Image and Watermark Registration for Monochrome and Coloured Images

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Abstract

This paper addresses issues concerned with image registration of monochrome and coloured images, where the image contains an invisible watermark. We discuss a selection of registration masks which can be deliberately overlaid on a watermarked or raw image, allowing the recovery of the correct registration. This extends our earlier work in steganography, (the art of hiding messages in text and images). We discuss more recent techniques which include watermarks to carry more data and become more resistant to image distortions and lossy compression, such as JPEG.

Keywords: watermark, registration, correlation

1. Introduction

Digital watermarking of electronic images has gained prominence as a result of the proliferation of multimedia and the internet, with the need to protect copyright and ensure authenticity. In 1993, Tirkel and Osborne introduced the concept of embedding an invisible message throughout an image using spread spectrum techniques [1]. The information can be embedded in the spatial or pixel domain [1], or the transform domain, using magnitude [3] and phase [4]. Thresholding techniques using statistical [5] and psychophysical masking criteria [6] have enhanced watermark robustness, without compromising detectibility, by hiding information in statistically or spectrally significant regions of the image.

2. Image Registration

Image registration is a problem of current interest. Imperfect registration can result from cropping, editing, or as a consequence of framing or sync corruption in the communication channel. This causes substitution and/or loss of pixels and improper watermark decoding. In schemes where the watermark recovery process is predicated on a comparison with the unwatermarked image registration is a minor problem. The method proposed by Tirkel and Osborne [1] and developed further in [10],[11],[12],[13] uses a correlative technique to recover the watermark, without reference to the original image. Correct watermark recovery using correlation requires perfect registration. Our method of registration recovery involves the use of a special pattern or mask. The mask can be used to carry a limited amount of watermark information, although it is preferable to embed that in a separate pattern, optimised for that purpose.

3. Registration Masks

The salient features of registration masks are: window property and autocorrelation peak to sidelobe ratio[14]. The former is important where the signal to noise ratio is high and only small segments of an image are available, or required to recover registration without ambiguity. The latter property is important...
where low signal to noise ratio is involved, but large sections of the image are available.

### 3.1 Window Property

A window is a special kind of subarray. If an array can be partitioned into all its constituent windows of equal size, such that each window appears exactly once, the array is said to possess the “strong” window property. Location of any window within an image identifies its position within the image without ambiguity. This ensures registration recovery. Arrays with “weak” window property do not need to contain all possible windows of a given size, as long as no two windows are identical. Such arrays are also useable for registration, although their windows are larger than those of the arrays with the strong window property and hence there are fewer of them. Where image corruption is significant, the smaller the window, the more robust the recovery. Whenever multiple windows can be located in an image, error correction can be achieved by a maximum likelihood decision process. Perfect maps are the only known arrays with the strong window property. Examples of these are shown in section 6.1. M-arrays and twin-prime arrays, used in coded aperture imaging have a “near” window property, since only the null window is missing. Hall and Tirkel have developed new arrays, with the near window property, which is extended to cover split windows. This dramatically increases the number of available windows and hence the robustness of mask recovery. Initially, these arrays have only been available in array sizes of \((2^n-1)(2^n-1)\), although these have recently been extended to other sizes, non-binary alphabets and three and more dimensions. The non-binary alphabets enable masks to be embedded in colour space, whilst three dimensional masks are useful for video encoding, with time acting as the third dimension. Examples of such arrays are shown in section 6.2.

### 3.2 Autocorrelation

The choice of optimum registration masks for correlation based recovery requires an understanding of different definitions of correlation: even periodic, odd periodic and aperiodic. These correlations are related but different. The aperiodic correlation is appropriate to registration recovery for images or watermarks which do not include repetitive patterns (mosaics). For highly repetitive mosaics, the periodic autocorrelation dominates. The ratio of the peak to highest positive or absolute sidelobe ratio determines the probabilities of false or missed detection and is a useful figure of merit. Registration of one-dimensional patterns is equivalent to synchronisation, which has been studied extensively and reviewed in communications literature[15]. Higher dimensional patterns have not received as much attention. Only two dimensional arrays with good periodic autocorrelation figure of merit have been studied. These include perfect even and odd binary arrays, m-arrays, twin prime arrays and quasi m-arrays. We have examined the periodic and aperiodic autocorrelation for these and found the latter to be significantly degraded, compared with the periodic case. Examples of these arrays will be presented. Three and higher dimensional arrays have received scant attention at this stage.

Another approach has involved an exhaustive computer search of optimal aperiodic arrays. Computational limitations have restricted these to binary arrays with fewer than 30 elements.

In order to be useful as registration masks for real images, these arrays should be available in a variety of suitable sizes, commensurate with image format. They should be well balanced (equal occurrence of all elements of the alphabet). This ensures minimum skew of image statistics and minimises the crosscorrelation with the image. Arrays should possess a “random” appearance, free from repetition or symmetries in order to minimise visibility and detection by cryptographic attack.

We have performed an analysis of the performance of the known constructions. This trade-off study will be presented.

