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Performance Comparison of Product Codes and Cubic Product Codes using FRBS for Robust Watermarking

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***Abstract*: In this paper, a novel technique for robust digital image watermarking is proposed using simple product codes (PC) and cubic product codes (CPC) respectively. Product codes are two dimentional matrix codes while CPC are three dimensional product codes where the constituent codes in each dimension are linear block codes. The structure of PC and CPC makes them suitable for the proposed scheme. The embedded watermark is vulnerable to various attacks on the image like compression, noise and geometric attacks namely translation rotation and scaling (TRS) etc. This could limit the performance of digital watermarking schemes. Our proposal is to encode the watermark with PC/CPC prior to embedding it into the image. This could easily be done because our watermark is also a three dimensional data (image/logo etc), so each dimension can easily be encoded with corresponding codes in PC/CPC. The modified iterative decoding algorithm (MIDA) is employed to decode the PC/CPC. Moreover, a Fuzzy Rule Based System (FRBS) is used to find the suitable regions in the host image where watermark can be embedded such that the imperceptibilityof the host image should not be affected. The FRBS makes used of Human Visual System (HVS) parameters to obtain those regions. The scheme is tested against various attacks and compared with the well-known schemes in the literature. Moreover, role of PC is also compared with CPCs and results are demonstrated.**

Keywords: Digital Watermarking, Product Codes, Cubic Product Codes, Robustness, linear block codes, MIDA, FRBS

I. Introduction

Digital watermarking for authentication and copyright protection is one of the interesting areas of research in information security. This technique is used for authentication, copyright protection, owner identification and copy control etc of a digital document. This technique is no more limited to the images but also applied to the audio, video, softwares and databases etc.

There are three basic properties of digital watermarking namely, capacity, imperceptibility and robustness. Capacity is measured with the size of watermark being embedded. Imperceptibility is measured with the degradation that is caused by embedded watermark in the image. That is the degradation should not be noticeabe. Robustness measures is resistance to certain attacks on the watermarked image.

According to the watermarking terminology, an attack is an event that can cause tampering in the image, thus making the watermark difficult to detect. Mainly attacks can be divided into two categories, incidental and malicious. Incidental attacks are friendly attacks and are required sometimes for example, JPEG compression is used in many of internet applications to make the file size small. Malicious attacks can be divided into four main categories namely, geometrical attacks, removal attacks, protocol attacks and cryptographic attacks as discussed by Gokozan [1].

Product codes are serially concatenated codes and were initially proposed by Elias [2] in 1952. Product codes are two dimensional linear block codes. Later the same concept was extended to three dimensional codes, called Cubic Product Codes (CPC) by [3]. In this concept long codes were generated by using much shorter constituent block codes in each dimension. Construction process of the CPC is presented in a subsequent section as well.

Robust watermarking schemes allow both incidental and malicious attacks while the fragile watermarking schemes donot allow any modifications. Semi-fragile watermarking schemes in such a way that they are robust against friendly modifications but are fragile against malicious attacks.

Mostly, retransmission is considered as a solution to this problem but only after the tampering is detected (a case of fragile watermarking). But when the time is stringent then retransmission may be costly (online scenario) also there is no guarantee that the received signals are error free. Morevoer, in retransmission throughput is also compromised.

Similarly use of cryptography for security is always a good choice. But the property that makes a cipher strong, makes it sensitive to the channel error at the same time. Solution is again retransmission but at the cost of throughput [4].

A reliable wireless error correction technique for secure image transmission is proposed in [5], where turbo codes were used for error free communication in contrast to chaos based encryption technique. Real BCH (Bose Choudhary Hoqagan) codes have been investigated for robust image transmission using a joint source-channel coding technique [6]. Error Correcting Codes (ECC) provides error free communication at the cost of redundancy. There are two major types of ECC that is Convolutional Codes (CC) and Linear Block Codes (LBC) [7].

In [8], authors proposed a reversible watermarking technique that improves the security of medical images with additional features to detect the tampering region and then to recover the tampering region of the watermarked image.

A Residue Number System (RNS) based reversible watermarking was proposed in [9]. In this paper authors used RNS to rescue the watermark. The proposed scheme was highly fragile against all kind of attacks. In [10], authors proposed a robust watermarking scheme resistant to geometric attacks. This was accomplished by Arnold's transform. It was also stated that transformed domain techniques provide significant improvement in robustness.

Atta-ur-Rahman et al [11] proposed a novel technique for reliable image transmission using Product Codes. In that technique the image was encoded prior to transmission. Product codes being comprised of two dimensional block codes, were observed structurally compatible with the images.

Atta-ur-Rahman et al [12] proposed a novel robust watermarking technique using Cubic Product Codes and Fuzzy Rule Based System. In this technique the watermark was encoded by CPC prior to embedding in the host image. FRBS was used to embed the watermark on suitable places in the host image. The scheme was demonstrated robust against a number of attacks.

