# COMPUTATIONALLY EFFICIENT BLIND EQUALIZATION BASED ON DIGITAL WATERMARKING

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## ABSTRACT

A blind equalization method based on digital watermarking is presented. A chunk of data is selected from the data to be transmitted. This chunk of data is hidden in the entire data using digital watermarking. For watermarking, DS-CDMA based spread spectrum watermarking scheme is used. On receiving side, watermark is extracted from the watermarked data. With the help of received chunk of data and the extracted watermark, which is actually extracted version of the selected chunk of data, the channel is equalized by using Normalized LMS algorithm. In this method, neither receiver requires to know the training sequence in advance nor the sender requires to send training sequence. Proposed algorithm can simultaneously be used for usual watermarking applications and blind equalization.

## 1. INTRODUCTION

Intersymbol Interference (ISI) is a very common type of distortion which a signal undergoes during transmission [1]. To cope with ISI channel equalization is most commonly used. The channel is estimated by sending a known training sequence over the channel along with the data. With the help of received and already known reference training sequence, receiver calculates an estimate for the inverse of the channel by using algorithms like Least Mean Square (LMS) [2]. Later, received data can be equalized by using the estimated inverse of the channel.

Digital Watermarking is a well known technique used for applications like authentication, copyrights protection, avoiding illict copying etc. Watermark is simply a sequence of bits which is hidden in host data (e.g. videos, images or some other data). In this paper digital watermarking is used to convert traditional trained equalization algorithm into a blind equalization algorithm. Some researchers already used watermarking for equalization. Watermarking is used for dynamic equalization in [3] and for adaptive equalization in [4]. None of these algorithm is considered as blind, since in both cases the receiver requires to know the training sequence in advance.

In comparison to blind equalization, traditional trained equalization is known to be computationally efficient. But the most crucial drawback of trained equalization is that it consumes extra bandwidth. Another disadvantage is that the receiver must have prior information of the original training sequence. There are some blind equalization algorithms, where training sequences are not used and data can still be equalized [5], [6]. To design a blind equalization algorithm convergence of the algorithm and computational complexity are two important issues. Constant Modulus Algorithm (CMA) [5] is one of well known algorithm used for blind equalization. Disadvantage for CMA is its slow convergence. Therefore, researchers tried to lessen the computational complexity of CMA and tried to make convergence faster [7], [8].

In this paper a completely different approach to blind equalization is taken by using digital watermarking. The proposed method does not require training sequences and works with standard trained equalization algorithms (e.g. LMS) at low computational complexity. Furthermore, proposed scheme can simultaneously be used for blind equalization and usual watermarking applications. The only condition is that the watermark must be a part of the data.

In the proposed method a chunk of data, which is a part of the data actually to be transmitted through the channel, is used as a watermark. This chunk is embedded in the data as a watermark. With the help of received chunk and extracted chunk (extracted watermark) the channel can be equalized blindly. Watermarking algorithm used for this blind equalization scheme, must have the following two qualities:

- Robust (to withstand distortions due to transmission).
- Carry enough payload (which can be used as training sequence).

CDMA based spread spectrum watermarking scheme [9] fulfills the above requirements. The main advantage of spread spectrum watermarking is that each watermark bit is embedded in a number of pixels. Because of that it is proven to be robust in transmission. By using multiple orthogonal spreading codes, CDMA based watermarking scheme can carry more payload (large watermark). Normalized Least Mean Square (NLMS) algorithm [2] is used in this scheme for equalization. Other equalization algorithms e.g. Least Mean Square (LMS) and Recursive Least Square (RLS) can also be used.

This paper is organized as follows: Section 2 presents an overview of previously described CDMA based watermarking algorithm. In section 3 blind equalization scheme using digital watermarking is described. Section 4 presents the experimental results and section 5 concludes this paper.

## 2. OVERVIEW OF THE WATERMARKING SCHEME

An oblivious watermarking scheme is presented in [9], which is further improved by using by-part interleaving in [10]. In this watermarking scheme every bit of the watermark is hidden in mutually similar frequency coefficients in the DCT domain. These specially selected frequency coefficients are preferably in middle frequency range. Every vector of the modified frequency coefficients $\mathbf{i'_j}$ is formed according to:

$$\mathbf{i'_j} = \mathbf{i_j} + \alpha[b_1\mathbf{s_1} + b_2\mathbf{s_2} + \ldots + b_k\mathbf{s_k}] \quad (1)$$

where $\mathbf{i_j}$ is a vector of similar frequency coefficients, $b_i$ is a watermark bit, $\alpha$ is the gain factor and $\mathbf{s_i}$ are the spreading codes. Watermark bits can be extracted by using:

$$b_i = sign < \mathbf{i'_j}, \mathbf{s_i} > \quad if\ |\mathbf{i_j} \cdot \mathbf{s_i^T}| < |\alpha \mathbf{s_i} \cdot \mathbf{s_i^T}| \qquad (2)$$

