# Fuzzy-ART Based Geometrically Invariant Robust Watermarking Scheme

Neethu V. Gopal and Madhu S. Nair

***Abstract*—This paper describes a novel transform domain oblivious image watermarking method that combines Fuzzy-ART clustering and image normalization to design a watermarking system that is robust to any type of attacks like geometric attacks, jpeg compression, noise attacks and other image processing attacks. The use of Fuzzy ART clustering as a pre-processing step helps in the accurate selection of locations for watermark insertion so that the watermarked image is robust as well as perceptually invisible. The watermark is embedded adaptively using Just Noticeable Distortion (JND) mask that ensures the required quality for the watermarked image. The loss of synchronization in case of geometric attacks is corrected using image normalization technique that makes the watermark detectable even in the case of geometric attacks. Replicated copies of the binary watermark image are used to create a composite watermark that is scrambled using Arnold Transform which gives better reliability in extraction. Normalized Correlation (NC) is used as the verification metric.**

***Index Terms*—Image watermarking, Fuzzy-ART clustering, Image Normalization, Arnold Transform.**

## I.INTRODUCTION

The world is now in a digital era. Digital data are electronically generated and can be easily accessed, edited and utilized from anywhere any time ever since the introduction of World Wide Web. So the electronically generated digital data are to be well secured and safeguarded.

Digital watermarking provides copyright protection and also preserves image quality. The major challenge in watermarking is that as the image quality increases the robustness decreases and vice versa. A good watermarking system is that which address this trade off efficiently. Transform domain watermarking schemes [1] [4] [5] [7-10] are more robust than spatial domain schemes [2] [6] and also most of the applications prefer oblivious watermarking scheme where original image is not required for watermark extraction [5] [9].

In [11] C.H.Chang et al. proposed a work in which a visually meaningful binary watermark is embedded by adaptively modifying the DCT coefficients in selected regions of the host image. The locations for watermark insertion are selected with the help of Fuzzy adaptive resonance theory (Fuzzy-ART) [3] [12] [27] [28]. Even though this method is robust to jpeg compression attacks and other image processing attacks, the system fails in case of geometric attacks.

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Various approaches have been proposed to surmount geometric attacks. [13-15]. In [16], Ruanaidh and Pun proposed a watermarking scheme that uses the invariant properties of Fourier–Mellin transform (FMT) to combat with RST attacks. But the method is difficult to implement. In [18], Dong et al. proposed a multi-bit public watermarking scheme based on image normalization, aimed to be robust against general affine geometric attacks. In this approach, both watermark embedding and extraction were performed using a normalized image. This method requires the original image to be subjected to several affine transformations that degrades the quality of the image. Weiwei et al. used image normalization for synchronization recovery in [19]. Since image normalization is done only at detection side, the quality degradation of the watermarked image due to affine transformations at the embedding side is avoided.

The proposed work is an invisible transform domain oblivious watermarking scheme that is robust to common image processing attacks like jpeg compression attacks, noise attacks, filtering attacks etc. At the same time the system is also robust to geometric attacks like rotation scaling, translation and flipping. In this work, fuzzy-ART helps in choosing the appropriate blocks for watermark insertion so that the system becomes robust against common image processing attacks [11]. In order to combat with geometric attacks, image normalization [18] [19] is used in the synchronization recovery of the geometrically distorted watermarked image. A visually meaningful binary watermark image is used to design a composite watermark. Instead of embedding the watermark directly, it is first scrambled using Arnold transform [20]. The watermark is embedded by adaptively modulating the selected DCT coefficients by a factor that depends on the image content specified using the JND value [23]. Fig.1 gives an overview of the Fuzzy-ART based geometrically invariant robust watermarking scheme (FGRW).

Section II describes Fuzzy-ART clustering and Section III describes the design of composite watermark and scrambling using Arnold transform. Section IV discuss about the image normalization technique for synchronization recovery of geometrically distorted images. Section V describes the formal steps in watermark embedding and watermark detection. Section VI throws light on Normalized correlation, a quantitative measure used to verify the detected watermark. The experimental results are given in section VII and conclusions are drawn in section VIII.