In this paper, PC and CPCs are employed to digital image watermarking for robustness. A specific sized watermark (image) is encoded by PC/CPC, prior to embedding into the image. The embedding positions (pixels) for the watermark are obtained from a fuzzy rule based system (FRBS) that highlights the positions intuitively on behalf of parameteres of HVS. The scheme is verified for natural as well medical images.

Rest of the paper is organized as follows: Section 2 presents the construction of PC and CPC and their decoding technique, the fuzzy rule based system is given in Section 3, watermark embedding and extraction is discussed in Section 4, results of the proposed scheme are depicted in section 5 while section 6 concludes the paper.

II. Construction of PCs and CPCs

This section contains the brief introduction to the construction of product codes and cubic product codes respectively. Cubic Product Codes are an extention to simple PC.

A. Product Codes

Product codes are serially concatenated codes in which short constituent codes are used to construct bigger codes. In Product codes that are two dimentional (matrix) codes are consisted of linear block codes in row and column wise. This arrangement is shown in fig-1. Consider two linear block codes **A1** and **A2** with the coding parameters $[n_1, k_1, d_1]$ and $[n_2, k_2, d_2]$ respectively, where n_i, k_i and $d_i; i = 1,2$ are the length, dimension and minimum Hamming distance ($d_{\min}$) of the code $\mathbf{A}_i\ (i = 1,2)$ respectively. Code $\mathbf{A}_1$ will be used as row code while $\mathbf{A}_2$ will be used as column code. The rates of individual codes are R_1 and R_2 respectively given by,

$$R_i = \frac{k_i}{n_i}, i = 1,2 \qquad (1)$$

The product code $\mathbf{\Omega}$ can be obtained by codes $\mathbf{A}_i, i = 1,2$ in the following manner.

- Place $k_1 \times k_2$ information bits in an array of k_2 rows and k_1 columns
- Encode k_2 rows using code $\mathbf{A}_1$, which will result in an array of $k_2 \times n_1$
- Now encode n_1 columns using code $\mathbf{A}_2$, which will result in $n_2 \times n_1$ product code.

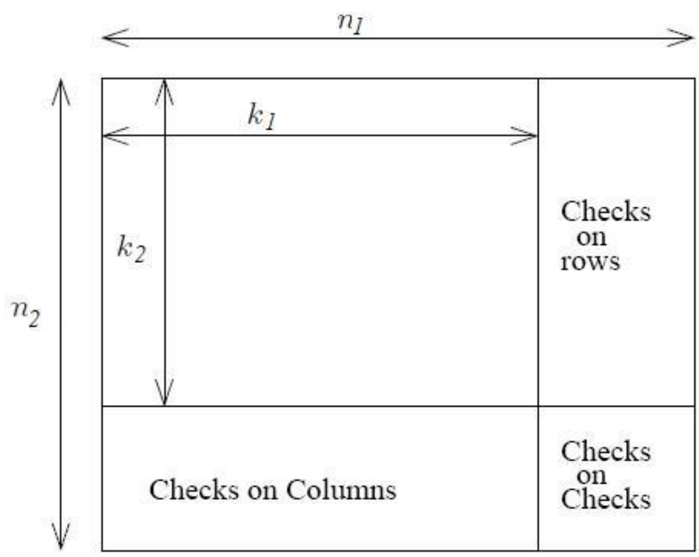

Figure 1. Structure of the Product code

The resultant product code $\mathbf{\Omega}$ has the parameters $[n_1 n_2, k_1 k_2, d_1 d_2]$ and the rate will be $R_1 R_2$. In this way long block codes can be constructed using much shorter constituent block codes.

This concept can also be viewed as that product code $\mathbf{\Omega}$ is intersection of two codes $\mathbf{A}_1^{'}$ and $\mathbf{A}_2^{'}$. Where $\mathbf{A}_1^{'}$ is a code represented by all $n_2 \times n_1$ matrices whose each row is a member of code $\mathbf{A}_1$, similarly $\mathbf{A}_2^{'}$ is a code represented by all $n_2 \times n_1$ matrices who's each column is a member of code $\mathbf{A}_2$. This can be written as;

$$\mathbf{\Omega} = \mathbf{A}_1^{'} \cap \mathbf{A}_2^{'} \qquad (2)$$

B. Cubic Product Codes

In cubic block codes (CPC) all three dimensions are encoded by three different linear block codes. In this paper, Bose Chaudhuri Hocquenghem (BCH) codes [13] are considered as constituent codes in the construction of CPCs.

Let there be three BCH codes, namely A_1, A_2 and A_3 with the parameters $[N_1, K_1, D_1]$, $[N_2, K_2, D_2]$ and $[N_3, K_3, D_3]$ respectively. N_i, K_i and D_i represent codeword length, message length and minimum hamming distance (d_{min}) of the code A_i, respectively and i=1, 2, 3. The code rate of the constituent codes in 3D product codes can be written as;

$$R_i = \frac{K_i}{N_i}, i = 1,2,3 \quad (3)$$

The 3D product code can be constructed in the following manner.

