Compressed Image Transmission over AWGN Channel using DCT and Raised Cosine Filter

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Abstract - Compressed image transmission through model channel like AWGN implementing DCT and Raised Cosine Filter is demonstrated in this paper. The transmission performance of still image with Qam-32 modulation scheme is compared to communication model having no filter in presence of additive white Gaussian noise (AWGN). By comparing communication model having filter in the same scenario, results showed that the received image quality is better in terms of PSNR and MSE for low value of SNR. The simulation results reveal that with lower signal to noise ratio, raised cosine filter exhibits better performance in comparison with employing no filter. Inter symbol Interference (ISI) that plays an important role in image transmission degrades the image quality and may be eliminated by employing filter.

Keywords- AWGN; DCT; Raised Cosine Filter; QAM; PSNR; MSE; ISI; SNR

I. INTRODUCTION

During the past few years, people begin to play more and more attention on reliable wireless multimedia transmission, such as Image, Video, and Audio based on high speed data communication, high quality channel and high quality transmission of visual data, for instance, high quality image over the communication channel. In general, High quality image transmission demands more storage capacity and high bandwidth requirements. For that reason, image compression is performed so that less storage capacity and required bandwidth is achieved. Nevertheless, compressed image is prone to noise both in wire and wireless communication channel. In addition, ISI degrade the image quality over wireless channel and/or wired channel due to band limited characteristic of transmitted data. Appropriate filter technique may improve the image quality that transmitted through the noisy channel.

In this paper, a raised cosine filter is proposed before transmission of compressed image through noisy communication channel. Typical communication model is tested by transmitting still image using conventional QAM-32 modulation scheme. The simulation results proved that proposed communication model for image transmission yields quality image when channel is more vulnerable to noise.

In this section provide a descriptive summary of some technique that have been implemented and tested for image compression and transmission over noisy channels. A. Mishra et al. [1] proposed the polar coding for gray scale image transmission over AWGN channel using QAM-64. However, does not suggest about band limited characteristic of medium and the influence of inter symbol interference. On the other hand, Md. Abdul Kader et al. [2] suggested the image transmission using Hierarchical Quadrature Amplitude Modulation (HQAM) for better protection of high priority data. Nevertheless, no channel model is considered such as AWGN and salt and pepper noise has been taken into account. Furthermore, Md. A. H. Khandokar et al. [3] used a simple conventional communication model with various M – array modulation technique with AWGN Channel but does not show the lower value of $E_b/N_0$. Only the value of 10 dB has been used. This paper has investigated the conventional communication model with proposed communication model for image transmission using filter and the effect of low and high signal to noise ratio have been considered for both communication models for still image transmission.

The paper is organized as follows. In Section II, theoretical background of DCT compression, 32-QAM modulation, raised cosine filter, White Gaussian Noise (AWGN) channel, signal to noise ratio (SNR), bit error rate (BER), and $E_b/N_0$ (Energy per bit to Noise power spectral density ratio) has been demonstrated. In Section III the proposed method is described. In the next section the experimental result is explained. The paper is concluded in Section IV.

II. THEORETICAL BACKGROUND

A. DCT Compression

The proposed compression method is based on the Discrete Cosine Transform (DCT) [15] applied to the global image. The complete image is considered as a single block. Let $I$ be the original image defined as $I=I(u,v)$, $\{0\leq u\leq M-1, 0\leq v\leq N-1\}$. $MxN$ is the size of the image and $(u,v)$ denote the gray level pixel’s at $(u,v)$ coordinates. The $MxN$ DCT coefficients are given by:

$$F(i,j) = \frac{2c(i)c(j)}{\sqrt{MN}} \sum_{u=0}^{M-1} \sum_{v=0}^{N-1} f(u,v) \cos \left[ \frac{(2u+1)i\pi}{2M} \right] \cos \left[ \frac{(2v+1)j\pi}{2N} \right]$$

where, $c(i)$ is defined by:

$$c(i) = \begin{cases} \frac{1}{\sqrt{2}}, & \text{if } i = 0 \\ 1, & \text{if } i \neq 0 \end{cases}$$

Respectively, the inverse DCT coefficients are given by:

$$f(u,v) = \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} c(i)c(j) F(i,j) \cos \left[ \frac{(2u+1)i\pi}{2M} \right] \cos \left[ \frac{(2v+1)j\pi}{2N} \right]$$

In the following sections, we consider square images (M=N).
B. 32-QAM modulation technique