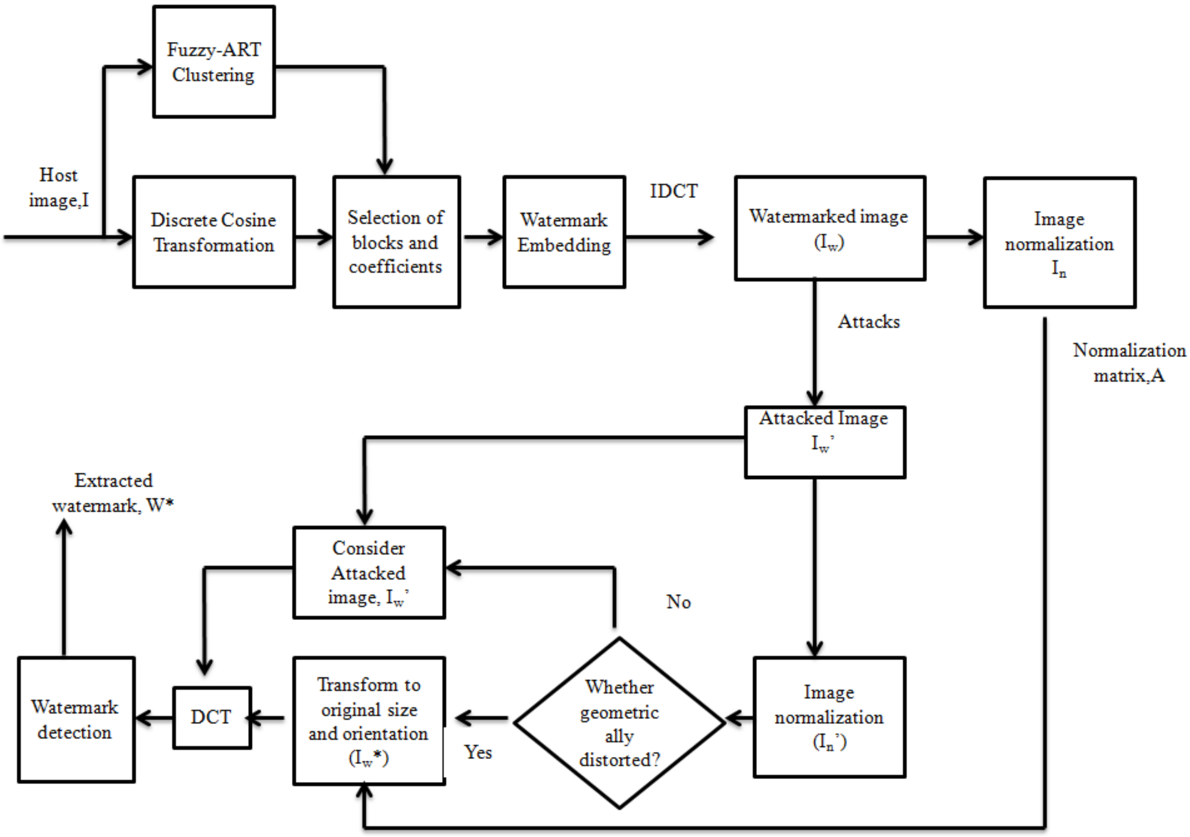



**Fig. 1.** The block diagram for FGRW Scheme.

## II. FUZZY-ART

In the proposed work Fuzzy-ART is used to cluster the input host image blocks for selecting the most competent locations for watermark insertion. Each host image is clustered separately and only the image blocks belonging to the selected clusters are used for watermark insertion.

### *A. SUMMARY OF FUZZY ART ALGORITHM*

The fuzzy-ART network [12] consists of two layers, the input and output layers, and a vigilance subsystem controlled by the vigilance parameter, $\rho \in [0,1]$.

*Input vector*: The host image, $I$ of size M×N is divided into 8×8 non-overlapping blocks. Each block is converted to a column vector of length 64. This is then normalized using complement coding rule [12]. The resultant vector, $(I_1,...,I_L)$, where L=128, is given as input to the fuzzy-ART network.

*Weight vector*: The pattern that defines each category (j) is a weight vector $W_j \equiv (w_{j1},\dots,w_{jM})$. Initially $w_{j1} = \cdots = w_{jL} = 1$ and each category is said to be uncommitted. After a node is selected for coding, it becomes committed. Each weight component $w_{ji}$ is monotonically non-increasing through time and hence converges to a limit.

*Parameters*: Fuzzy-ART dynamics are determined by a choice parameter $\alpha, > 0$; a learning parameter $\beta \in [0,1]$; and a vigilance parameter $\rho \in [0,1]$.

*Category choice*: For each category j, the choice function Tj is defined by

$$T_j = \frac{|I \wedge W_j|}{\alpha + |W_j|} \tag{1}$$

The category choice is indexed by J selected based on winner take all policy, where

$$J = max\{T_j : j = 1,..,N\} \tag{2}$$

If more than one index $j$ gives a maximal $T_J$ , the node with the smallest index is chosen.

*Resonance or reset*: The category is chosen only if it meets the match criterion. Resonance occurs if the match function of the chosen node meets the vigilance criterion. That is,

$$\frac{|I \wedge W_j|}{|I|} \geq \rho \tag{3}$$

Otherwise, mismatch reset occurs. A new index $J$ is chosen, using (2). The search process continues until the chosen $J$ satisfies eq. (3).

*Learning*: The weight vector $W_J$ is updated according to the equation

$$W_j^{(new)} = \beta\left(I \wedge W_j^{(old)}\right) + (1-\beta)W_j^{(old)} \tag{4}$$

Fast learning corresponds to setting $\beta = 1$.

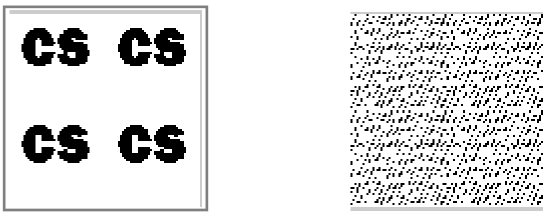
## III. WATERMARK SCRAMBLING

A visually meaningful binary image is used as the watermark in the proposed work. The watermark image, $W$ is replicated to form a composite watermark, $W_m$. The use of composite watermark enables a weighted superimposition during detection that increases the reliability of the detected watermark. Fig. 2 shows the watermark image and the composite watermark designed using the watermark image.


(a) (b)

**Fig. 1.** Watermark images.(a) Watermark image. (b) Composite watermark

The composite watermark, $W_m$ is first scrambled to a meaningless form. By using the scrambling transform, the spatial relativity of the watermark pixels is lost and the pixels are spread across the entire image. This increases the robustness of the watermarking system against attacks. Also an attacker knowing the extraction algorithm could only extract the meaningless watermark image. Thus the security of the watermarking system is increased. The proposed work uses Arnold transform [20-22] to convert the watermark image to a chaotic form.