1. Place $K_1 \times K_2 \times K_3$ information bits in a cube like structure such that K_1 is height, K_2 as width and K_3 as depth of the cube
2. Encode $K_1 \times K_3$ rows using code A_2, which will result in $K_1 \times N_2 \times K_3$ sized cube
3. Encode $N_2 \times K_3$ rows using code A_1, which will result in $N_1 \times N_2 \times K_3$ sized cube
4. Encode $N_1 \times N_2$ rows using code A_3, which will result in $N_1 \times N_2 \times N_3$ sized cube. This is the final codeword of the cubic product code.

This process is shown in fig-2. The parameters of the resultant cubic product code Ω are given as [N, K, D], where

$$\begin{aligned} N &= N_1 N_2 N_3 \\ K &= K_1 K_2 K_3 \qquad (4) \\ D &= D_1 D_2 D_3 \end{aligned}$$

And the resultant code rate of the CPC can be given as;

$$R' = \prod_{i=1}^{3} R_i \qquad (5)$$

Since CPCs possess a high minimum distance compared to their constituent codes, they have a much better error correction capability also. The error correction capability 't' is given as;

$$t = floor[\frac{d_{\min} - 1}{2}] \qquad (6)$$

Cubic product block codes can also be considered as the Cartesian product of its constituent linear block codes. Also in some definitions it is also considered as the intersection of the constituent linear block codes. Hence two different notions are used as given in Equ-5 and Equ-6.

$$X = A_1 \otimes A_2 \otimes A_3 \qquad (7)$$

where $\otimes$ represents Kronecker product of two codes and X is resultant product code. Also it can be viewed as;

$$X = A_1^{'} \cap A_2^{'} \cap A_3^{'} \qquad (8)$$

Hence this can also be written as the cubic product code is intersection of three codes that are $A_i^{'} : i = 1,2,3$, where $A_1^{'}$ is a code represented by all $N_1 \times N_2 \times N_3$ cubic matrices whose each element is a member of code A_1. Similarly $A_2^{'}$ is a code represented by all $N_1 \times N_2 \times N_3$ cubic matrices whose each element is a member of code A_2 and $A_3^{'}$ is a code whose each element of is a member of code A_3.

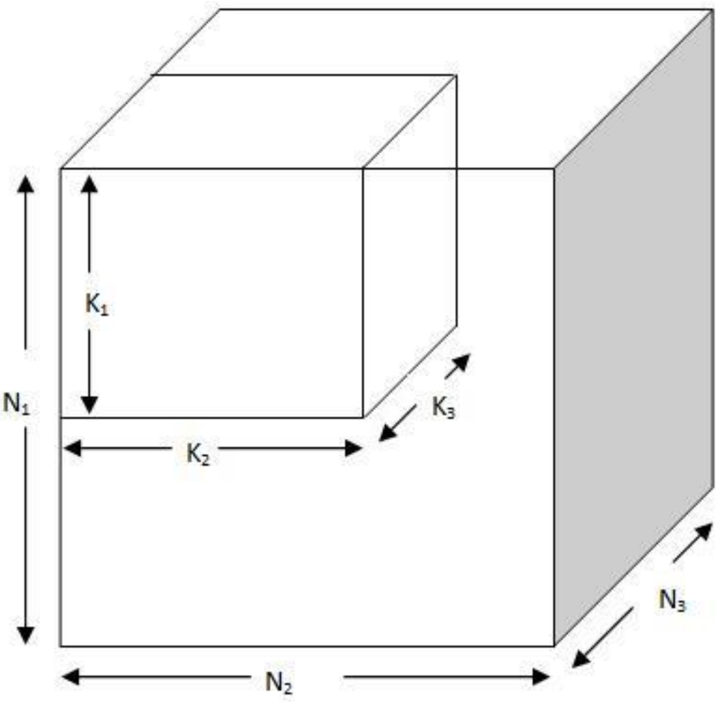

Figure 2. Cubic Product Codes

C. Modified Iterative Decoding Algorithm

Modified Iterative Decoding Algorithm (MIDA) was proposed by [14] and it is a revised version of Iterative decoding algorithm origionally proposed by [15] which is a suboptimum decoder. MIDA is a hard decision decoder.. It is actually a list decoder in which separate lists are generated for each row in row code and each column in column code or the product code. Syndrome decoding of linear block codes is used for complexity reduction [16]. In this way number of rows/columns, for which lists are to be built, is reduced significantly, hence the decoding complexity is reduced significantly. Also the complexity reduction grows significantly with each passing iteration in decoding.

MIDA has been applied for decoding various codes used for digital image watermarking as well as for adaptive communication systems like adaptive frequency division multiplexing (AOFDM) systems in the literature [17-20].