QAM is used in applications including microwave digital radio, DVB-C (Digital Video Broadcasting Cable), and so on. In 32-QAM, Quadrature Amplitude Modulation used in this paper has five I values and five Q values. This results in a total of 32 possible states for the signal. It can transition from any state to any other state at every symbol time. Since \( 32 = 2^5 \), five bits per symbol can be sent which is as shown in Fig. 1. This is too many states for a power of two (the closest power of two is 32). So the four corner symbol states, which take the most power to transmit, are omitted. This consists of two bits for I and two bits for Q. The symbol rate is one fifth of the bit rate. So this modulation format produces a more spectrally efficient transmission. It is more efficient than BPSK, QPSK, or 8PSK. However, the symbols are very close together and are thus more prone to errors due to noise and distortion which is shown in simulation result [5].

\[ h_{\text{RC}}(t) = \frac{\sin(\frac{\pi T}{2}) \cos(\frac{\pi t}{T})}{\frac{T}{2}(1-(\frac{T}{2T})^2)} \]  

This expression can be simplified further by introducing the sinc function \( \text{sinc}(x) = \frac{\sin (x)}{x} \). The sinc function in the response of the filter ensures that the signal is band-limited. The time domain impulse response of the square root raised cosine filter is given as:

\[ h_{\text{RC}}(t) = \sin c \left( \frac{t}{T} \right) \frac{\cos(\frac{\pi t}{T})}{1-(\frac{t}{T})^2} \]  

The sinc function of the pulses be such that they do not interfere with one another at the optimal sampling point. There are two criteria that ensure non-interference [7].

a. The pulse shape exhibits a zero crossing at the sampling point of all pulse intervals except its own. That is Minimized inter symbol interferences (ISI).

b. The shape of the pulses is such that the amplitude decays rapidly outside of the pulse interval. That is high stop band attenuation.

The rectangular pulse meets first requirement because it is zero at all points outside of the present pulse interval. It cannot cause interference during the sampling time of other pulses. The trouble with the rectangular pulse, however, is that it has significant energy over a fairly large bandwidth as indicated. The unbounded frequency response of the rectangular pulse makes it unsuitable for modern transmission systems. This is where pulse shaping filters come into play. If the rectangular pulse is not the best choice for band-limited data transmission, then what pulse shape will, decay quickly, and provide zero crossings at the pulse sampling times [5]. There are several choices that have but in most systems Raised cosine filter are used to shape the input pulse.

In most cases, the square root raised cosine filter is used in the transmitter and receiver part of the system so that the overall response resembles that of a raised cosine filter. The impulse or time domain response of the raised cosine filter and the square root raised cosine filter are given by (3), (4), (5), (6) [7].

\[ h_{\text{RRC}}(t) = \frac{\sin[\pi(1-\alpha)T+\pi T^2]}{(4\pi T^2)[(1-\alpha)T]^2} \cos\left[\pi(1-\alpha)T^2\right] \]  

The overall response of the system is given by (14).

\[ h_{\text{RC}}(t) = h_{\text{RRC}}(t) h_{\text{RC}}(t) \]  

The impulse and magnitude response of Raised Cosine filter are shown in Fig. 2 and Fig. 3.

**Fig. 1.** Constellation diagram for QAM-32.

**Fig. 2.** Impulse response of raised cosine filter.
by communication link and measured in decibels and represented by (10).

\[ \text{SNR} = 10 \log_{10} \left( \frac{\text{Signal Power}}{\text{Noise Power}} \right) \text{ dB} \]  

#### F. Bit error rate (BER)

The BER, or quality of the digital link, is calculated from the number of bits received in error divided by the number of bits transmitted.

\[ \text{BER} = \frac{\text{Bits in Error}}{\text{Total bits received}} \] (11)

In digital transmission, the number of bit errors is the number of received bits of a data stream over a communication channel that has been altered due to noise, interference, distortion or bit synchronization errors. The BER is the number of bit errors divided by the total number of transferred bits during a particular time interval. BER is a unit less performance measure, often expressed as a percentage [10].