For complete description of the watermarking scheme see [9]. This scheme is proven to be robust against many intentional and unintentional attacks. Transmission of watermarked image through a channel can be seen as an unintentional attack. The watermark easily survives the transmission attack by using this watermarking scheme. The use of multiple spreading codes makes this scheme able to carry large watermark.

## 3. WATERMARKING-BASED BLIND EQUALIZATION

Fig. 1 shows how traditional trained equalization works. In order to equalize the data receiver must know the reference training sequence in advance. Error $e(n)$ is calculated with the help of received training sequence and reference training sequence. Now by minimizing $e(n)$, the inverse of the channel is estimated and weights (taps) $\mathbf{w}(n)$ are updated. The received data can be equalized by using $\mathbf{w}(n)$.

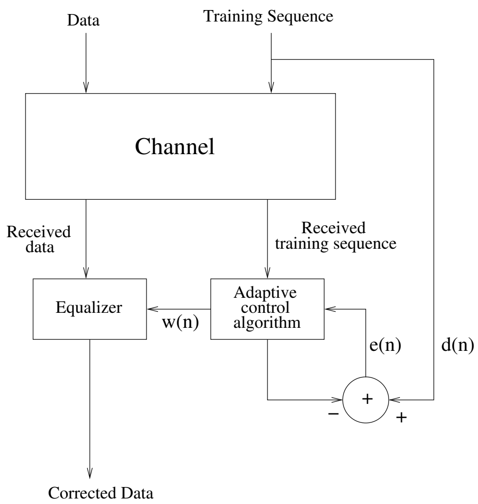



Figure 1: *Traditional trained equalization technique.*

Fig. 2 proposes a blind equalization scheme, where a selected chunk of data is hidden (or superimposed) in the entire stream of data (Fig. 3 ). After transmission, this hidden chunk of data is extracted from the received data. This extracted chunk can be used as reference training sequence and received chunk can be used as received training sequence. Thus $e(n)$ can be calculated and NLMS algorithm can be used to update $\mathbf{w}(n)$. Hence received data can be equalized blindly.

The above mentioned blind equalization method is implemented by using digital watermarking. Fig. 4 shows how watermarking can be used for blind equalization. A selected part of an image is hidden in that image as a watermark. After transmission the watermark can be extracted by the receiver. If the watermarking scheme is robust then this extracted watermark can be used as a reference training sequence. Received selected part can be used as received training sequence.

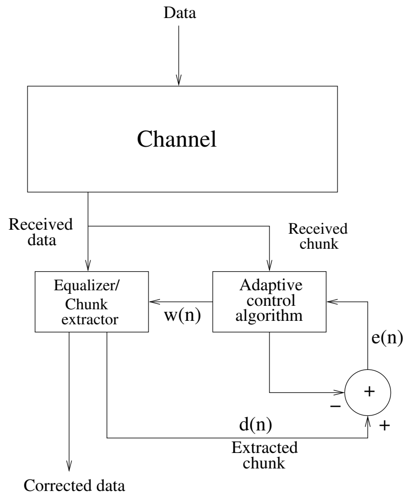



Figure 2: *Blind equalization method.*

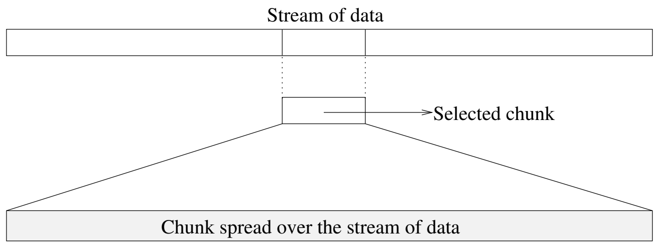



Figure 3: *Selecting a chunk of data and hidding it in the stream of data.*

For equalization Normalized LMS algorithm is used. This algorithm works as under [2]:

$$\begin{aligned} Parameter: M &= \text{number of taps} \\ a &= \text{positive constant} \\ \tilde{\mu} &= \text{adaption constant (step-size parameter)} \\ 0 &< \tilde{\mu} < 2 \end{aligned}$$

*Initialization*. If prior knowledge on the tap-weight vector $\hat{\mathbf{w}}(n)$ is available, use it to select an appropriate value for $\hat{\mathbf{w}}(0)$. Otherwise, set $\hat{\mathbf{w}}(0) = \mathbf{0}$.