III. Human Visual System

All areas of the image are not equally suitable for embedding the watermark information because different regions may have different level of sensitivities. For example, uniform areas of image are very sensitive to the addition of watermark information so, only small amount of information can be added in the uniform areas whereas, the edge areas can support for embedding greater watermark information. The Human visual system (HVS) has been considered with several phenomenon that permits to adjust the pixel values to elude perception [21]. The FRBS has been used here to adapt the HVS different properties. In this scheme, we are considering texture, brightness and edge sensitivity, so that embedding the watermark information in these features makes the image imperceptible.

A. Brightness Sensitivity

As brighter background areas are less sensitive than the dark ones, pixels with high values of brightness are chosen for embedding the watermark bits. It is common practice to represent the images in 8-bit format, that is one byte per pixel, each of which has a value from 0 to 255. The pixel value '0' represents the maximum darkness in the image while the value '255' represents the maximum brightness in the image whereas, the grey shades represent the values in between these limits.

B. Edge Sensitivity

To make the lower visibility of embedded signal, higher edges are chosen for embedding the watermark [13]. A gradient analysis has been made to test the model by using different edge detection methods such as sobel, prewitt and canny. In the present scheme, we have used Canny method for calculating edge sensitivity S_E .

C. Texture Sensitivity

The stronger the texture features, the lower is the visibility of the embedded data so, our scheme search for the pixels with the highest texture for embedding the watermark data. Texture sensitivity basically measures the activity of the center pixel with its neighbors (fig-3),

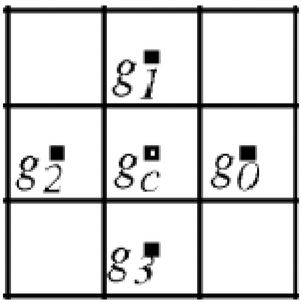

Figure 3. Neighbours of a pixel

$$Activity = |g_c - g_0|^2 + |g_c - g_1|^2 + |g_c - g_2|^2 + |g_c - g_3|^2 \quad (9)$$

Ojala et al. [14] proposed a local binary pattern (LBP) operator for calculating texture sensitivity that was based on the postulation that the texture has locally two paired aspects, strength and the pattern. The effectiveness has been proposed to be an operative descriptor in texture classification [15]. In experimental studies, LBP has became the strongest measure for texture analysis which can be comprehended as a universal methodology to the traditionally different statistical and physical models of texture analysis [16]. The most important property of LBP operator in real world applications is its invariance against monotonic gray level changes".

LBP is defined as a gray-scale invariant texture measure, resulting from a description of texture in a local neighborhood. A binary value from 0 to 255 is obtained by concatenating the values of the neighborhood results in a clock wise direction for each pixel. In the present scheme, LBP method for calculating texture sensitivity S_T is used.

IV. Human Visual System

Here a Fuzzy Rule Based System is used to find those regions in the image where more information can be embedded. This decision is based the HVS factors discussed in previous section. FRBS decides that how much data can be embedded in the which regions of the image with a significant level of imperceptibility.

A. Design of Fuzzy Rule Based System

As mentioned earlier, first FRBS has three input variables namely *brightness sensitivity*, *texture sensitivity* and *edge sensitivity* duly defined in previous section. The input range of brightness and texture sensitivity is between 0-255 and edge sensitivity could either be 0 or 1. Five membership functions are used to cover the input space of *brightness sensitivity* (very dark, dark, dim, bright and very bright), two membership functions are used to represent edge sensitivity (low, high) and five membership function for texture sensitivity (very smooth, smooth, average, rough and very rough). These relationships for the three input variables are shown in fig-4, fig-5 and fig-6 respectively. There is one output variable named capacity factor (alpha). Five membership functions (very low, low, medium, high and very high) are used to cover the range which is between 0 and 1 as shown in fig-7.

As cardinality the of rule base is the cartesian product of number of membership functions in each input variables, there are fifty rules in the rule base, so the rule base is complete as it contains rule for each input combination. As all three features are somewhat in directly proportional to the output, the rules are formulated accordingly. The possible values of variable *edge sensitivity* are 0 or 1, so twenty-five rules are formulated for each case. Rules can be found in table-1 and table-2 for edge sensitivity 1 and 0 respectively. Each table contains twenty-five rules. The first row and first column of each table contains IF part while rest of the table contains according value of THEN part. A rule format can be expressed as;

IF (Texture= 'Average' AND Brightness = 'Dim' AND Edge = '1') THEN (Alpha = 'Medium')

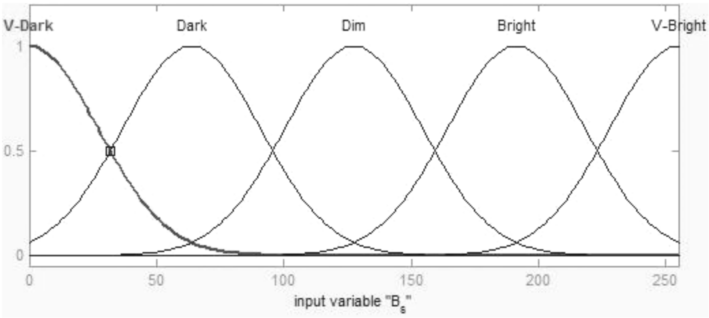

Figure 4. Input variable “Brightness sensitivity (Bs)”

