# On the Design of Pattern Sequences for Spread Spectrum Image Watermarking

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*Abstract*—**This article investigates pattern sequences for Direct Sequence Code Division Multiple Access (DS-CDMA) spread spectrum communication of image watermarks. The problem is stated and three choices of sequence generation are proposed, namely: traditional pseudorandom generation, deterministic sequences from Walsh and Hadamard basis, and generation by Gram-Schmidt orthogonalization of pseudorandom sequences. The desirable properties for a sequence are defined and the choices are compared based on the detection reliability of the watermark. We present analysis, comparisons and conclusions about the proper choice of sequences for watermarking applications.**

*Keywords*—**Image Processing, Image Watermarking, Spread Spectrum.**

## I. Introduction

Digital watermarking allows us to embed hidden data into a host content (image, speech, music, video, etc) for a variety of important applications: copyright protection, fingerprinting, copy protection, broadcast monitoring, data authentication, indexing, data hiding and others applications [1], [2], [3]. An exponentially increasing number of publications has appeared on the subject during the last decade, indicating the increasing interest of the scientific community [2].

Among the many existing watermark insertion approaches, spread spectrum has been shown to have very desirable properties. One of most interesting propoerties is that narrow band watermarks are spread over many frequency bins so that the energy in any given bin is very small and hardly detectable [4]. Many works use the concept of spread spectrum communications to understand watermark insertion as information transmission over a noisy channel [4], [1], where the noise in this case is the host content. The implementation of efficient spread spectrum watermarking requires the generation of a set of patterns with very specific properties. To the authors' best knowledge, this issue has not yet received the due attention in the literature. This is specially important in practical watermarking systems, in which the length of the pattern sequences is usually not very long. It is common in many works to assume that pseudorandom generation of sequences suffices for watermarking applications. However, we verified that this is not the case when the sequence length is constrained to a fration of the full image size.

In this paper, we investigate the issue of pattern design for spread spectrum watermarking and propose two techniques which can significantly improve watermark detection. We state the necessary conditions a pattern sequence must satisfy in order to maximize correct detection. We provide examples with image data to illustrate the improvements obtained using the proposed patterns. We compare the new techniques with the classical pseudorandom sequence generation method, highlighting advantages and limitations of each method.

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## II. Watermark Insertion

Consider a watermark bit string as a sequence with $N$ bits:

$$B = \{b_1, b_2, \ldots, b_N\}, b_i \in \{0, 1\} \quad (1)$$

Define a new sequence $\hat{B}$ such that $\hat{b}_i = 2 \cdot b_i - 1$. Then, $\hat{b}_i \in \{-1, 1\}$. Also, $\hat{B}$ is a zero average sequence if $B$ has equal number of zeros and ones.

Consider a set $P$ of $N$ patterns to be used for spread spectrum watermarking image blocks $I$ of length $M$ (also known as the host image). Thus,

$$P = \{P_1, P_2, \ldots, P_N\}, P_i = \{p_{1i}, p_{2i}, \ldots, p_{Mi}\} \quad (2)$$

where each pattern $P_i$ is a sequence of length $M$.

The watermark bit string $B$ with $N$ bits is spread into a watermark sequence $W$ with dimension $M$ by performing the operation [1]:

$$W = \sum_{j=1}^{N} \hat{b}_j \cdot P_j \quad (3)$$

Finally, the watermark is inserted into the image block $I$ through the operation:

$$I_W = I + \alpha \cdot W \quad (4)$$

where $\alpha$ is a gain factor and $I_W$ is the watermarked image block, also known as the stegoimage.