*Data*

$$\begin{aligned} (a)\text{Given}: \mathbf{u}(n) &: \text{M-by-1 tap-input vector at time n} \\ d(n) &: \text{desired response at time n} \end{aligned}$$

$$(b)\text{To be computed}: \hat{\mathbf{w}}(n+1) = \text{estimate of tap-weight vector at time n+1}$$

$Computation: n = 0, 1, 2, \ldots$

$$\begin{aligned} e(n) &= d(n) - \hat{\mathbf{w}}^H(n)\mathbf{u}(n) \\ \hat{\mathbf{w}}(n+1) &= \hat{\mathbf{w}}(n) + \frac{\tilde{\mu}}{a + \| \mathbf{u}(n) \|^2} \mathbf{u}(n) e^*(n) \end{aligned} \qquad (3)$$

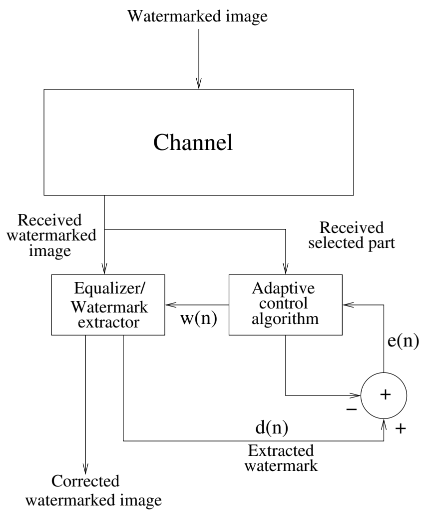



Figure 4: *Blind equalization using digital watermarking.*

Normalized LMS is a modified version of LMS algorithm. LMS algorithm also works fine in proposed blind equalization method. However simulations have shown that Normalized LMS algorithm works slightly better than LMS algorithm. LMS algorithm experiences a gradient noise amplification problem when $\mathbf{u}(n)$ is large, because the correction applied to the tap-weight vector $\hat{\mathbf{w}}(n)$ at iteration $n+1$ is directly proportional to the tap-input vector $\mathbf{u}(n)$. In normalized LMS algorithm correction applied to tap-weight vector $\hat{\mathbf{w}}(n)$ at iteration $n+1$ is normalized with respect to squared Euclidean norm of tap-input vector $\mathbf{u}(n)$ at iteration $n$. That is why it is called "normalized" LMS.

### 3.1 Implementation Problem

A very crucial problem arose while implementing proposed scheme using digital watermarking. A part of an image is selected, and later it is spread over whole image forming watermarked image. Obviously, watermarked image is slightly different from the original image. When this watermarked image is transmitted, channel can not be equalized. Because, the extracted watermark is a part of the original image and received part is from watermarked image. Hence both of them are different and channel can not be equalized using extracted watermark and received part of the watermarked image.

One of the simplest solutions to this problem is to hide selected part in the remaining image (other than selected part). However, this simple solution causes problems for usual watermarking applications, like copyrights protection etc., and for blind equalization. From general watermarking applications point of view, it is not good to leave a reference to the original image. Watermark should be spread over whole image. If reference to the original image is present in the watermarked image, some denoising algorithm can detect watermark as noise. So watermark can be removed easily. Therefore, this scheme can not be used for usual watermarking applications.

This problem is solved by watermarking selected portion with some dummy bits first and then hide this dummy watermarked selected portion into remaining image (Fig. 5). Now this watermarked image has same level of noise over whole image and has no reference to the original image. Therefore, this watermarked image can simulteneously be used for blind equalization as well as for usual watermarking applications.