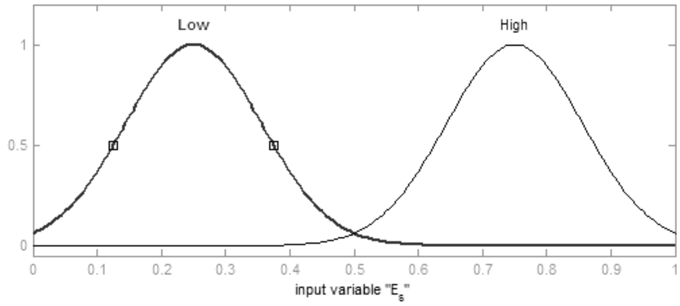

Figure 5. Input variable “Edge sensitivity (Es)”

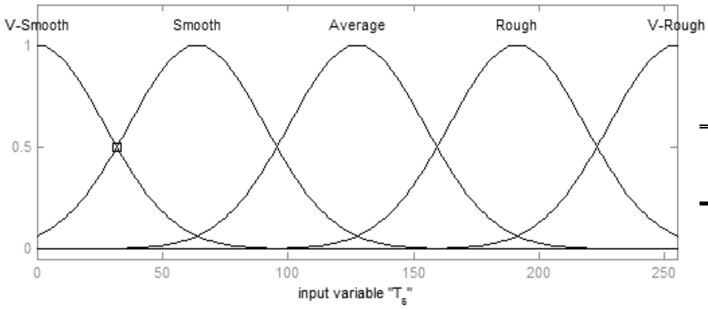

Figure 6. Input variable “Texture sensitivity (Ts)”

The surface views of the rule base between texture and brightness for edge-1 and edge-0 are shown in fig-8 and fig-9 respectively. Both of these figures narrate that higher the values of brightness and texture sensitivity, image capacity factor, alpha, is higher and vise versa.

However, this impact is even more when the edge sensitivity is 1 and less when edge sensitivity is 0, which conforms to the definitions given in previous section. That is regions with edge sensitivity one, can carry more information and vice versa.

B. Components of Fuzzy Rule Base System

- **Fuzzifier**: Standard Gaussian fuzzifier is used to transform crisp values of input into corresponding fuzzy values. Among other fuzzifiers, Gaussian has its own significance due to continues approximations unlike triangular and trapozoidal fuzzifiers, where mapping is not that fine.

- **Inference Engine:** Mamdani Inference Engine (MIE) is used for inferring that an input vector is mapped on to which corresponding/appropriate output point/value by making use of the rules and their weights in the rule base. In MIE, fuzzy operation AND is chosen as MIN while OR is chosen as MAX.

- **De-Fuzzifier:** Standard Center Average Defuzzifier (CAD) is used to transform the fuzzy output value into the closest and accurate crisp value. CAD is preferred among its peers due to its effectiveness as well as less computational requirements during de-fuzzification process.

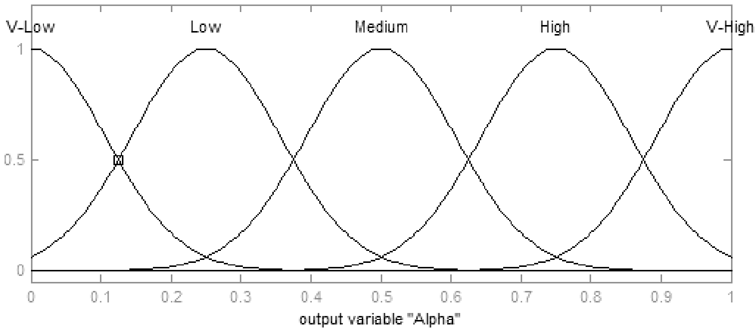

Figure 7. Output variable “The Capacity factor (alpha)”

		Brightness				
	Edge = 1	V-Low	Low	Dim	High	V-High
Texture	V-Smooth	VL	L	L	M	M
	Smooth	L	L	M	M	H
	Average	L	M	M	H	H
	Rough	M	M	H	H	VH
	V-Rough	M	H	H	VH	VH

Table 1. Rulebase with Edge Sensitivity=1

		Brightness				
	Edge = 0	V-Low	Low	Dim	High	V-High
Texture	V-Smooth	VL	VL	L	L	M
	Smooth	VL	L	L	M	M
	Average	L	L	M	M	H
	Rough	L	M	M	H	H
	V-Rough	M	M	H	H	VH

