# A Multiplicative Colour Watermark

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## ABSTRACT

*Digital watermarks are imperceptible signals additively embedded in image, video or audio data. Ongoing research has largely concentrated on embedding watermarks in scalar data.*

*Here we introduce a non-linear watermarking scheme for multi-variate data that deliberately perturbs an angle formed between associated variables.*

*Our application embeds a spread-spectrum based watermark in the hue component of transformed RGB colour image data. This watermark, being additive in the angular domain, is multiplicative in the data domain. This contrasts with other spread-spectrum based watermarking schemes.*

## 1. INTRODUCTION

Linear embedding of spread-spectrum noise-like signatures in signals has found application in communications, navigation, radar, acoustics, and instrumentation. In these applications, correlative recovery is employed at the receiver. Watermark signatures that possess an impulse-like auto-correlation are chosen. The result is a flat spectral distribution in the Fourier transform domain. Because the watermark appears over the full band of frequencies, the robustness of the watermark recovery is increased significantly. Numerous advances in spread-spectrum techniques and image watermarking have resulted in both becoming rapidly developing technologies [10]. In most cases, the embedding techniques have been assumed to be linear. For image watermarking, where minimally visible perturbation of the signal is required, the signature is usually added adaptively, exploiting the masking characteristics of the human visual system.

In this paper, we present a non-linear method of embedding a signature in a colour image and demonstrate its recovery. The embedding process can be viewed as pseudo-random perturbations to the phase of vectors. The embedding process is additive in the angular domain and therefore multiplicative in the signal domain. Since the magnitude of the image vector is conserved, the image energy is largely unaltered by the embedding process.

Section 2 describes the generation of a suitable sequence or array of angles used for the embedding process. The embedding process is independent of the sequence or array used. Section 3 discusses the process of embedding a signal in the angle domain and its recovery. We also describe a number of ways of transforming RGB colours to a coordinate system to produce a polar mapping. In section 4, we review these results and present an analysis of some of the sources of error. Section 5 examines possible approaches to improve watermark security and robustness of angle-based watermarks to attack.

## 2. The Embedded Watermark Array

The array of angles chosen here to be embedded in the image are 2D generalised Legendre arrays, based on the generalised Legendre sequence [3,4,5]. Elements in such an array can be formed as a term by term product of row and column generalised 1D Legendre sequences.

The 1D sequences are comprised of a prime number, p, of unit magnitude vectors, with an alphabet of selected phase angles uniformly spread over the unit circle, corresponding to rotations between $-\pi$ and $+\pi$. The number of angles, or alphabet size, is a factor of p-1. In this case, the first element of the Legendre sequence has zero magnitude, the remaining elements are unit magnitude.

The Table below shows a 2D watermark array construction based on the row and column products formed from a 1D 5 element Legendre sequence.

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | ▨ | **Magnitude = 0** |
| | $0$ | $-\pi/2$ | $\pi/2$ | $\pi$ | ☐ | **Magnitude = 1** |
| | $-\pi/2$ | $\pi$ | $0$ | $\pi/2$ | | |
| | $\pi/2$ | $0$ | $\pi$ | $-\pi/2$ | | |
| | $\pi$ | $\pi/2$ | $-\pi/2$ | $0$ | | |

**Table 1.** *5 x 5* Legendre Phase Array

It is also possible to generate arrays using m-sequences or poly-phase sequences [5]. A primary requirement is that the watermark can be expressed as an angle, so that, under addition (mod $2\pi$), all angles will map onto the same angle alphabet [3]. Information can then be encoded as cyclic shifts of the arrays.

## 3. Embedding in the Angle Domain

The image pixels from a multivariate data set are then transformed into a representation that includes a polar component, and the angle of this polar component is perturbed by the corresponding angle of the watermark at each image coordinate.

The watermark information is extracted via cross-correlation between the watermarked image and reference watermarks.

In order to make the encoded signature less obtrusive, this perturbation angle is scaled in the embedding process to the domain $-\pi/s$ and $+\pi/s$, where s is a scaling factor. In the recovery process, the image angle is multiplied by s to restore the angular excursions of the signature to the range $-\pi$ to $+\pi$, prior to correlation with the original angles of the reference array.
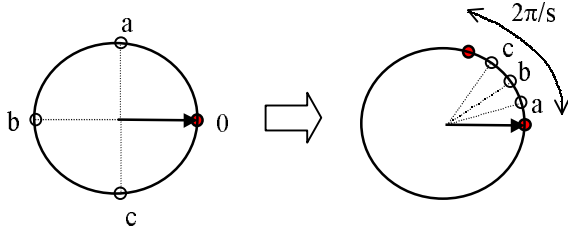


**Figure 1.** The four roots of unity for a Legendre sequence with an alphabet of 5 elements are compressed by the angular scale factor *s*.