(a) (b)

**Fig. 2.** Scrambling using Arnold transform. (a) Watermark image. (b) Scrambled watermark

### A. ARNOLD TRANSFORM

Arnold transform is an image scrambling method, proposed by Vladimir Arnold in 1960's. For a digital square image of size N×N, discrete Arnold mapping can be done as

$$\begin{pmatrix} x \\ y \end{pmatrix} = \left[ \begin{pmatrix} 1 & 1 \\ 1 & 2 \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix} \right] modN \tag{5}$$

A scrambled image is obtained by transforming every pixel in the watermark image using eq. (5). This transformation is done continually until the required chaos is obtained. Since the transform is reversible, the original image can be recovered. Fig. 3 shows the watermarked image and its scrambled form

## IV. IMAGE NORMALIZATION

The proposed work uses image normalization for synchronization recovery in the case of geometrical attacks [19]. Normalization transforms the image $I$ to a standard form $I_n$ that has a size and orientation invariant to any type of affine transformations using a composite normalization matrix $A_I$ [18] [25] [26].

$$I_n = A_I\, I \tag{6}$$

Any affine transformed form of I, $I_t$ gives the same normalized image, $I_n$ using $A_{I_t}$ .

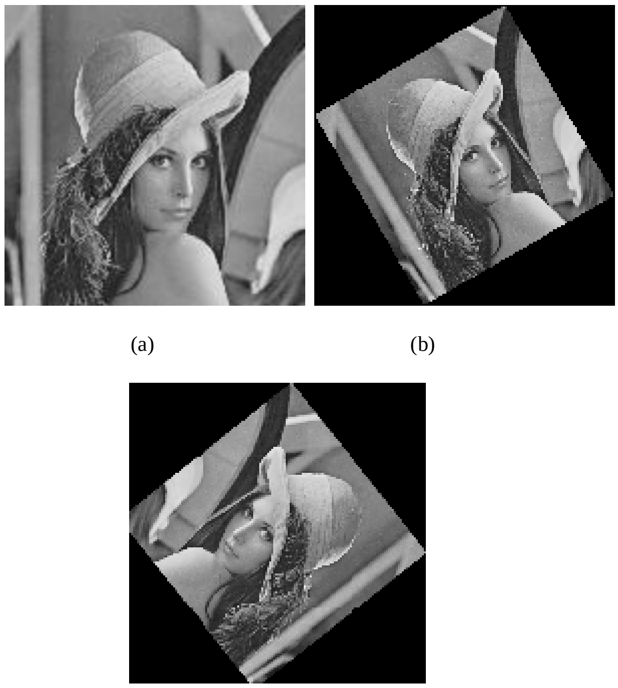
$$I_n = A_{I_t}\; I_t \tag{7}$$

Since even distorted images give the same $I_n$ ,the corrected image, $I_c \cong I$ can be obtained by inverse transformation using $A_I$.

$$I_c = A_I I_n \tag{8}$$

The requirement is that the composite normalization matrix $A_I$ should be known for correction. $A_I$ can be calculated at the embedding side after obtaining the watermarked image $I_w'$ and be made available at the detection side.

The normalization procedure described in [18] is used in this paper. Fig. 4 shows how the original *Lena* image and its rotated form yield the same normalized image, as shown in Fig. 4 (c).



(c)

**Fig. 3.** Normalization procedure. (a). Lena image. (b). Rotated Lena image. (c). Normalized image of both (a) and (b)

## V. WATERMARK EMBEDDING AND EXTRACTION

### A. WATERMARK EMBEDDING

The binary watermark image is adaptively embedded into the selected DCT coefficients of the host image. The watermark to be embedded is processed to form a composite watermark which is then scrambled. Fig. 5 gives an overall view of the watermark embedding scheme.

*Watermark processing*

1) The composite watermark $W_m$ of size m×n is scrambled using Arnold transform as discussed in section II.
$$W_s = Arnold\_Transform(W_m) \quad (9)$$
2) $W_s$ is divided into $q$ non-overlapping blocks of size 4×4. Now, the 16 binary watermark pixels in each block are embedded into each of the selected host image blocks.

*Host image processing*

Consider a host image $I$ of size $M \times N$ .The steps in watermark embedding is given below

1) Divide the host image $I$ into non-overlapping blocks of size 8×8.
$$I = I_1 \| I_2 \| \dots \dots \| I_p \quad (10)$$
where $p$ is the total number of blocks.

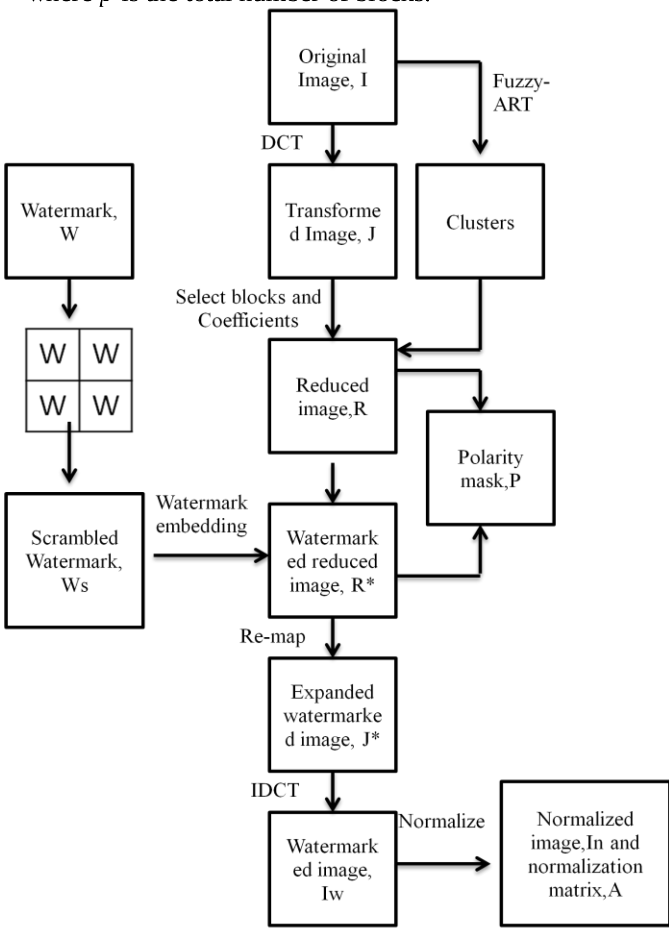



**Fig. 4.** Watermark embedding scheme

The size of the image is truncated to make $p$ a whole number.