## III. Watermark Detection

Watermark detection is implemented using correlation. A decision variable $t_i$ is extracted from the received image $I_W$ (assuming no transmission errors or distortions) for each pattern $P_i$ by evaluating the zero-lag spatial cross-covariance function [5]

$$t_i = \langle P_i - m_1(P_i), I_W - m_1(I_W) \rangle (0) \tag{5}$$

where the average $m_1(S)$ of a sequence $S$ with elements $s_k$, $k = 1, \ldots, M$ is given by

$$m_1(S) = \frac{1}{M} \sum_{k=1}^{M} s_k \tag{6}$$

and the zero-lag cross-correlation of two sequences $S$ and $R$ with elements $s_k$ and $r_k$, respectively, $k = 1, \ldots, M$, is given by

$$\langle S, R \rangle (0) = \frac{1}{M} \sum_{k=1}^{M} s_k r_k \tag{7}$$

The bit $b_i$ is detected as zero if $t_i < 0$ and as one otherwise. In the following, the $(0)$ used in (7) to indicate zero lag will be dropped for simplicity.

## IV. Desirable Properties

The patterns can be designed to minimize the number of detection errors. Detection errors are directly associated to the computation of $t_i$. If the patterns $P_i$ are chosen so that $m_1(P_i) = 0$ for all $i$, it results in:

$$m_1(I_W) = m_1(I + \alpha \cdot \sum_{j=1}^{N} \hat{b}_j \cdot P_j) = m_1(I) \tag{8}$$

And the computation of $t_i$ becomes:

$$t_i = \left\langle P_i, \left[ I + \alpha \cdot \sum_{j=1}^{N} \hat{b}_j \cdot P_j - m_1(I) \right] \right\rangle$$
$$= \langle P_i, I \rangle + \alpha \cdot \sum_{j=1}^{N} \hat{b}_j \cdot \langle P_i, P_j \rangle - \langle P_i, m_1(I) \rangle \tag{9}$$

Assuming zero average $P_i$ sequences, it reduces to:

$$t_i = \langle P_i, I \rangle + \alpha \cdot \sum_{j=1}^{N} \hat{b}_j \cdot \langle P_i, P_j \rangle = \langle P_i, I_W \rangle \tag{10}$$

### *A. Decorrelating the Stegoimage*

A technique frequently employed to improve detection is to realize image prediction or whitening before evaluating the cross-correlation [5], [6]. Using this approach, a prediction $I_P$ of the image is computed such that $I = I_P + \epsilon$, where $\epsilon$ is the prediction error, which includes modeling errors, noise and distortions introduced by filtering, lossy compression, D/A conversion, etc. Then, the prediction $I_P$ is subtracted from the stegoimage $I_W$.

After detection, the cross-covariance becomes:

$$t_i = \langle P_i, [I_W - I_P - m_1(I_W)] \rangle$$
$$= \langle P_i, [I_W - I + \epsilon - m_1(I_W)] \rangle$$
$$= \left\langle P_i, \left[ I + \alpha \cdot \sum_{j=1}^{N} \hat{b}_j \cdot P_j \right] \right\rangle - \langle P_i, I \rangle +$$
$$+ \langle P_i, \epsilon \rangle - \langle P_i, m_1(I_W) \rangle \tag{11}$$

For zero-average sequences $P_i$ and assuming that the prediction error is uncorrelated with every $P_i$, $i = 1, \ldots, M$, (11) reduces to

$$t_i = \alpha \cdot \sum_{j=1}^{N} \hat{b}_j \cdot \langle P_i, P_j \rangle = \langle P_i, (I_W - I_P) \rangle \tag{12}$$

The image prediction $I_P$ can be computed using deterministic or statistical averaging, as well as linear or nonlinear low-pass filtering [7].

### *B. Summary of the Desirable Properties*

The analysis above indicates some desirable conditions for the pattern $P_i, i = 1, \ldots N$ to be used in spread spectrum watermarking. Watermark detection is improved if the following conditions are satisfied:

1. $P_i, i = 1, \ldots, M$ should be zero average sequences.
2. The spatial correlations $\langle P_i, P_j \rangle$, $j \neq i$ should be minimized. Ideally, sequences $P_i$ and $P_j$ should be orthogonal whenever $j \neq i$.
3. Each $P_i$, $i = 1, \ldots. M$ should be uncorrelated with the image $I$ when image prediction is not used. Otherwise, each $P_i$ should be uncorrelated with the prediction error sequence $\epsilon$.
4. The spatial correlation $\left\langle P_i, \hat{b}_i \cdot P_i \right\rangle$ should be maximized, but constrained by the allowed distortion in the original image due to the watermarking process.