### 3.1 An Example Colour Space - HSV

A common representation of colour image pixels is Hue/Saturation/Value (HSV), where the hue is represented by a phase angle ($0^0=360^0$=Red, $120^0$=Green, $240^0$=Blue). There are several algorithms to obtain hue from RGB values [9].

Hue can be represented as an angle on the unit circle so that the hue vector length can be ignored. Hue also depends on the values of all three RGB components of an image in a non-linear manner. After adding the watermark perturbation to the hue angle, the data is transformed back to RGB coordinates. The watermark is thus spread over the three channels of data.

The HSV / HLS mapping was used as proof of concept. Any mapping of the RGB vectors which produces a polar mapping in one of the output coordinates could be used. Some alternative colour spaces are derived by a faster and more

straight-forward linear process. Some examples are YUV, YIQ, YCbCr, Lab, Luv [12].

### 3.2 Modulating the Hue

In angle space, we can represent the watermarked image hue, $H_{IW}$ as

$$H_{IW}(x, y) = H_I(x, y) + W(x, y) / s,$$

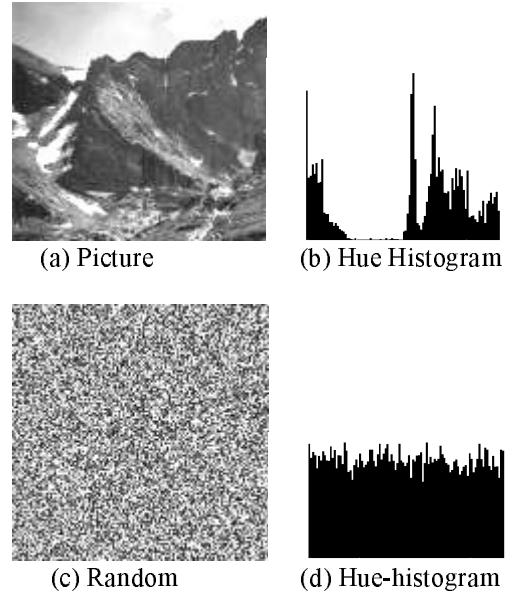and to extract the watermark, we subtract the original image and up-scale by *s*.



(a) Picture       (b) Hue Histogram

(c) Random       (d) Hue-histogram

**Figure 2**: A 128x128 image (a) and a histogram of its hue values (b), and a random-hue image (c) and its hue histogram (d).

$$W(x, y) = s\big(H_{IW}(x, y) - H_I(x, y)\big).$$

Given the original image, $H_I$, a perfect recovery is possible up to the level of pixel quantisation errors. If the original image, $H_I$, is not available, a method of estimating $H_I$ must be found.

Figure 2 shows a 128 x 128 colour image. The image was converted to HSV and a 2D watermark array of size 127 x 127 was embedded by perturbing the image hue using a scale factor s = 20.

### 3.3 Estimating the Original Image Hue

The up-scaling process given in section 3.2 also scales the $H_I$ component by $s$. This effectively randomises $(H_{IW} - H_I)$, and thus the recovered watermark. Figure 3 shows the problem arising from the rescaling of the perturbed data, where for
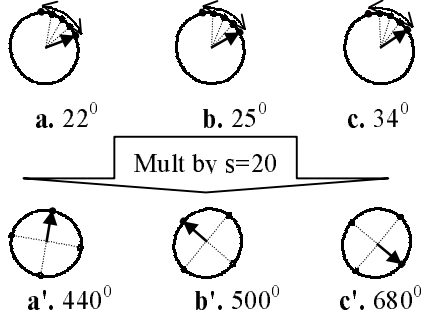


**a.** $22^0$     **b.** $25^0$     **c.** $34^0$

Mult by s=20

**a'.** $440^0$     **b'.** $500^0$     **c'.** $680^0$

**Figure 3.** The sequence roots-of-unity are not aligned because the original $H_I$ cannot be established from $H_{IW}$. So **b'** and **c'** which should have aligned, are now in opposition. If the original $H_I$ is available, then the above vectors can be synchronised prior to multiplication by $s$, and the sequence roots-of-unity would then align.

example, components b' and c' now cancel.