2) Cluster the host image blocks using fuzzy-ART where each block is categorized to a particular cluster as discussed in Section II.
3) Apply block wise DCT to the image $I$.
$$J = DCT(I_1) \| DCT(I_2) \| \dots\dots \| DCT(I_P)$$
$$= J_1 \| J_2 \| \dots \| J_p \quad (11)$$
4) Select the locations for watermark insertion using fuzzy-ART [11].
5) A reduced image $R$ is formed using the selected coefficients
$$R = Reduce(J)$$
$$= R_1 \| R_2 \| \dots \dots \| R_q \quad (12)$$
The size of $R$ is same as the watermark image size.
6) The watermark is embedded to the selected DCT coefficients based on the equation given below
$$R_i^*(k,l) = R_i(k,l) \pm \alpha(i) \left| \left( R_i(k,l) \right) \right|$$
$$\forall 1 \le i \le q, 0 \le k \le 4, 0 \le l \le 4 \quad (13)$$
where $R_i(k,l)$ is the DCT coefficient at coordinate location $(k,l)$ of the block $R_i$ and $R_i^*(k,l)$ is the marked DCT coefficient. $\alpha(i)$ is an adaptive embedding strength depending on the image content designed using JND mask [23].
7) The equation can be modified as
$$R_i^*(k,l) = R_i(k,l) \pm \gamma J_F(i) \left| \left( R_i(k,l) \right) \right| \quad (14)$$
where $J_F(i)$ represents the JND value for the block i. The value is designed so as to make the change in the DCT coefficient in a block below the distortion limit and $\gamma$ is the scaling factor which is set to 2.
The direction of scaling is determined by the watermark pixels.
If $W_i(k,l) = 1$
$$R_i^*(k,l) = R_i(k,l) + \gamma J_F(i) \left| \left( R_i(k,l) \right) \right| \quad (15)$$
Else
$$R_i^*(k,l) = R_i(k,l) - \gamma J_F(i) \left| \left( R_i(k,l) \right) \right| \quad (16)$$
8) Create the polarity mask, $P$ to enable oblivious detection [11].
9) Re-map the modified coefficients $R^*$ into $J$ to get $J^*$.
10) Apply inverse DCT on $J^*$ to get the watermarked image $I_W$
$$I_W = IDCT(J^*)$$
$$= IDCT(J_1^* \| J_2^* \| \dots \dots \| J_p^*) \quad (17)$$
11) Compute the composite normalization matrix $A$ obtained by normalizing the watermarked image, $I_W$.

### B. WATERMARK EXTRACTION

In watermark extraction, instead of sending the original image, a binary polarity mask indicating the relative positions of the marked and unmarked coefficients is send. This reduces the overhead in sending the original image itself.

*Requirements for watermark detection*

- Watermarked image, $I_W$
- Location map of the blocks selected for watermark insertion.

- Indexes of the selected coefficients for block reduction.
- Embedding strength, $\alpha$
- Scrambled watermark, $W_s$
- Polarity mask, $P$
- Composite normalization matrix, $A$

*Steps in watermark detection*

1) Detect whether the image is geometrically distorted. The following steps are followed for detecting geometrical distortion
   a. Normalize the obtained watermarked image to get normalized image $I_d' \approx I_n'$ and the composite normalization matrix $A'$
   b. Compare A and $A'$. If the difference calculated by taking Euclidean distance, Δ>10, then the image is geometrically distorted and the distorted image $I_w'$ is corrected using A
   $$I_w^* = A^{-1} I_d' \tag{18}$$
   where $I_w^*$ is the corrected image and $I_d'$ is the normalized distorted image.
   And if Δ<10, no geometrical distortion is detected and go for the following steps
2) Now we have either $I_w'$(Δ<10) or $I_w^*$(Δ>10). The next step is to transform the image to its frequency coefficients using DCT to obtain $J'$.
3) Reduced image, $R'$ is formed using the location map of the selected blocks and the indices of selected coefficients.
4) From the reduced image, $R'$, the unmarked reduced image $R$ is obtained using the polarity mask, $P$.
5) Generate verification mask V, such that
   $$V(i,j) = \begin{cases} 0, & if\, R'(x,y) \geq R(x,y) \\ 1\,, & \text{Otherwise} \end{cases} \tag{19}$$
6) $V$ *XOR* $W_s$ gives the embedded scrambled watermark. This is unscrambled using inverse Arnold transform to obtain the embedded watermark.
7) This composite watermark consists of $t$ copies of the original watermark. The watermark $W'$ is obtained by superimposing the $t$ copies weighted by the gain factor (JF).
   $$W'(4k+i, 4l+\mathrm{j}) = \begin{cases} 1, if & \dfrac{\sum_{s=1}^{t} \frac{W_s'(4k+i,4l+\mathrm{j})}{J_F(k,l)}}{t} \\ 0, & otherwise \end{cases} \tag{20}$$

Fig. 6 presents a general scheme of watermark detection

## V. NORMALIZED CORRELATION

Normalized correlation (NC) is used as the quantitative measure to verify the similarity of the extracted corrupted watermark with the correct one.

$$NC = \frac{\sum_i \sum_j W(i,j) W'(i,j)}{\sum_i \sum_j |W(i,j)^2|} \tag{21}$$

We know that in some cases the objective measure given by NC is not comparable with the visual result. So a more reliable measurement is taken by considering the NC at object pixels (black points) only. Since the main object pixels are zero valued complimented images are considered for calculating NC. A threshold value of 0.6 can be considered to give a fair authentication avoiding false positives and false rejections.

