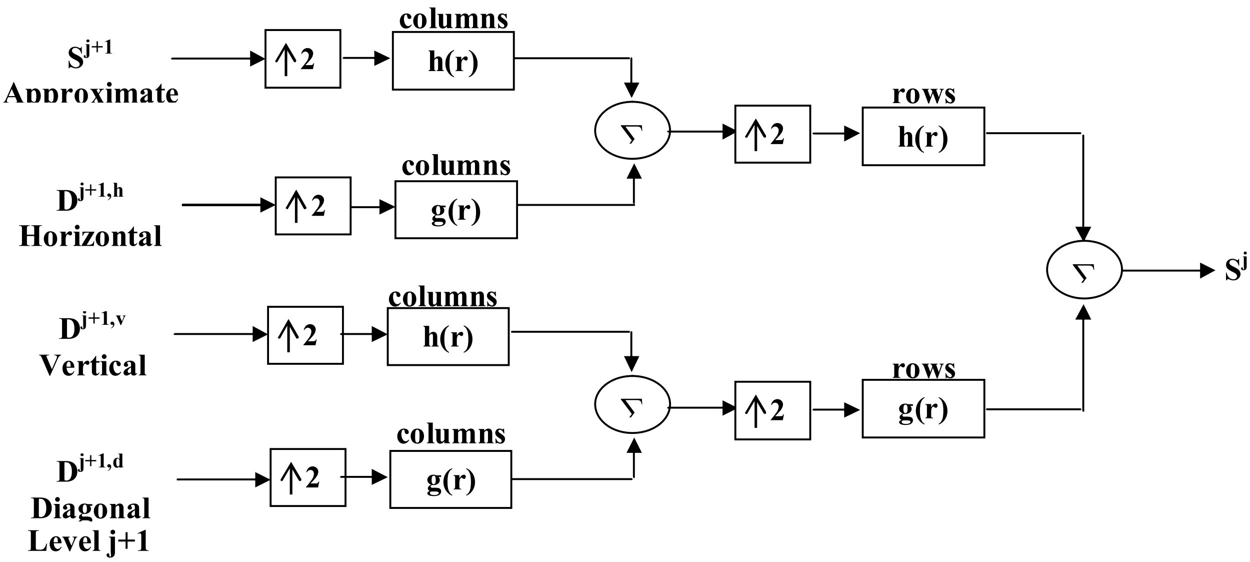


Fig.(2) Inverse discrete wavelet transform (synthesis)