We have also adapted the Hall and Tirkel constructions for application to correlative recovery. Their performance is very promising and will be contrasted with the known constructions. Their particular advantages are: ease of generalisation to any dimensions, availability of variable array sizes and aspect ratios and multiplicity of “almost orthogonal”
arrays of equal size. The last feature is particularly important, since it permits the overlay of many patterns, each of which can be recovered separately.

4. Registration Mask Embedding

Methods of combining watermarks with registration patterns are presented. The masks studied include: perfect maps and the Hall and Tirkel arrays. The method of watermark encoding is discussed where embedding relies on intensity or colour modification to (pseudo)randomly selected pixels or points in transform space. The amount of modification may itself be “random”, adaptive or fixed. To hide the watermark, whilst preserving robustness, the values to be added/subtracted can be determined by statistical [16], psychovisual [6] or iterative [17] means. We concentrate on the simplest case, namely scaled addition/subtraction. The raw image pixel stream has added to it a watermark in the form of a scaled binary array. Colour watermarks can be generated from binary masks of three times the required size by collecting binary triplets (RGB) and performing the reverse operation before recovery. This punctuation results in a non-binary array with 8 states per pixel. An alternative scheme can be applied to the Hall and Tirkel arrays. This uses m-sequences over the Galois Field of 8 elements as column seeds to construct colour arrays. The correlation properties of these are being investigated. Traditionally, correlation of arrays over complex alphabets has been computed using an isomorphism of these elements with roots of unity in the same finite field. In our case this is not necessary.

5. Registration Mask Recovery

To decode the watermark we have concentrated on a recovery process which involves the correlation of the encoded image with a template pattern of the same size and unknown phase offset.

In the general case, e.g. where multiple watermarks are embedded, or where a decision on the most likely signature is required, the correlation template need not be identical to the encoded mask. This cross-correlation based recovery is illustrated in section 6.3. In most practical applications, misalignment is likely to be a small fraction of the image. Hence, sidelobes near the main peak are likely to be more important. A real image can also be subject to geometrical distortions such as skew and rotation, intensity or colour transformations and effects due to lossy compression. The combined effects of such distortions on registration will be discussed.

6. Examples

We consider the construction and properties of perfect maps and Hall and Tirkel arrays.

6.1 Perfect Maps

General techniques of perfect map construction are discussed in [18]. Examples of 8*8 and 4*16 maps are shown in Figure 1. The 8*8 map exhibits a 3*2 strong window property, whilst the 4*16 has a 2*3 strong window.

![Figure 1. Perfect Maps (a) 8*8(from [18]) and (b) 4*16](image)

The correlation with an identical template displaced by $\tau_{xy}$ is shown in Figure 2.

![Figure 2. Aperiodic Autocorrelation of Perfect Map: Left Half (Figure of merit =6.4)](image)
It is evident that the above perfect maps have complementary symmetry resulting in a negative sidelobe of equal magnitude to the peak. In cases where image inversion is possible, ambiguities may result. The arrays are balanced, so that its cross-correlation with a null (black, or white) image is 0.

6.2 Hall and Tirkel Arrays

Construction details of these have been presented in [19]. A comprehensive theoretical treatment of these arrays is near completion. A 7*7 binary array based on an m-sequence column seed is shown in Figure 3.

![Figure 3.](image)

A 5*5 Legendre sequence based array is shown in Figure 4. This requires a ternary alphabet.

\[
\begin{array}{ccccccc}
0 & 0 & -1 & +1 & -1 \\
+1 & +1 & +1 & 0 & +1 \\
-1 & -1 & 0 & +1 & 0 \\
-1 & -1 & +1 & -1 & +1 \\
+1 & +1 & -1 & -1 & -1 \\
\end{array}
\]

![Figure 4. 5*5 Hall and Tirkel array based on Legendre sequence](image)

The autocorrelation of this array is shown in Figure 5.

![Figure 5. Periodic autocorrelation of array above](image)

There are 3 other such arrays of the same size. A typical periodic crosscorrelation is shown in Figure 6.

![Figure 6. Periodic crosscorrelation between two Hall and Tirkel arrays](image)

The crosscorrelation figure of merit of these arrays is 4. Such arrays can be used as a basis to generate larger arrays by forming Kroneker products with selected perfect arrays. An example of a 10*10 array is shown in Figure 7(a) and its autocorrelation in Figure 7(b).

![Figure 7(a) 10*10 Modified Array (b) Autocorrelation](image)

6.2 Cross-correlation based recovery

The array of Figure 4 can be modified into a binary format as shown in Figure 8(a). In the recovery process, this array can be correlated with a modified template shown in Figure 8(b). The resultant cross-correlation is displayed in Figure 8(c).
It is clear that the cross-correlation figure of merit is adequate for unambiguous recovery. The scheme employed here has been adapted from a one-dimensional version developed by S.W. Golomb.

7. Conclusions

This work addresses registration issues in image watermarking. This is an important practical problem. Our solution is to employ special registration masks. Two such masks are examined: perfect maps and Hall and Tirkel arrays. The key features of these masks are window properties and autocorrelation. Further work is required to analyse aperiodic correlation properties and address practical implementation issues. Extensions of this technique to colour watermarks and video images are also being investigated.

References