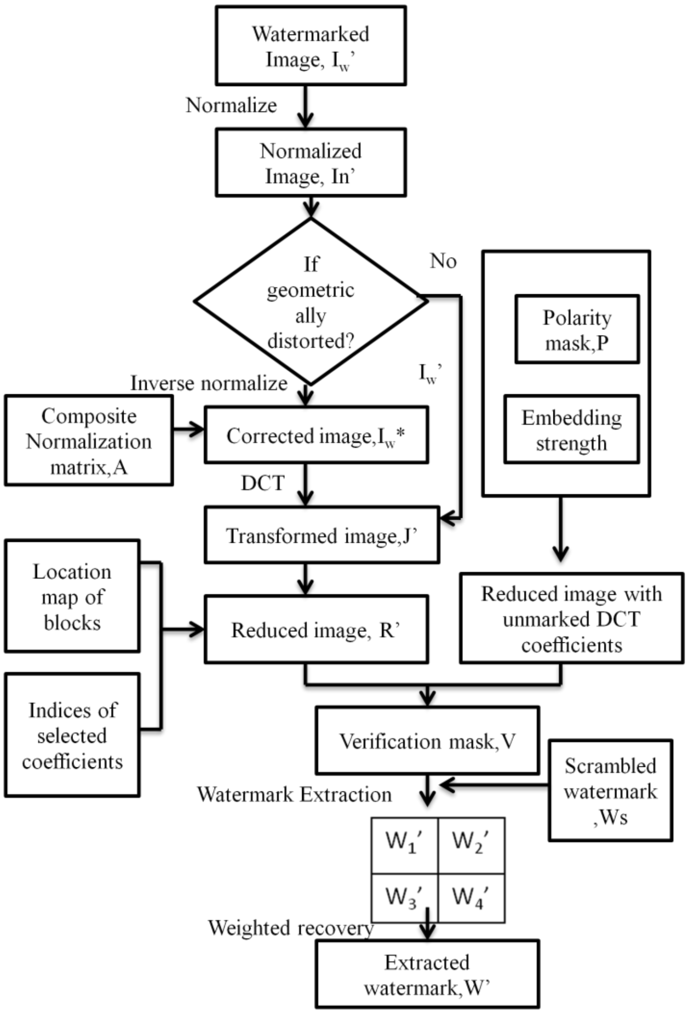



**Fig. 6**. Watermark detection scheme

(a)

(b)

**Fig. 7**. Test images and their corresponding watermarked images. (a). Test images. (b) Watermarked images

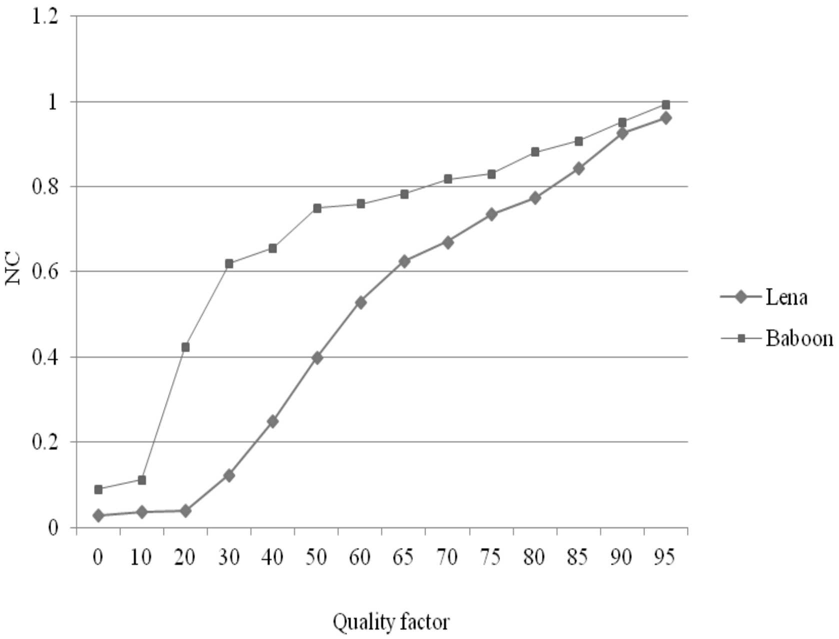



**Fig.8.** Performance against compression attack

## VI. EXPERIMENTAL RESULTS

Two test images of size 512×512 are used for evaluating the performance of the proposed watermarking scheme. Fig. 7 shows the test images and their corresponding watermarks. The host images are divided into non-overlapping blocks of size 8×8 that gives a total of 4096 blocks.

The composite watermark image of size 128×128 is divided into non-overlapping blocks of size 4×4 giving 1024 blocks. These blocks are embedded into 1024 selected host image blocks. The nature of fuzzy-ART clustering is decided by the parameters used that include choice parameter, α, learning parameter, β and a vigilance parameter, ρ. The choice parameter is given a value closer to zero (0.000001). Vigilance parameter controls the vigilance subsystem. It determines the similarity of an input pattern with a particular cluster. A higher vigilance value gives detailed categorization leading to large number of clusters. A vigilance value of ρ=0.85 is used in the work. The following section discuss about the performance of the system against various attacks. For ease of presentation the scheme is abbreviated as FGRW that represents Fuzzy-ART based Geometrically invariant Robust Watermarking.