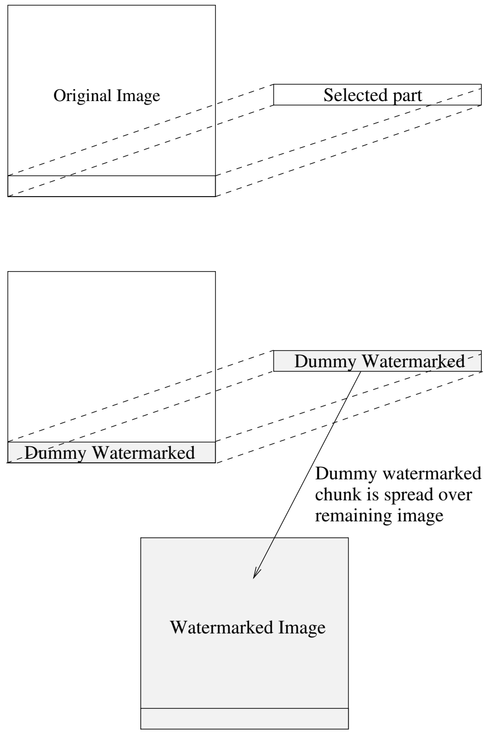



Figure 5: *Forming a watermarked image, considering implementation problem.*

### 3.2 Possible Security Issue

As watermark is a part of the watermarked image, it can be considered as a possible security issue. By using proposed scheme, watermark can be any part of watermarked image, which is very difficult to locate for an evedropper. Furthermore, because of proposed implementation scheme noise level (watermark intensity) is same over the whole image. So it is difficult to distinguish between selected part, watermark, and remaining watermarked image.

## 4. EXPERIMENTAL RESULTS

In all the experiments 512×512 (8 bits/pixel, gray scale) images (Lena Fig. 6(a) and Gold hill Fig. 7(a)) are used. The simulations are done in MATLAB. The quality of an image is measured in terms of Peak Signal to Noise Ratio (PSNR).

$$PSNR = 10log\frac{255^2}{MSE}\,dB \tag{4}$$

First eight rows of an image are watermarked with eight dummy bits. These dummy bits are hidden in 3rd, 4th, 5th and 6th row of 8×8 blocks of the DCT coefficients [9]. First 504 bits are selected from the dummy watermarked part and hidden in remaining rows of the image again in 3rd, 4th, 5th and 6th row of 8×8 blocks of the DCT coefficients. Two spreading codes, each of length 512 are used to spread each bit. These watermarked images (watermarked at 40dB, here

$\alpha = 0.01$) are transmitted over four different channels:

| | |
|---|---|
| channel 1: | { 0.986, 0.845, 0.237, 0.123+0.310i} |
| channel 2: | { 0.986, 0.845, 0.537, 0.323, 0.123} |
| channel 3: | Frequency-flat (single path) Rayleigh fading channel, sample time $1 \times 10^{-5}$ and maximum Doppler shift 0.09 Hz. |
| channel 4: | Frequency-flat (single path) Rician fading channel, sample time $1 \times 10^{-5}$, maximum Doppler shift 0.9 Hz and Rician factor equal to 1. |

On the receiving side, watermark is extracted from the watermarked image. The watermark extracted from the received image, which forms the training sequence, has a few erroneous bits (column 2 and 3 of Table 1). However, the BER is good enough to use it as the reference training sequence. This is similar to decision feedback equalization, where there is also no exact training sequence available. The received selected part is treated as the received training sequence. $\hat{\mathbf{w}}(n)$ are calculated using Normalized LMS with $M = 8$ weights, step size $\tilde{\mu} = 0.01$ and $\hat{\mathbf{w}}(0) = \mathbf{0}$. The calculated weights $\hat{\mathbf{w}}(n)$ are used to equalize the received image. Received and corresponding equalized images are shown in Fig. 6 and Fig. 7. Respective errors and PSNR values are shown in Table 2 and 3. Here, second and third columns show PSNR value of received and equalized images with respect to watermarked images. Fourth and fifth columns show percentage of erroneous bits in received and equalized images. Column 4 and 5 of Table 1 show the BER in the watermarks extracted from equalized images. These watermarks are almost error free. Therefore they can easily be used for usual watermarking applications.