Table 2. Rulebase with Edge Sensitivity=0

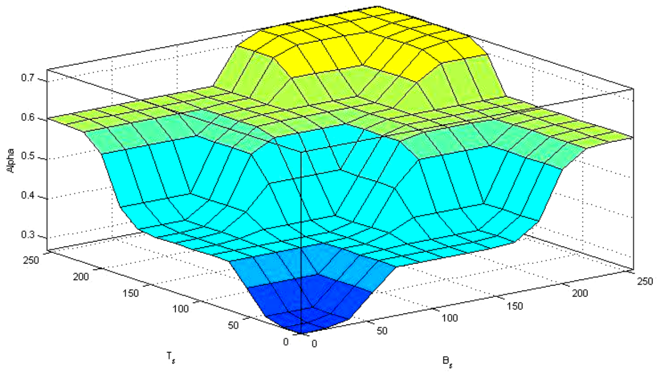

Figure 8. Surface view with edge sensitivity = 1

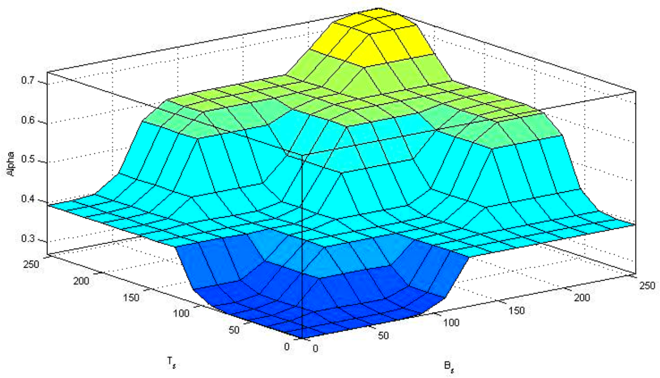

Figure 9. Surface view with edge sensitivity = 0

V. Simulation Results

In this section, effectiveness of the CPCs is shown initially in terms of bit error rate (BER) and their immunity against certain attacks in digital image watermarking. The simulation parameters used in the experiment, are listed in table-3 given below.

Sr. #	Parameter	Value
1	Constituent code-1	[16,11,4]
2	Constituent code-2	[31,21,5]
3	Product Code-1	$[16,11,4]^2$
4	Product Code-1	$[31,21,5]^2$
5	Cubic Product Code-1	$[16,11,4]^3$
6	Cubic Product Code-1	$[31,21,5]^3$
7	Decoder	MIDA [3]
8	Attack type-1	AWGN
9	Attack type-2	Salt & Pepper noise
10	Attack type-3	JPEG Compression

Table 3. Simulation Parameters

Two different BCH codes are used for the experiment. First one is [16,11,4], in which the minimum distance is 4, that means the error correction capability is 1. The second one is [31,21,5] with a minimum distance of 5, that means it is a two bit error correction code. Same codes are used for construction of product codes as well as cubic product codes, so that comparison can be made more interesting. Moreover, same code is used in both dimensions of PC and all three dimensions of CPC.

Fig-10 shows the performance of Product Codes in terms of bit error rate (BER) over an Additive White Gaussian Noise (AWGN) channel. It is apparent from the figure, that the Product Code with [31,21,5] as component code performs better than Product Code with [16,11,4] as component code. This is because the former code has a greater minimum distance and greater error correction capability.

Fig-11 shows the performance of CPC in terms of BER over an Additive White Gaussian Noise (AWGN) channel. It is apparent from the figure, that the CPC with [31,21,5] performs better than CPC with [16,11,4]. This is because this code has a greater minimum distance and better error correction capability. One thing that is noteworthy, product codes with same constituent codes can achieve same performance as CPC but with a greater signal to noise ratio (SNR). For example, to achieve a BER of 10e-5, product code $[31,21,5]^2$ demands almost 26dB SNR, while same code in CPC demands almost 13dB SNR. Similarly, in the case of [16,11,4] constituent code, Product code demands almost 27dB SNR is required to achieve BER 10e-4, while in CPC we need almost 13dBs to achieve the same BER performance which is again half than the previous case. So from the figures it is clear that product codes need double SNR compared to CPC in order to achieve same BER performance. That is mainly because the third dimension is paying in terms of performance imporvement.

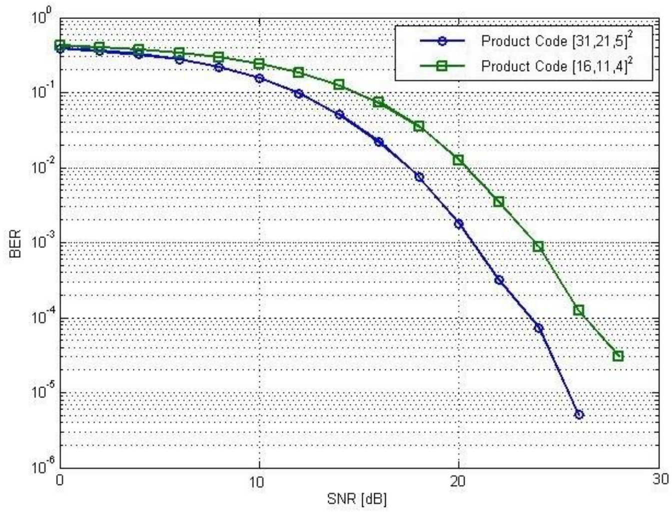

Figure 10. Performance of Product codes over AWGN

Though the decoding complexity of CPC is more that Product codes, however, their BER performacne is significantly greater than that of product codes. To make this comparison crystal clear, constituent codes for both product codes and cubic product codes are kept similar so that the comparison can made on the structures rather than constituent codes.