It is thus necessary to obtain a more accurate estimate of $H_I$. One can achieve this by taking a spatial average of the local hue values (say, 3x3). [7] has shown that the median filter is a good estimator. The mean is the optimal estimator for uniform or Gaussian distributions. Figures 4a-c show, respectively, the correlation response with no hue recovery, using the local mean, and using a median filter estimator, for a scale factor of $s = 20$.

For a 127x127 Legendre array, the correlation peak for perfect watermark recovery will $(p-1)^2 = 15876$.
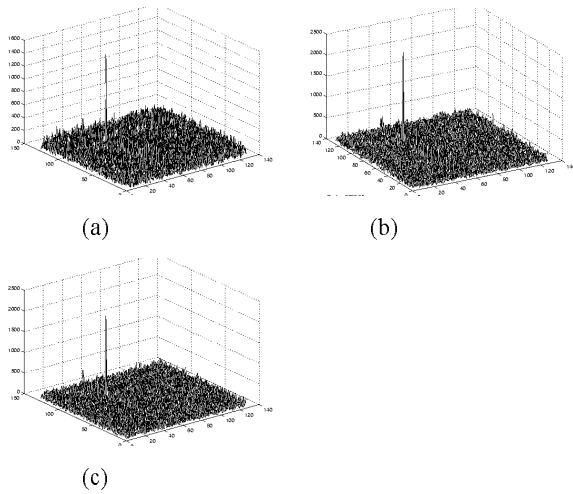


(a)        (b)

(c)

**Figure 4.** Cross-correlation of watermarked image with reference watermark (a), with the spatial 3x3

average hue subtracted prior to cross-correlation (b), and with the spatial 3x3 median hue subtracted (c). Peak heights are (a) 1507, (b) 2295, (c) 2070.

For the random hue image (figure 2(c)) the local estimation method will not work, so that the embedded watermark is not recoverable.

## 3.4 Pre-quantising the Image Hue

An alternative strategy is to quantise the hue angles of the image prior to embedding. The embedding is then done across the width of the angle sections determined by the quantisation interval.

$H_I$ can be quantised as

$$H_{IQ} = 2\pi \frac{\text{int}\left(sH_I / 2\pi\right)}{s},$$

where **int** is integer truncation, and $H_I$ and $H_{IQ}$ are expressed in radians.

After scaling by $s$, all image hue values will map to $2n\pi$, and the roots-of-unity alignment of the watermark angles is assured. Effectively this synchronises the expanded perturbation angles on recovery (the zero angle location a' b' and c' in figure 3 would always be aligned).



(a) Picture      (b) Cross-Correlation
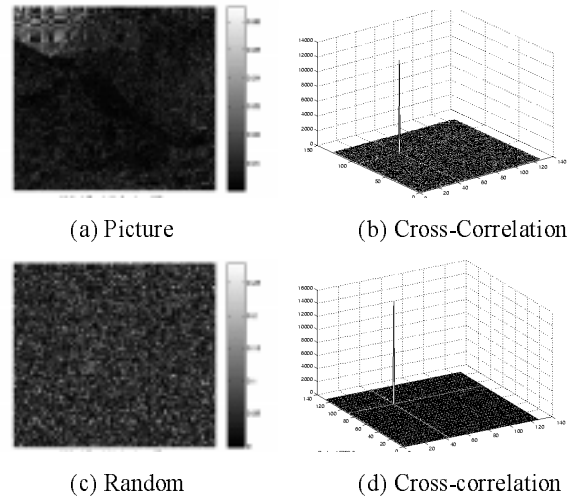
(c) Random      (d) Cross-correlation

**Figure 5.** By pre-quantising the image hue, it is possible to separate image from watermark in the decoding process, yielding significantly improved cross-correlation responses. (a,c) A difference image between original and watermarked image in figure 2(a), (b,d). The peak value for (b) here is 12654.

By effectively separating the hue values occupied by the image from those occupied by the watermark, recovery has been substantially improved over the local-mean method. It is

now also possible to recover the watermark from the random hue image.

The perfect separation of image and watermark also means that the watermark can be removed from the watermarked image given knowledge only of $s$. An attacker would merely need to quantise the angle by successive values of $2\pi/s$, subtract the quantised image from the watermarked image and look for a uniformly distributed remainder (since the angles in a Legendre sequence have a uniform probability distribution and are balanced).

Brute-force could then be used to determine $s$, rendering the watermark vulnerable to attack, given prior knowledge of the embedding method and its parameters.

## 4. LIMITS OF EMBEDDING

Watermark angle recovery is affected by the hue transformations as well as the initial quantisation of the image data and the value of the scale factor used to compress the watermark.