## V. Generating Sequences

In this section we discuss one existing technique and propose new techniques for generating sequences to be used as patterns for spread spectrum watermarking. The objective is to properly design such sequences in order to achieve the desirable properties discussed in the previous section.

### *A. Pseudorandom Sequences*

A technique frequently used is to generate patterns $P_i$ that are pseudorandom sequences. The simplest way to generate a pseudorandom sequence is by using linear congruential generators such as those provided by the functions `rand()` and `srand()` available in the ANSI C library.

This simple generation approach, however, may not produce the randomness desired for a given application, as discussed in detail in [8]. Moreover, a pseudorandom generator can theoretically guarantee that $m_1(P_i) = 0$ and $\langle P_i, P_j \rangle = 0$ only for infinite length sequences. This is certainly not the case in practical applications of image processing. As the image size increases, $m_1(P_i)$ and $\langle P_i, P_j \rangle$ approach zero.

In order to investigate if this approach can generate good sequences for CDMA watermarking applications, we proceed as follows. Using the `rand()` function, we generate an $N \times M$ binary matrix with values in $\{-1, 1\}$. The $N$ sequences $P_i, i = 1, \ldots, N$ with length $M$ are then extracted from this matrix. The binary watermark bit string $B$ with values in $\{0, 1\}$ and dimension $N$ is generated using the same procedure with the appropriate dimensions.

### B. Walsh and Hadamard Sequences

Another way to generate sequences where $\left\langle P_i', P_j' \right\rangle = 0, i \neq j$ is by using the orthogonal basis from either Walsh transform or Hadamard transform [9]. Each basis is already defined with values in $\{-1, 1\}$ and are orthogonal to each other, such that $\left\langle P_i', P_j' \right\rangle = 0, i \neq j$ only for sizes $M$ power of two, $M = 2, 4, 8, 16, 32, \ldots$. For other sizes of $M$, we need to generated an orthogonal basis with size $2^{\lfloor log_2 M \rfloor + 1}$ and truncate the vectors to size $M$. Thus for sizes $M$ not power of two, we do not achieve orthogonality among the sequences.

### C. Orthogonalization with Gram-Schmidt

As discussed in the section of results, for small size $M$ the pseudorandom sequences present high cross correlation such that $\langle P_i, P_j \rangle \quad > 0, i \neq j$. By using the Gram-Schmidt [10] method for orthogonalization of pseudorandom sequences generated as described, we can achieve $\left\langle P_i', P_j' \right\rangle = 0, i \neq j$. Moreover, each sequence $P_i'$ is normalized such that its energy is equal to the energy of $P_i$, which is $M$ since $P_i$ has values in $\{-1, 1\}$. With this normalization we are, in average, introducing the same distortion as before and the techniques may be fairly compared.

## VI. RESULTS

### A. Watermarking System

In order to compare the sequence generation techniques we propose a watermarking system described as follows. We split the image into blocks of $K$ by $K$ pixels. We spread the same watermark into each block according to Eq. 4. Our insertion procedure considers the image as a partition of size $K$ by $K$. The watermark of size $N$ is randomly generated using the linear congruential function rand(). The matrix $P$ of sequences will generated accordingly to one of the three choices explained before.

### B. Evaluating the Sequences

We evaluate the techniques by randomly generating $100$ watermarks of size $N$ for each different block size of $K$ by $K$. For each simulation we use one watermark. This watermark is inserted in all blocks of size $K$ by $K$, for the same image. We detect the watermark by using Eq. 12 and for each simulation $j$, we count the number of blocks where i-th bit, $b_i$, of the watermark was correctly detected, we name this count as $hit_{j,i}$. For each simulation $j$ we compute the watermark detection reliability for the bit $b_i$ as the ratio $c_{j,i} = \frac{hit_{j,i}}{L}$, where $L$ is the total number of blocks in the image and the ratio $c_{j,i}$ is in the range $[0, 1]$. We repeat this procedure for all $N$ bits of the watermark. Notice that the image block size is $M = K \cdot K$ and the watermark size is $N$. We use the block averages of the stegoimage as predictions for Eq. 12.