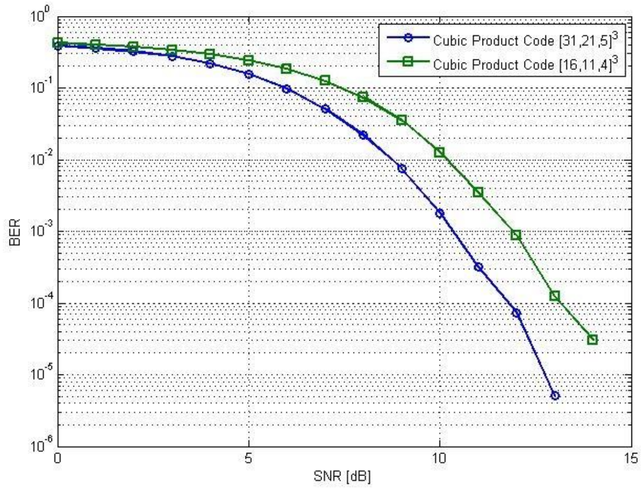

Figure 11. Performance of CPC over AWGN

Fig-12 shows the original cover image of Lena while the watermark image is shown in fig-13. It is a custom designed watermark, just to make it compatible (in all dimensions) for encoding with the product codes and CPC being used respectively.

Figure 12. The cover image

Figure 13. The watermark image

After encoding the image by the Product Code with [31,21,5] (being superior between the constituent codes, it is the only code that is used in subsequent comparisons) as the constituent code, the watermark is embedded in the regions of the original image selected by the Fuzzy Rule Based System (FRBS) discussed in the previous section. The watermarked image is shown in fig-14. From the naked eye view, it’s clear that the image is still imperceptible. This is due to the pixels selected by FRBS. The image is then offered a number of attacks and the recovered watermark is shown after extracting from the host image. The peak signal to noise ratio (PSNR) which is considered as the perceptual measure of origional and watermarked image. This is actually the measure of imperceptibility that how much origional and watermarked images are different. That can be written as [10]:

$$PSNR = 10\log_{10}(\frac{255^2}{MSE})$$
$$where \qquad (10)$$
$$MSE = \frac{1}{MN}\sum_{i=0}^{M-1}\sum_{j=0}^{N-1}[f(x,y) - f'(x,y)]^2$$

Here M and N are dimensions of the image, mean squared error (MSE) is a normalized difference between origional image $f(x,y)$ and the $f'(x,y)$ watermarked image. Though the practical level of imperceptibility varies from application to application, however, in the literature 50dB or higher level of PSNR is considered as a good imperceptibility [10]. After embedding the watermakr encoded by the product code the PSNR of the image is found 70dB which is practically a very good level of imperceptibility.

After encoding the image by the CPC with [31,21,5] as the constituent code, the watermark is embedded in the regions of the original image selected by the Fuzzy Rule Based System (FRBS) discussed in the previous section. The watermarked image is shown in fig-15. From the naked eye view, it’s clear that the image is still imperceptible. This is due to the pixels selected by FRBS. The image is then offered a number of attacks and the recovered watermark is shown after extracting from the host image. After embedding the watermakr encoded by the product code the PSNR of the image is found 63dB which is practically still a good level of imperceptibility. The difference in PSNR in fig-14 and fig-15 is because in case of CPC, we have to embed more information in terms of watermark since our watermark is encoded in three dimension which results in relatively bigger information contents. This would help us in enhanced robustness but at the cost of little reduced imperceptibility. This is depicted in subsequent figures.

Fig-16 shows the recovered watermark after speckle noise attack with variance 0.01 resulting in Nc=0.796 in case of Product Codes while Nc = 0.873. Here Nc is the similarity index between orgional image and the recovered image. So higher the index, more robust will be the image. Though required value of Nc varies from application to application however, as a common practice, value of Nc higher than 0.7 is considered as a good level of robustness [10]. From fig-16 it is aparant that CPCs are more robust compared to the simple product codes.

Fig-17 shows the recovered watermark after the attack of Gaussian noise with variance 0.01, showing Nc = 0.713 in case of Product codes while Nc=0.814 in case of the CPC.

Fig-18 shows the recovered watermark after attack of Salt & pepper noise with variance 0.01, having Nc = 0.863 in case of CPC and Nc=0.801 in case of Product codes.