Figure 6a and 6b show the decrease in the ability to recover the watermark as the scale factor, s, is increased. Both graphs show, that large values of s are practicable

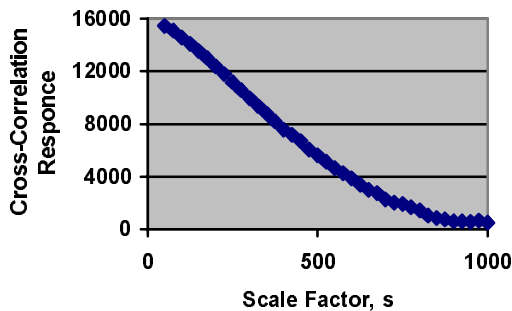The embedded watermark will have a low perceptual impact for large s values.



**Figure 6a:** The cross-correlation response magnitude as a function of s, for 'picture' image of figure 2a.
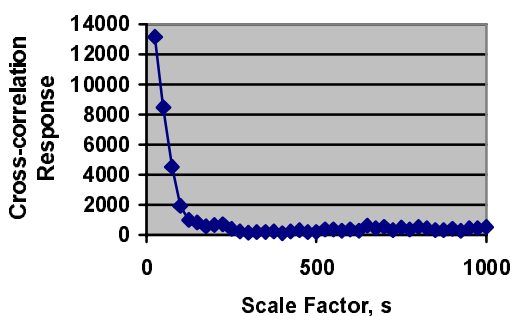


**Figure 6b:** The cross-correlation response magnitude as a function of s, for 'random' image of figure 2c.

## 5. FURTHER WORK

### 5.1 Secure Hue Embedding

Because use of a uniform scale factor, s can be exploited by an attacker to remove the watermark, an alternative is to employ an adaptive scale factor.

Each pixel can be treated independently in terms of scaling so the constant s changes with image position.

Thus

$$H_{IW}(x, y) = H_I(x, y) + W(x, y) / s(x, y)$$

and

$$W(x, y) = s(x, y)\left(H_{IW}(x, y) - H_I(x, y)\right)$$

The scale factor $s(x,y)$ could be determined adaptively in such a manner that it is invariant to the presence of the watermark, $s(H_I) = s(H_{IW})$, so that the same local scale factor will be used in encoding and decoding without this information needing to be passed separately from transmitter to receiver.

Human Visual System parameters can be used [8] to determine an appropriate adaptation mechanism. This would require use of all the image information, not only the polar mapping component (eg. In HSV, not just the hue should be considered, but also the saturation and value components).

The variation of $s$ helps reduce the watermark's vulnerability to attack. An added benefit is that watermark can be made less intrusive by employing the adaptive $s$ to 'hide' within local colour or intensity discontinuities.

This technique can be extended even further by allowing $s(x,y)$ to be perturbed in amplitude by a function of x and y known to both transmitter and receiver. This function could even be another watermark.

### 5.2 Multiple Watermarks

Multiple watermarks may be superimposed additively (in the angle domain) with their mutual cross-correlations dependant only on the type of arrays actually used. The only requirement is that they be applied at the same time using the same scale factor.

Different Legendre product arrays of the same dimensions have a two-valued cross-correlation – a peak of magnitude 0 and background of magnitude $\sqrt{(p-1)(q-1)}$, where p and q are the side lengths. This uniform cross-correlation enables

several watermarks to be superimposed with minimal mutual interference [5].

## 5.3 Alternative Polar Spaces

While conceptually convenient, there is no particular requirement that a polar colour representation be used – merely that a polar or cyclic quantity be extractable from the image data.

For example, any two channels can be made to represent the real and imaginary components of a complex number with its resulting phase angle being manipulated as before, thus allowing a YIQ or YCbCr mapping to be employed. Figure 6 shows an image and its recovered watermark, where the watermark for an RGB image is encoded as:

$$W(x, y) = \angle \big( R(x, y) + iG(x, y) \big)$$

where R and G are the red and green component channels of the RGB image. This is an example of a watermark spread over two channels.

The vector length $R_k + iG_k$ is maintained, but its angle, $\theta_k$ is modified by the watermark. When recovering the watermark, a unit vector with angle $\theta_k$ is cross-correlated against the reference watermark.

This differs from the HSV where the hue itself is represented by unit vectors. The quantisation of angle, $\theta_k$ thus depends on the quantisation of $R_k$ and $iG_k$.

Similarly, for a single channel gray scale image, different pixels from the same image can be used as real and imaginary components of the watermark, provided that each pixel is used only once.

# 6. ACKNOWLEDGEMENTS

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