### C. Simulations

In our simulations we tested for $K$ ranging from $20$ to $65$ and for $N$ ranging from $64$ to $1023$ bits. We illustrate the results by showing the reliability curves for a watermark of $1023$ bits. In the Fig. 1 are illustrated the maximum, minimum and average reliability curves for pseudorandom sequences. The maximum, minimum and average values are computed based on a reliability vector of dimension $100$ for each bit. Each simulation $j$ for a given $K$ uses a different watermark and has $N$ reliabilities $c_{j,i}$. By computing the average for each simulation we may show the average variability in the Fig. 2 for pseudorandom sequences. The average reliability for simulation $j$ is given as $\hat{c_j} = \frac{\sum_{i=1}^{N} c_{i,j}}{N}$.

Similarly, we present the curves for sequences generated from the Hadamard and Walsh basis in the Figs. 3, 4, 5 and 6. For sequences generated by Gram-Schmidt orthogonalization, we present the results in Figs. 7 and 8.

### D. Analysis of Results

For pseudorandom sequences we notice that for small size $M = K \cdot K$ there exists a considerable cross correlation and it results in lower reliability as illustrated in the Figs. 1 and 2. From these figures we see that the minimum is zero, which means that one or more bits of the watermark cannot be detected. Minimum reliability value above 0.5 assure detection of bit $i$.

For sequences generated from Walsh and Hadamard basis, we achieve high reliability only for $M = K \cdot K$ power of two. In the Figs. 3, 4, 5 and 6, we found better results for $K$ nearby $32 = \sqrt{M = 1024}, 45 \approx \sqrt{M = 2048}, 64 = \sqrt{M = 4096}, \ldots$. We achieve a better performance than pseudorandom sequences at these block sizes, specially for small sizes of $M$. In many practical watermarking applications, small $M$ are used. If block sizes $M$ are nearby power of two, the proposed Walsh and Hadamard sequences are recommended since for these sizes they have better average reliability with lower variability.

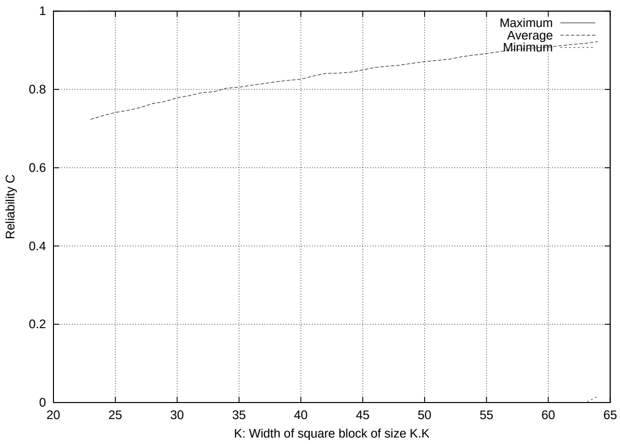


Fig. 1. Reliability Range for Pseudorandom Sequences.

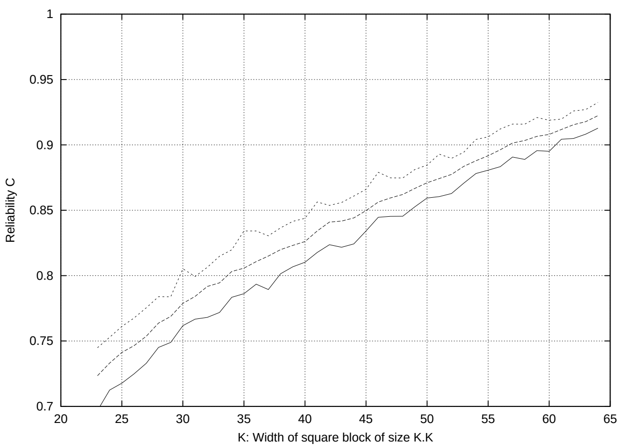


Fig. 2. Average Reliability and Dispersion for Pseudorandom Sequences.