### A. *COMPRESSION ATTACKS*

Being the most classical and ubiquitous image processing attack, JPEG compression of various compression ratios is applied to the watermarked images. Fig. 9 shows the compressed test images with quality factor 85 and the corresponding extracted watermarks. The NC values of the extracted watermarks are given in brackets. The extracted watermarks are visually recognizable, despite being contaminated by noisy spots. Nevertheless, the objective measurements detect the existence of watermark unambiguously. Fig 8 shows the performance of the FGRW scheme against compression attacks for two images. The baboon image is showing a higher performance than the Lena image. Baboon image which is highly textured can embed the watermark more robustly in the textured area as it can accommodate higher embedding strength without making distortion.

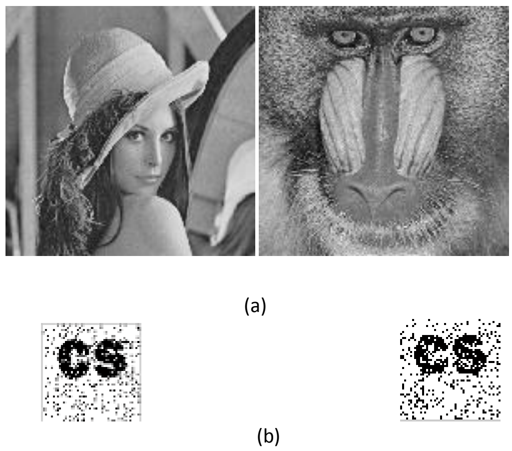



**Fig. 9.** Compression attacks. (a) Compressed test images. (b) Extracted watermarks. Lena (0.8435), Baboon (0.9069)

### B. *GAUSSIAN NOISE ATTACKS*

In this set of test, Gaussian noise of different energy levels is applied to the watermarked images. Fig.10 shows the noise attacked images with noise energy 100 and the corresponding extracted watermarks Fig.14 shows the performance of the scheme against Gaussian noise attacks. It can be seen that both test images give an outstanding performance in case of noise attacks. This shows that the FGRW scheme is robust against additive noise attacks

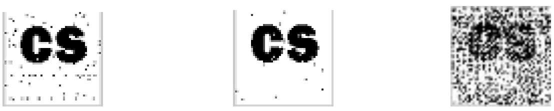
(a)

(b)

**Fig. 10.** Gaussian noise attacks. (a) Noise attacked watermarked images. (b) Extracted watermarks. Lena (0.9595), Baboon (0.9811)

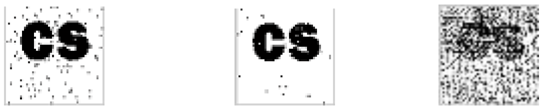
### *C. OTHER IMAGE PROCESSING ATTACKS*

The watermarked images are tested against several image processing attacks including 1) blurring, 2) sharpening, and 3) filtering. Fig.11 and 12 shows the extracted watermarks from blurred, sharpened and filtered test images. All extracted watermarks are recognizable to different extent, and their corresponding NC values are high enough to indicate the presence of the watermark. Experimental result shows that the proposed watermarking scheme is less robust against filtering attacks but resilient to sharpening and blurring attacks



(a) (b) (c)

**Fig. 11**. Extracted watermarks from (a) Blurred (0.9973) (b) Sharpened (0.9865) (c) Filtered (0.7760) watermarked Lena image



(a) (b) (c)

**Fig. 12.** Extracted watermarks from (a). Blurred (0.9973) (b) Sharpened (0.9865) (c) Filtered (0.6991) watermarked Baboon image

### *D. ROTATION ATTACKS*

(a) (b)

(c) (d)

**Fig. 13.** Watermark extraction process in case of rotation attacks. (a) 30 degree rotated Lena image. (b) Normalized image. (c) Corrected image. (d) Extracted watermark (0.8286)