BER can also be defined in terms of the probability of error (POE) [14] and represented by (12).

\[ \text{POE} = \frac{1}{2} (1 - \text{erf} \left( \frac{E_b}{\sqrt{N_0}} \right)) \] (12)

Here, ‘erf’ is the error function, \( E_b \) is the energy in one bit and \( N_0 \) is the noise power spectral density (noise power in a 1Hz bandwidth). The error function is different for the each of the various modulation methods. The POE is a proportional to \( E_b / N_0 \), which is a form of signal-to-noise ratio. The energy per bit, \( E_b \), can be determined by dividing the carrier power by the bit rate. As an energy measure, \( E_b \) has the unit of joules. \( N_0 \) is in power that is joules per second, so, \( E_b / N_0 \) is a dimensionless term, or is a numerical ratio.

#### G. \( E_b/N_0 \) (Energy per bit to Noise power spectral density ratio)

\( E_b/N_0 \) is an important parameter in digital communication or data transmission. It is a normalized signal-to-noise ratio (SNR) measure, also known as the "SNR per bit”. It is especially useful when comparing the bit error rate (BER) performance of different digital modulation schemes without taking bandwidth into account. \( E_b/N_0 \) is equal to the SNR divided by the "gross" link spectral efficiency in (bit/s)/Hz, where the bits in this context are transmitted data bits, inclusive of error correction information and other protocol overhead.

#### III. PROPOSED METHOD

This section has described the proposed method in details. The basic steps of the proposed method are, 1) converting RGB image into gray scale image, 2) applying DCT in gray scale image to compress and quantized the gray scale image, 3) then encoded the quantized image and finally find the compressed image, 4) utilizing modulation technique on encode values to obtain the symbols, 5) before transmitting symbol value through AWGN channel, the symbol data values are filtered with raised cosine filter and apply the Inverse first fourier transform to convert the value from frequency domain to time domain, 6) at receiver site the noisy values are passed through the inverse raised cosine filter and then converted to time domain to frequency domain by applying fourier transform, 7) these transformed values are demodulated with QAM 32 and, 8) decode the demodulated values accordingly, 9) after that, the
IDCT has been applied to get the original gray scale values, and 10) finally, retrieve the original image. The workflow of the proposed framework is as shown in Fig. 4.

![Workflow of the proposed framework](image)

**Input Image** → **Convert RGB to gray image** → **Applying DCT** → **Encode** → **Modulation** → **AWGN channel** → **Adding noise** → **Inverse raised cosine filter** → **IDCT** → **De-quantization** → **Decoding** → **Reverse raised cosine filter** → **IFFT** → **Inverse discrete cosine transform** → **Demodulation** → **Output Image** → **Convert gray to RGB image** → **Applying inverse DCT** → **Restore original image**

**A. Converting RGB image into gray scale image**

In this section, initially the input RGB image is converted into gray scale image. The gray scale image contains only one channel value that is intensity value. The RGB image is converted to the gray scale image by using the formula mentioned in (13).

\[ I_{\text{gray}} = 0.299 \times R + 0.587 \times G + 0.114 \times B \]  

**B. Applying DCT to compress the gray scale image**

This section utilizes the image that is converted to the gray scale in the previous section. In an image, low frequency values are accumulated at the left upper corner and high frequency values are stored at lower right corner of the compressed image block. As most of the valuable information is stored at low frequencies, discarding certain information from higher frequency has little effect on the overall image quality.

Typically 8x8 or 16x16 block size is used instead of implementing DCT on the entire image. The DCT transform is usually applied firstly in row wise direction, then column wise direction. Avoiding the complexity, column wise DCT operation can be accomplished applying row wise DCT operator. For this reason, at first row wise DCT operation is applied on the image block, then transpose is implemented on the column wise and then perform the row wise DCT operation once again. The procedure is as shown in Fig. 5.

![Two dimensional DCT operation](image)

**DCT** operation has high degree of computational complexity. The mathematical expression for performing N-point DCT operation is given in (1). For instance, 8-point DCT operation equals 8 in (1). The inputs to the 8-point DCT operator are eight pixel values \((u(0),...,u(7))\). After executing the DCT computation, eight DCT values \((F(0),...,F(7))\) are yield at the operator output. For calculating each DCT value, the all obtained input values such as \((u(0),...,u(7))\) are used. These values are finally quantized. Quantization is achieved by dividing transformed image matrix by the quantization matrix used. Values of the resultant matrix are then rounded off.

**C. Encode**

In this section, the compressed quantization values are encoded to convert into binary code streams. The most commonly used entropy encoders are the Huffman encoder and the arithmetic encoder, although for applications requiring fast execution, simple run-length encoding (RLE) has proven very effective.