For sequences generated by Gram-Schmidt orthogonalization, we found a much better average performance than the previous techniques as illustrated in the Figs. $7$ and $8$. With this technique we can achieve orthogonality among the sequences for all block sizes $M$. Moreover, the minimum detection reliability is always greater than $0.5$ and the average variability is smaller than the others. For those blocks of size $K \cdot K$ where the minimum reliability is greater than $0.5$, we assure perfect detection for all bits and for all one hundred watermarks. The only restriction is that $N$ must be smaller than $M = K \cdot K$, otherwise we cannot generate $N$ orthogonal sequences of length $M$. We notice that problem in the simulations for $K < 32$, since our test watermarks have $N = 1023$. This performance decreasing appears in the figures.

Since we enforce energy normalization of the sequences, we found a very similar level of distortion for all three techniques discussed. Therefore, the comparisons were made under conditions of same watermark energy.

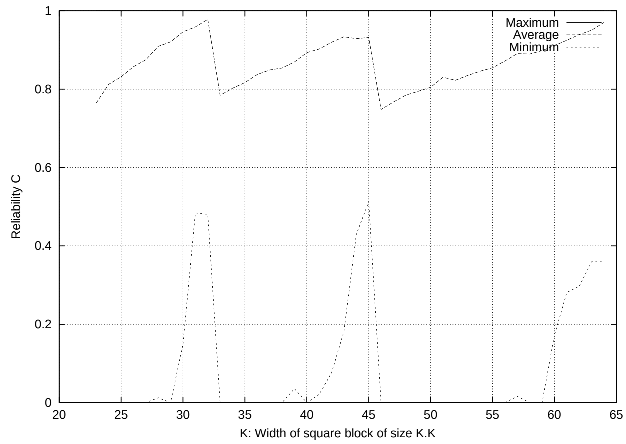


Fig. 3. Reliability Range for Walsh Sequences.

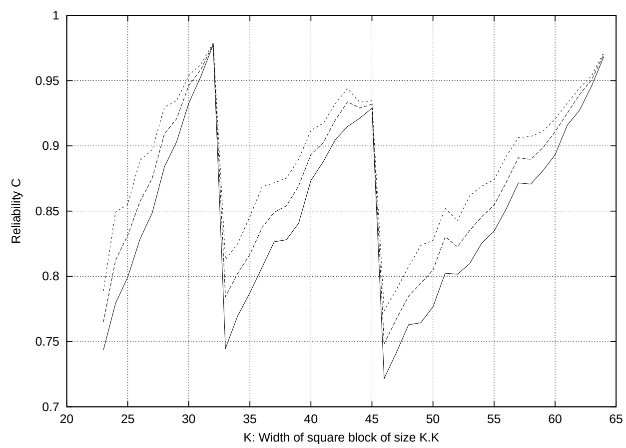


Fig. 4. Average Reliability and Dispersion for Walsh Sequences.

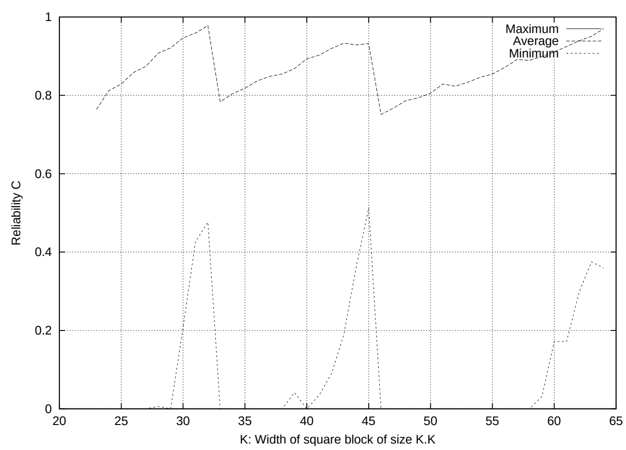


Fig. 5. Reliability Range for Hadamard Sequences.