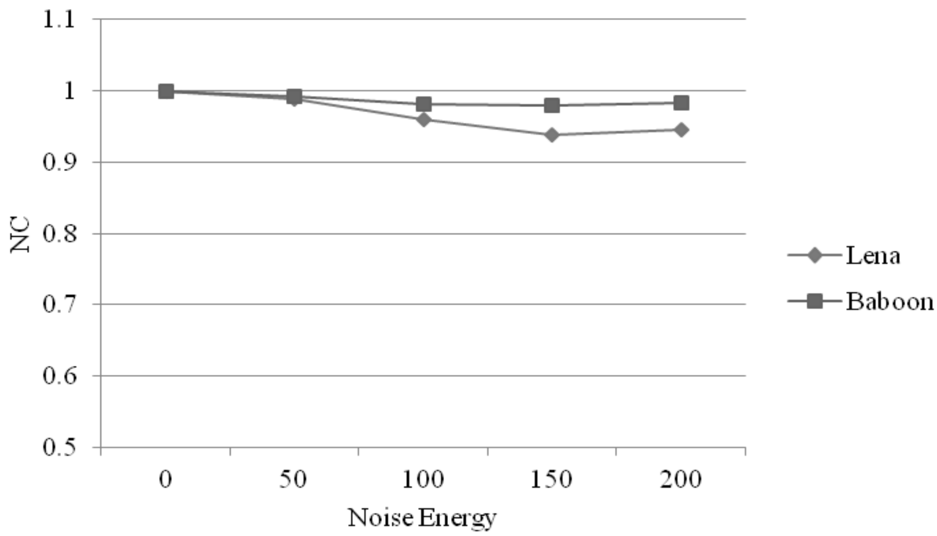



**Fig. 14.** Performance of FGRW scheme against additive noise attack

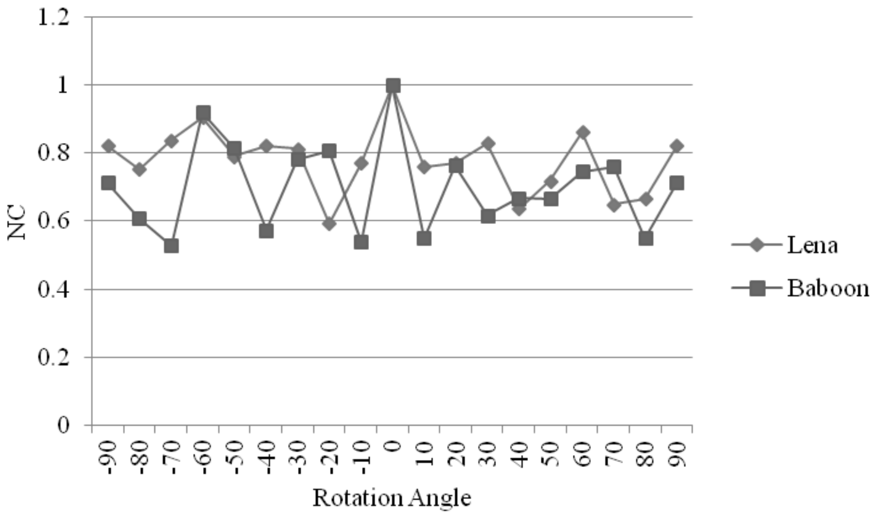



**Fig. 15**. Performance of FGRW against rotation attacks

The watermarked test images are rotated to various degrees and studied. Geometrically distorted images are first corrected using the composite normalization matrix obtained at the embedding side. Fig.13 (a) shows the geometrically distorted Lena image. Fig.13 (b) shows its normalized image and Fig.13(c) shows the corrected image obtained by inverse normalization. Fig.13 (d) shows the extracted watermark from the corrected image. It can be seen that the watermarks are reliably extracted. Fig.15 shows the performance of FGRW scheme against rotation attacks. It can be seen that the NC values do not show a uniform pattern. This is because of the error introduced by inserting zero valued pixels in affine transform process. This error varies depending on the rotation angle. However in most of the cases the NC values are above 0.6 and are acceptable

*E. SCALING ATTACKS*

The watermarked test images are subjected to different scaling ratios and the performance is analyzed Fig.17 demonstrates the process of watermark extraction during scaling attack. Fig.16 presents the performance of FGRW scheme against scaling attacks. It can be seen that as the scaling factor increases or decreases beyond a limit, the performance decreases

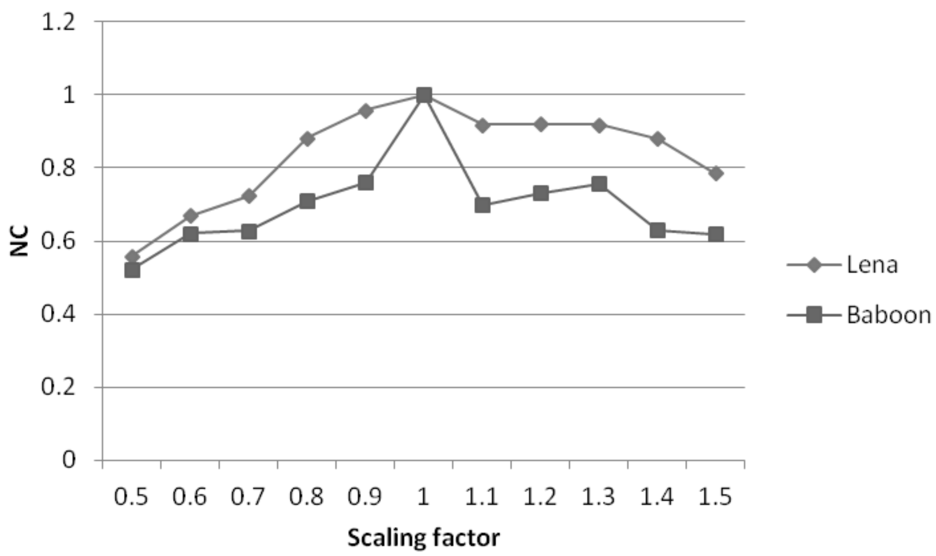
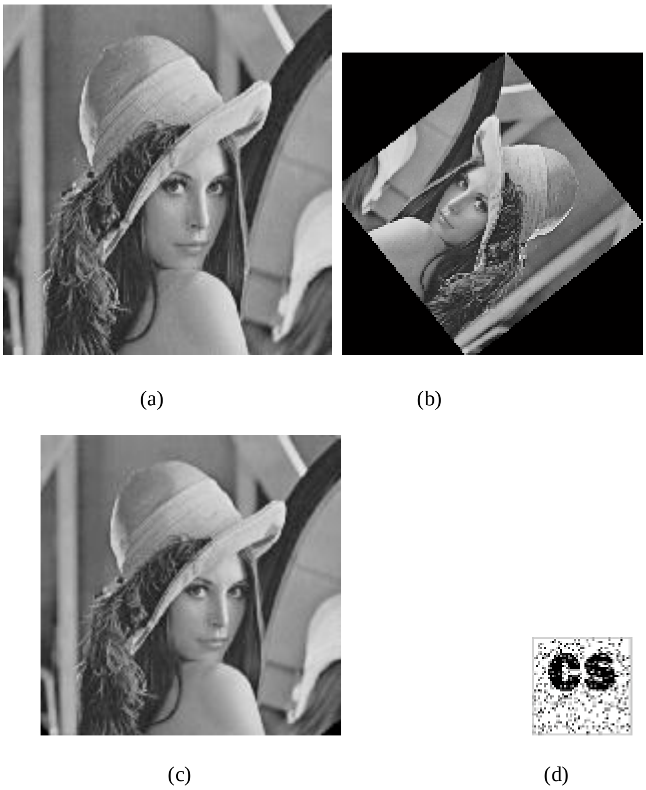