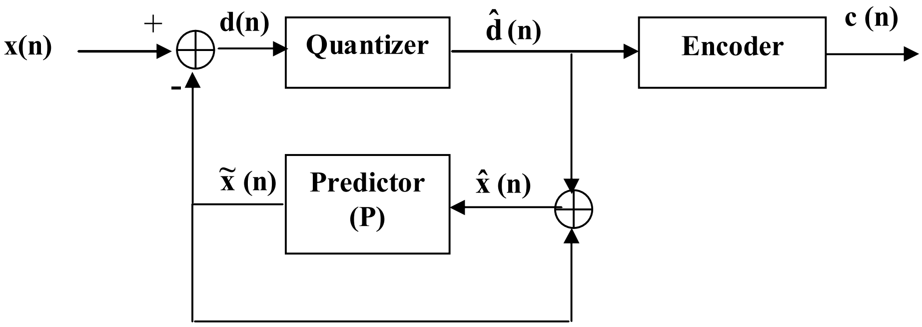


Fig. (3) DPCM encoder

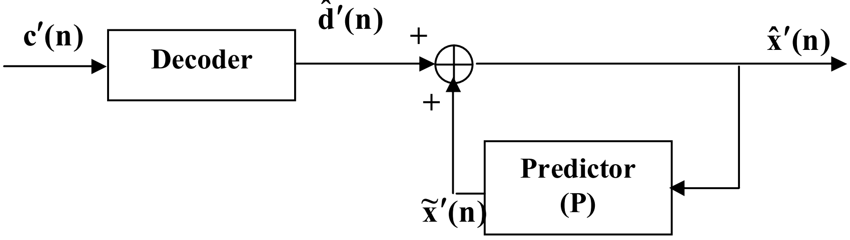


Fig. (4) DPCM decoder

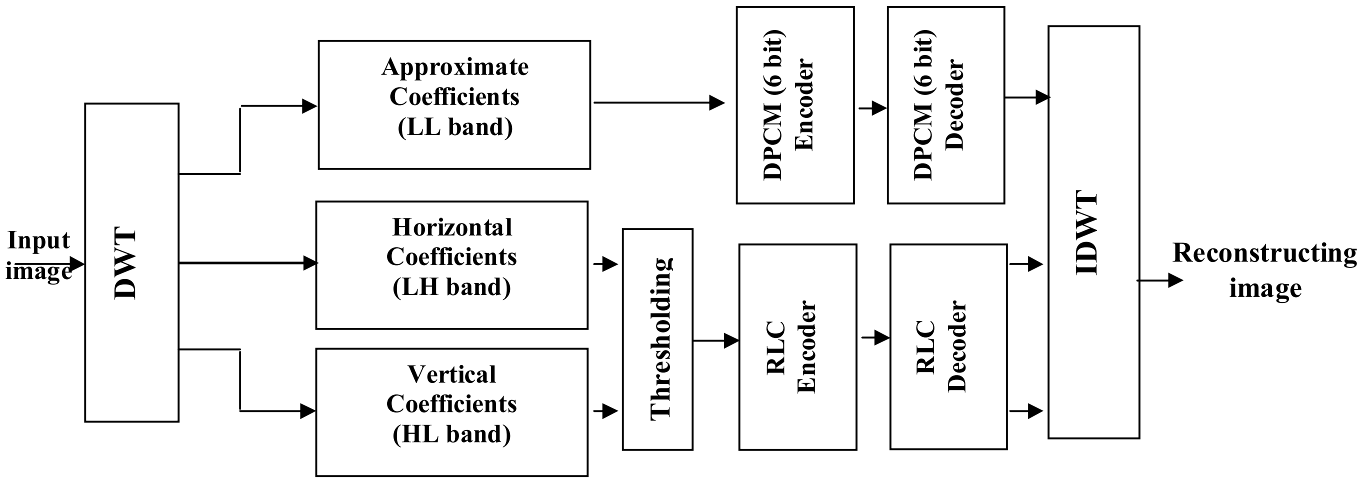


Fig.(5) Image compression and decompression system using DWT and RLC

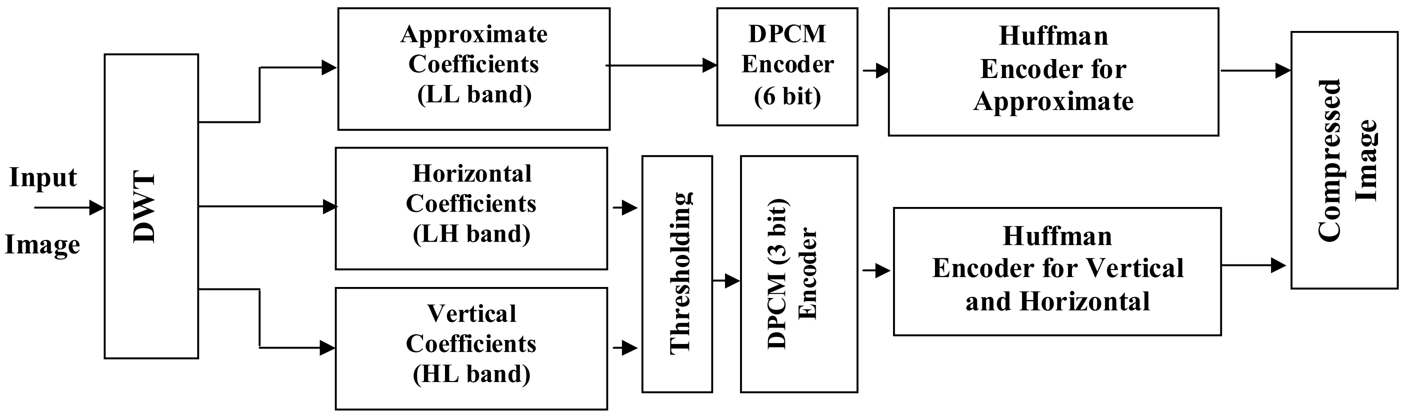


Fig.(6a) Image compression technique using DWT and Huffman code

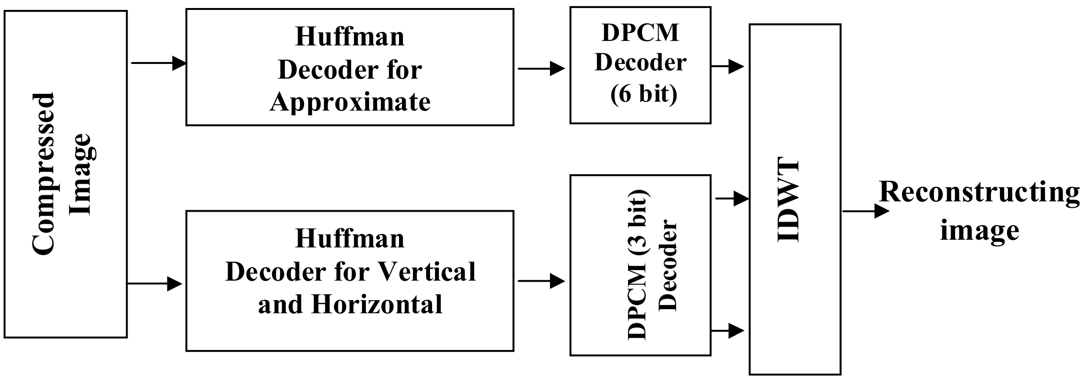
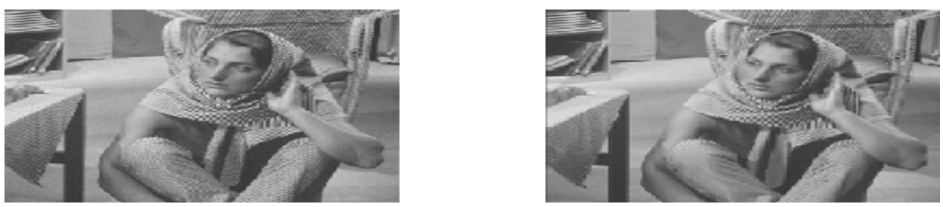


Fig. (6b) Image decompression technique

Table (1) Image compression using RLC technique and hard threshold

Wavelet family	CR(%)	PSNR
db1	71.055	30.975
db2	71.158	33.854
db4	69.774	34.880
db6	69.050	31.026
db8	68.893	28.271



Original image **Reconstructed image**

Fig. (7) Original and reconstructed image for hard threshold and db2

Table (2) Image compression using RLC technique and soft threshold

Wavelet family	CR (%)	PSNR
db1	71.055	27.932
db2	71.158	29.661
db4	69.774	34.703
db6	69.030	39.036
db8	68.893	30.880

Table (3) Image compression using Huffman code and hard threshold

Wavelet family	CR (%)	PSNR	Average code length
db1	77.015	32.245	2.451
db2	76.515	35.842	2.466
db4	75.597	34.461	2.485
db6	74.816	30.938	2.488
db8	74.256	28.437	2.468

Original image

Reconstructed image

Fig. (8) Original and reconstructed image for Huffman code with hard threshold and db8

Table (4) Image compression using Huffman code and soft threshold

Wavelet family	CR (%)	PSNR	Average code length
db1	77.239	27.820	2.4278
db2	76.566	29.414	2.4609
db4	75.655	33.816	2.4792
db6	74.897	42.424	2.4801
db8	74.23	31.350	2.4704