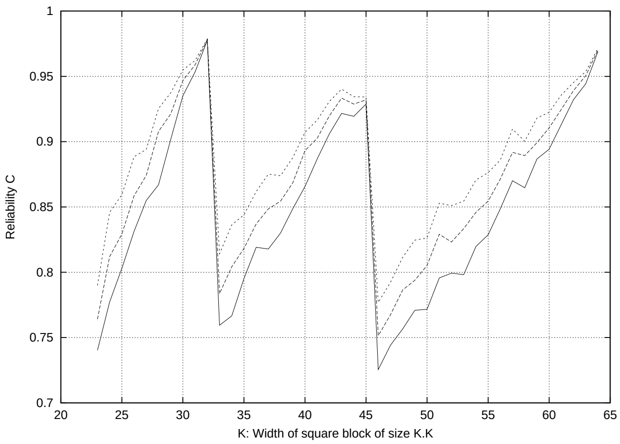


Fig. 6. Average Reliability and Dispersion for Hadamard Sequences.

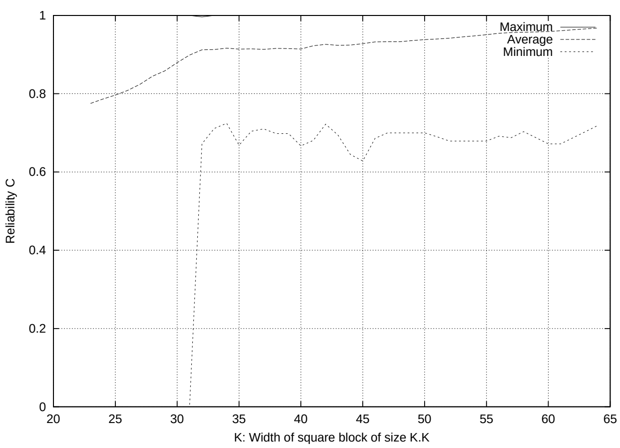


Fig. 7. Reliability Range for Orthogonal Sequences.

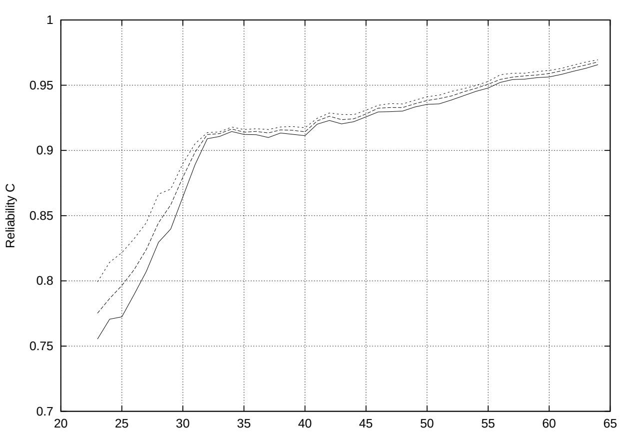


Fig. 8. Average Reliability and Dispersion for Orthogonal Sequences.

## VII. CONCLUSIONS

In this paper we discuss three techniques for generating pattern sequences. These sequences are used for spread spectrum watermarking applications. From a statistical and deterministic point of view, we derive some desirable properties for theses sequences when applied to watermarking. We clearly show that pattern sequences must have very low zero lag cross correlation in order to achieve high detection reliability of the watermark. Moreover, we show that sequences must have low zero lag cross correlation with either the image or the image prediction, depending if a prediction scheme is used.

We propose two techniques that presents the desirable properties and discuss their characteristics. We compare these two new techniques with the traditional pseudorandom generation and results indicate that both new techniques will increase significantly the detection reliability for practical watermarking applications. The improvement over the traditional pseudorandom generation is more significant when the block size is small. Although our results are based on images, the same conclusions can be applied to other type of data like speech, music, video, etc.

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