Fig-19 shows the recoverd watermark after rotation attack of 2 degrees, having Nc = 0.856 in the case of product codes while Nc=0.951 in case of CPC.

From fig-16 to fig-19, it can easily be deduced that proposed schemes are significantly robust against the said attacks. Moreover, Cubic product codes outperforms than Product codes in terms of robustness.

The proposed schemes are compared with each other for different kinds of wellknown attacks found in the literature and the comparison is enlisted in table 4. From both columns it is clear that CPC performs better than Product codes in terms of robustness.

Attack Type	**Product Codes (Nc)**	**Cubic Product Codes (Nc)**
Speckle Noise	0.796	0.873
Gaussion Noise	0.713	0.814
Salt & pepper Noise	0.801	0.863
Rotation of Degree 2	0.856	0.951

Table 4. Comparison of schemes

Figure 14. The watermarked image (having PSNR=70dB)

Figure 15. The watermarked image (having PSNR=63dB)

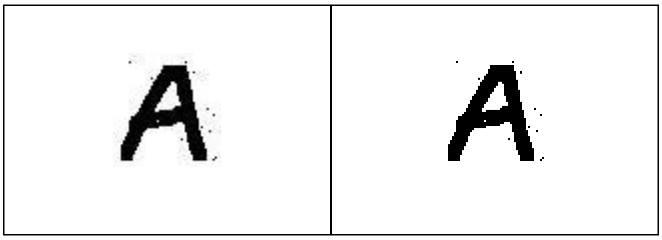

Figure 16. Recoverd watermark after attack of speckle noise with variance 0.01 showing (a) Nc = 0.796 case of product code (b) Nc = 0.873 case of cubic product code

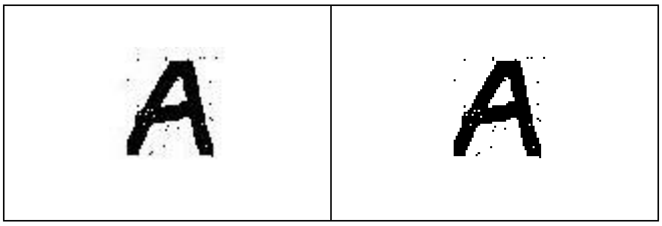

Figure 17. Recoverd watermark after attack of Gaussian noise with variance 0.01, having (a) Nc = 0.713 case of product codes (b) Nc = 0.814 case of cubic product codes

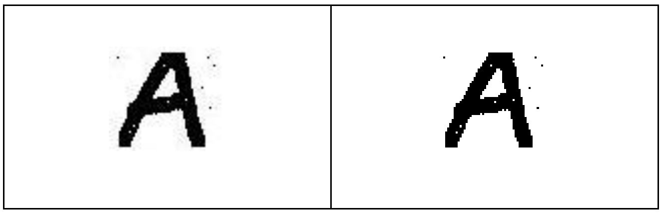

Figure 18. Recoverd watermark after attack of Salt & pepper noise with variance 0.01, having (a) Nc = 0.801 case of product codes (b) Nc = 0.863 case of cubic product codes

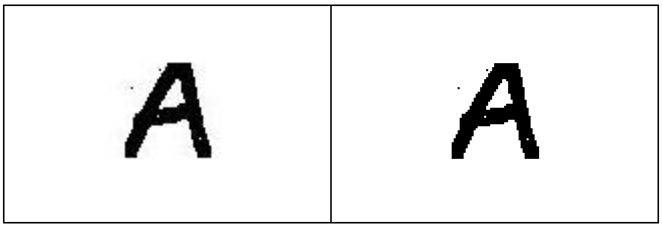

Figure 19. Recoverd watermark after rotation attack of 2 degrees, having (a) Nc = 0.856 case of product codes (b) Nc = 0.951 case of cubic product codes

VI. Conclusion

This paper presents a novel idea of using product codes and cubic product codes (CPC) for making the watermark robust in a digital image watermarking scenario. Product codes are two dimensional linear block codes while CPC are three dimensional linear block codes. The structure of both types of codes make them compatible and suitable with the digital image watermaking.

In a number of applications, the watermark is more important as compared to the cover image, so making the watermark robust is the major focus of the field. Like when the cover image is publically available and accessible but its ownership is still needed to be preserved.

A fuzzy rule based systems (FRBS) is proposed to highlight the areas of the cover image (pixels) where the watermark can be inserted with a significant level of imperceptibility. This is done by fuzzifying and adequately utilizing the parameters of Human Visual System (HVS).

Due to their error correcting capabilites, product codes and CPCs has shown the notable performance in the results in terms of robustness against various attacks. Moreover, it was observed that CPCs performs better than Product codes in terms of robustness while using Product codes may result in a little degradation in imperceptibility of the image that is still somewhat negligible. Comparisons are made through computer simulations using MATLAB 7.1.5.

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