**D. Utilizing 32-QAM modulation**

In this section, 32-QAM, Quadrature Amplitude Modulation is used in this paper which has five I values and five Q values. This results in a total of 32 possible states for the signal. It can transit from any state to any other state at every symbol time. Since \(32 = 2^5\), five bits per symbol can be sent. This is too many states for a power of two (the closest power of two is 32). So the four corner symbol states, which take the most power to transmit, are omitted.

Here 32-QAM is used as there is a tradeoff between power efficiency and bit error rate.

**E. Applying raised cosine filter and IFFT**

This section uses the root raised cosine filter to eliminate inter symbol interference which degrade the image quality severely at low signal to noise ratio. Single raised cosine filter at transmitter side cannot reduce the inter symbol interference. Therefore, a pair of raised cosine filter is used in this paper which acts as root raised cosine filter. The impulse and frequency response of the raised cosine filter are shown in Fig. 2 and Fig. 3. In addition, as original image block is in frequency domain but raised cosine filter and AWGN model work on real time operation. For that purpose, inverse first Fourier transform (IFFT) is introduced in this proposed method before using raised cosine filter.

**F. AWGN channel**

In practice, according to Shannon’s capacity theorem, there is no channel which is noise free. All transmitted signals are corrupted by noise and noise is unpredictable in nature. Precise mathematical operations can’t be done on noise. That’s why AWGN channel is chosen as channel model for simulation.

**G. Retrieving original image**

In this section, how original image is retrieved at receiver side is demonstrated. Firstly, the noisy image data are passed through the inverse raised cosine filter to obtain the modulated image data in time domain. Then, demodulation process is applied followed by first Fourier transform to obtain the encoded data in frequency domain. After that, the decoding technique is implemented to obtain quantized image value. In addition to this, inverse discrete cosine transform (IDCT) operation is performed to obtain the gray scale value. Finally, the original RGB image is retrieve from gray scale image by using appropriate method.
IV. SIMULATION AND EXPERIMENTAL RESULTS

In this paper, simulation is carried out for gray scale images. The simulation was performed using MATLAB environment.

The mean square error (MSE) and peak signal to noise ratio (PSNR) are typically used to measure the quality of the receiving image with respect to transmitting image. The MSE and PSNR are measured using (14) and (15).

\[
MSE = \frac{1}{MN} \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} || I(i,j) - R(i,j) ||^2
\]

\[
PSNR = 10 \log_{10} \frac{R_{	ext{max}}^2}{MSE}
\]  

(14)  

(15)

The result of bit error rate, MSE, and PSNR is constant which is 23.5973 and 4.1420 respectively. Fig. 6 shows the processing example of retrieve images with E_b/N_0 (dB) effect where raised cosine filter is used. From the experimental results, it is seen that the received image quality has improved with the increase of E_b/N_0 (dB) values. When the value of E_b/N_0 (dB) is greater than five the bit error rate is zero and the value of MSE and PSNR is constant which is 23.5973 and 4.1420 respectively. The result of bit error rate, MSE, and PSNR with respect to E_b/N_0 (dB) is as shown in Table I, where raised cosine filter was present.

![Fig. 6. Processing example of quantized image: a) original image, b) quantized image using filter, and c) quantized image without filter.](image)

![Fig. 7. Processing example of output images with different E_b/N_0 (dB) value using raised cosine filter: a) E_b/N_0 (dB)=1, b) E_b/N_0 (dB)=2, c) E_b/N_0 (dB)=3, d) E_b/N_0 (dB)=4, and e) E_b/N_0 (dB)=5](image)

<table>
<thead>
<tr>
<th>E_b/N_0 (dB)</th>
<th>Number of error</th>
<th>Bit error rate (BER)</th>
<th>MSC</th>
<th>PSNR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1625</td>
<td>9.9182xe^-4</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>2</td>
<td>467</td>
<td>2.8503xe^-4</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>3</td>
<td>68</td>
<td>4.1504xe^-4</td>
<td>25.1261</td>
<td>3.8900</td>
</tr>
<tr>
<td>4</td>
<td>9</td>
<td>5.4932xe^-4</td>
<td>23.5973</td>
<td>4.1420</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>6.1035xe^-4</td>
<td>23.5973</td>
<td>4.1420</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>0</td>
<td>23.5973</td>
<td>4.1420</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>0</td>
<td>23.5973</td>
<td>4.1420</td>
</tr>
<tr>
<td>8</td>
<td>0</td>
<td>0</td>
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<td>4.1420</td>
</tr>
<tr>
<td>9</td>
<td>0</td>
<td>0</td>
<td>23.5973</td>
<td>4.1420</td>
</tr>
<tr>
<td>10</td>
<td>0</td>
<td>0</td>
<td>23.5973</td>
<td>4.1420</td>
</tr>
</tbody>
</table>