**Fig. 16**. Performance of FGRW scheme against scaling attack


(a) (b)

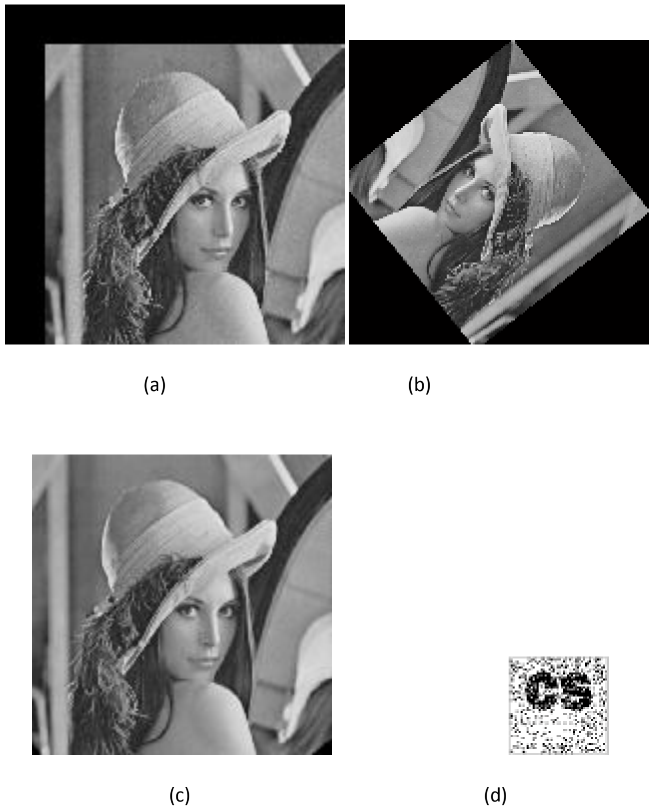
(c) (d)

**Fig. 17**.Watermark extraction process in case of scaling attacks. (a) Scaled Lena image with a scaling factor 1.2. (b) Normalized image. (c) Corrected image. (d) Extracted watermark (0.9204)

### *F. TRANSLATION ATTACKS*

For ease of analysis the watermarked images are translated by equal units in both x and y directions. Fig.18 demonstrates the watermark extraction procedure in case of translation attacks. The performance of FGRW scheme under different translation parameters is shown in Fig. 19.

It can be seen that the NC values show a repeated pattern. That is the error in synchronization for different units of translation is varying


(a) (b)

(c) (d)

**Fig.18**.Watermark extraction process in case of translation attacks. (a) 70 units translated Lena image (b) Normalized image. (c) Corrected image. (d) Extracted watermark (0.8435)

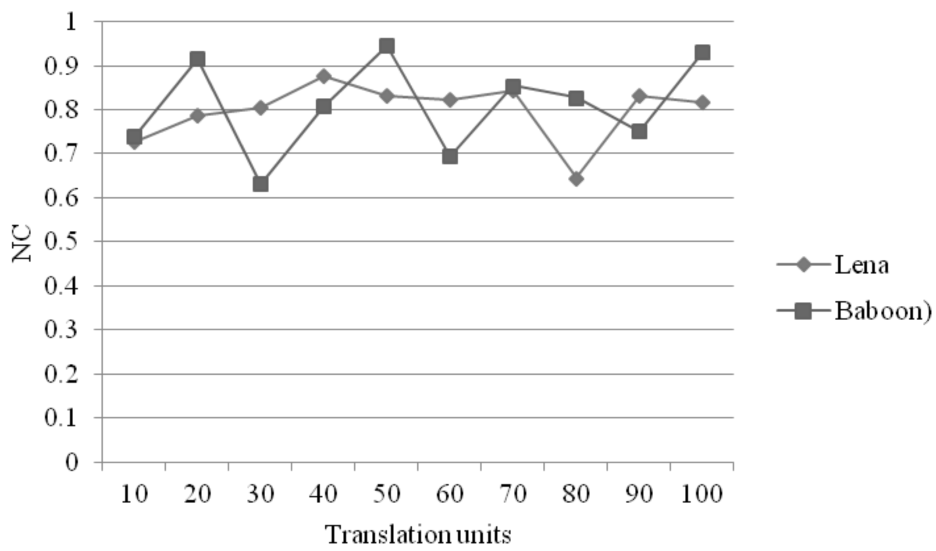



**Fig. 19.** Performance of FGRW scheme against translation attacks

## VII. CONCLUSION

A novel transform domain watermarking scheme that combines fuzzy-ART and image normalization is presented in the paper. The proposed FGRW scheme is robust against geometric attacks as well as other image processing attacks like jpeg compression, noise attacks etc. The composite watermark image used is scrambled using Arnold transform to provide more protection against counterfeiting attacks. The watermark information is embedded by modifying the selected DCT coefficients of the host image using an adaptive embedding strength. Fuzzy-ART clustering helps in the selection of appropriate clusters for watermark insertion. The adaptive embedding strength is designed based on JND mask where the JND value depends on the image characteristics like texture, edge, corner and luminance. Image normalization provides a convenient way for dealing with geometric attacks due to the fact that a normalized form is invariant under translation, rotation, scaling etc. In the proposed work image normalization is used to synchronize the distorted watermarked image. The performance analysis of the FGRW scheme shows that it is robust to geometrical attacks as well as other image processing attacks.

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