Table 1: BER in extracted watermarks

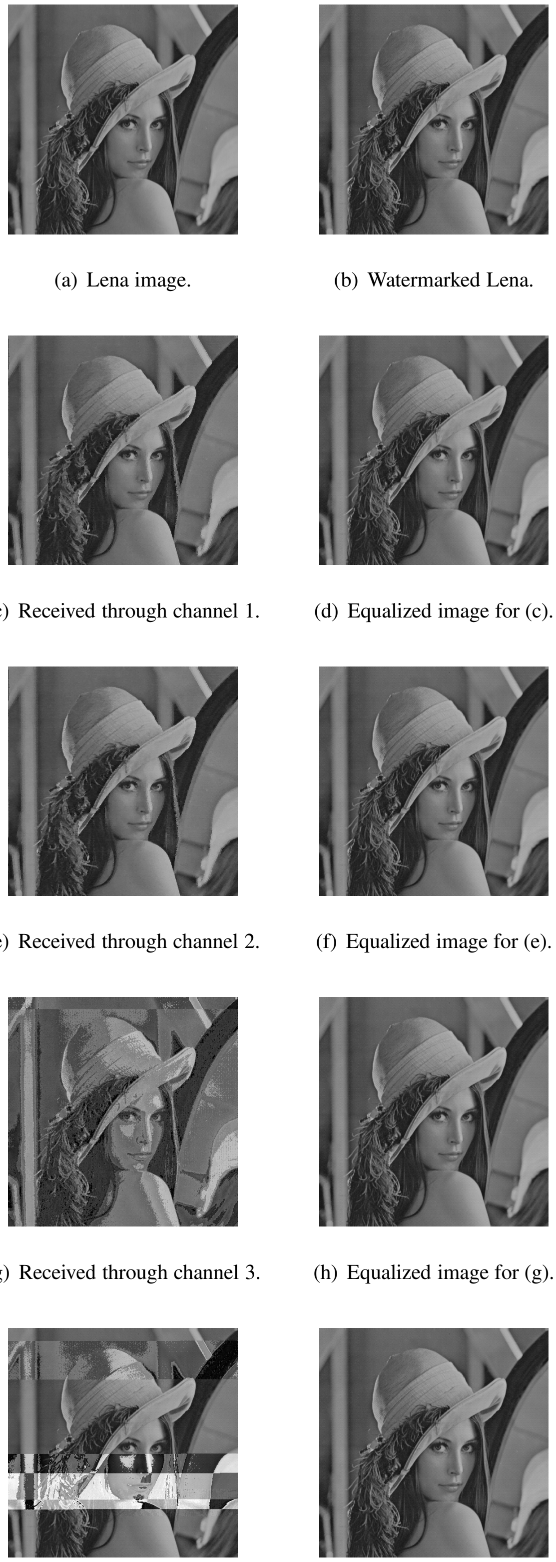
| channels | Received images | | Equalized images | |
|---|---|---|---|---|
| | Lena % | Gold hill % | Lena % | Gold hill % |
| 1 | 4.76 | 8.93 | 0 | 0.2 |
| 2 | 6.75 | 10.52 | 0 | 0.2 |
| 3 | 0.2 | 4.37 | 0 | 0.2 |
| 4 | 24.40 | 17.26 | 0 | 0.2 |

Table 2: Lena received and equalized

| channels | PSNR | | Erroneous bits | |
|---|---|---|---|---|
| | Received dB | Equalized dB | Received % | Equalized % |
| 1 | 26.8461 | 87.1311 | 9.67 | 0.00 |
| 2 | 26.8677 | 86.5184 | 13.04 | 0.00 |
| 3 | 22.5406 | 102.3162 | 33.60 | 0.00 |
| 4 | 12.3285 | 88.8920 | 8.06 | 0.00 |

Table 3: Gold hill received and equalized

| channels | PSNR | | Erroneous bits | |
|---|---|---|---|---|
| | Received dB | Equalized dB | Received % | Equalized % |
| 1 | 25.6681 | 84.4629 | 10.25 | 0.00 |
| 2 | 25.6381 | 76.4842 | 14.06 | 0.02 |
| 3 | 22.9631 | 85.9815 | 33.60 | 0.00 |
| 4 | 12.3257 | 93.2853 | 8.06 | 0.00 |



(a) Lena image. (b) Watermarked Lena.
(c) Received through channel 1. (d) Equalized image for (c).
(e) Received through channel 2. (f) Equalized image for (e).
(g) Received through channel 3. (h) Equalized image for (g).
(i) Received through channel 4. (j) Equalized image for (i).

Figure 6: *Lena received and equalized.*

## 5. CONCLUSIONS

How watermarking can be used to equalize transmission channels only using the received data is discussed in this paper. Simulations have shown that this scheme can correct almost all the errors from received watermarked images. An important advantage of this scheme is that it works at the complexity of traditional trained equalization methods unlike other very complex blind equalization methods. Proposed scheme can simultaneously be used for blind equalization as well as for usual watermarking applications. Further research can be done to develop a similar scheme for radio frequency communication signals. Another interesting topic is the investgation of the presented scheme in combination with decision feedback equalization. Furthermore, the suitability of different watermarking schemes for the proposed blind equalization algorithm can be studied.

(a) Gold hill image.

(b) Watermarked Gold hill.

(c) Received through channel 1.

(d) Equalized imagefor (c).

(e) Received through channel 2.

(f) Equalized image for (e).

(g) Received through channel 3.

(h) Equalized image for (g).

(i) Received through channel 4.

(j) Equalized image for (i).

Figure 7: *Gold hill received and equalized.*

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