Fig. 8 shows the processing example of output images with E_b/N_0 (dB) effect where raised cosine filter was not used. The experimental result shows that with the lower E_b/N_0 (dB) value the received image without filter is more blurred with respect to the images that are received with filter. The result of bit error rate, MSE, and PSNR without raised cosine filter is as shown in Table II. From that result, it has been seen that BER is zero when the E_b/N_0 (dB) value is greater than eight and the value of MSC and PSNR is constant for those E_b/N_0 (dB) values which is 13.7908 and 7.0874 respectively. The best-quality images are received by the proposed simulation with the E_b/N_0 (dB) = 5 dB and using the raised cosine filter.

![Fig. 8. Processing example of output images with different E_b/N_0 (dB) value without using raised cosine filter: a) E_b/N_0 (dB)=1, b) E_b/N_0 (dB)=2, c) E_b/N_0 (dB)=3, d) E_b/N_0 (dB)=4, e) E_b/N_0 (dB)=5, f) E_b/N_0 (dB)=6, g) E_b/N_0 (dB)=7, h) E_b/N_0 (dB)=8, i) E_b/N_0 (dB)=9, and j) E_b/N_0 (dB)=10](image)
TABLE II. EXPERIMENTAL RESULT OF NO OF ERROR, BER, MSC AND PSNR USING WITHOUT FILTER

<table>
<thead>
<tr>
<th>$E_b/N_0$(dB)</th>
<th>Number of error</th>
<th>Bit error rate (BER)</th>
<th>MSC</th>
<th>PSNR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>29675</td>
<td>0.0016</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>2</td>
<td>14460</td>
<td>0.0056</td>
<td>NA</td>
<td>NA</td>
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<tr>
<td>3</td>
<td>6121</td>
<td>0.0025</td>
<td>NA</td>
<td>NA</td>
</tr>
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<td>2148</td>
<td>8.5906xe^-5</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>5</td>
<td>501</td>
<td>1.9570xe^-6</td>
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<td>123</td>
<td>4.8047xe^-6</td>
<td>8.7112xe^-6</td>
<td>1.1220xe^-6</td>
</tr>
<tr>
<td>7</td>
<td>20</td>
<td>7.8125xe^-7</td>
<td>13.7908</td>
<td>7.0874</td>
</tr>
<tr>
<td>8</td>
<td>3</td>
<td>1.1719xe^-7</td>
<td>13.7908</td>
<td>7.0874</td>
</tr>
<tr>
<td>9</td>
<td>0</td>
<td>0</td>
<td>13.7908</td>
<td>7.0874</td>
</tr>
<tr>
<td>10</td>
<td>0</td>
<td>0</td>
<td>13.7908</td>
<td>7.0874</td>
</tr>
</tbody>
</table>

Putting the values, for instance, $E_b / N_0 = 1, 2, 3, 4$, and 5 dB respectively, the bit error rate (BER), PSNR is much better than transmitting image without filter. At those values, the retrieved images are blurred which is vague for human visualization using without filter. For the higher values of $E_b / N_0$, where no error is occurred, conventional communication model with QAM-32 reveals good results. For low signal to noise ratio, the interference caused by inter-symbol interference is dominated over noise. As a result without filter the image is blurred. That suggests that proposed method is more applicable than conventional communication model for image transmission.

The comparison of SNR and BER using with and without filter is as shown in Fig. 9.

![Comparison of SNR vs BER](image)

**Fig. 9.** Comparison of SNR vs BER using with and without filter.

V. CONCLUSIONS

For Low SNR, when compressed image is corrupted by noisy channel, it is hard to retrieve original image. The fact is that signal to interference ratio (SIR) is grater that SNR. For that reason, for lower value of $E_b/N_0$ the images are Vague. However, this problem is mitigated by introducing raised cosine filter in the proposed method. For higher SNR, the conventional communication model with QAM-32 works better. In future, the image quality and data protection may be ensured by implementing Hierarchical QAM (HQAM) and sophisticated coding technique using proposed communication model for image transmission.

REFERENCES


