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Signal Rich Art: Object Placement, Object Position Modulation and Other Advances

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Abstract

Signal rich art is an alternative paradigm for watermarking, in which we embed a signal in an image or software application such as a website or app as a visible artistic pattern. In this paper we present a new algorithm for generating signal carrying patterns from a dictionary of objects which we call object placement. In an alternative approach, called object position modulation, we locally perturb the positions of objects in a given pattern to embed the signal. We also present advances in previous techniques.

Introduction

Digital watermarking is a way of imparting a persistent identity to a digital object such as an image or audio. An alternative way of identifying objects is through fingerprinting. However, fingerprinting cannot distinguish between very closely related objects, such as edited or filtered media and may not be as robust in identification under noise, JPEG compression, cropping, and other modifications. Typically, digital watermarks are implemented by adding an additional signal to a digital media object. However, the additional signal must be added at a low level of human perceptibility, so that the appearance of the original object is not altered.

Recently we have presented an alternative paradigm for digital watermarking called Signal Rich Art (SRA for short), in which we embed a visible artistic pattern in an image which carries a unique ID. These may be used in several applications such as advertising pamphlets, product packaging, document security, webpage and phone app backgrounds, etc. wherever artistic patterns are added by designers to enhance the appearance of the image. We have previously presented techniques to create a broad palette of artistic signal carrying patterns.

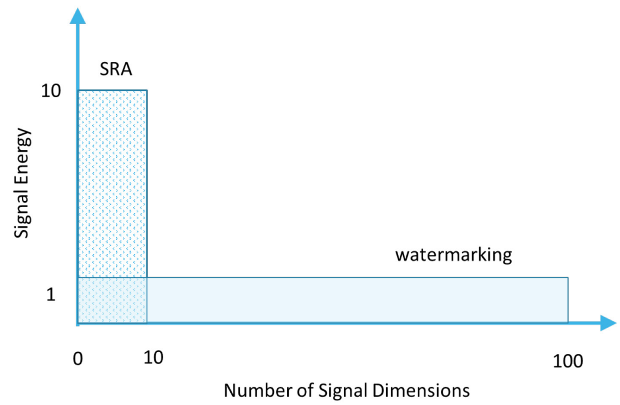

Figure 1 Tradeoff between signal dimensions and signal energy in watermarking versus SRA

A fundamental idea underlying SRA is the tradeoff between signal dimensions and signal energy as shown in Figure 1. Since SRA patterns are not constrained by signal visibility, we may concentrate the signal energy in a few dimensions at a higher amplitude relative to a watermark signal.

In this paper we present a new algorithm which can generate more SRA patterns different in appearance and variety from the previous techniques. We call this Object Placement, or OP for short. We will also describe some improvements to previously published techniques.

The techniques we describe below are completely general and may be applied to any two-dimensional information carrying signal with a sufficiently high level of redundancy. We have previously described how to construct such a signal in [4]. We illustrate the concept here using the Digimarc Barcode signal which is used to mark consumer packaging to improve retail efficiencies (inventory management, faster checkout, supplier ID etc.). The reader may test the signal carried by the patterns using the free Digimarc Discover App available in both the Apple and Android app stores. Simply hold the phone 3 to 6 inches away from the artwork to read the ID.

Object Placement

In [4] we described an alternative algorithm to Deep Learning Style transfer based on direct correlation of signal subblocks with a style image. As Figure 2 shows, we place the style image blocks in a sequential manner with additional edge constraints to reduce the visual impact of edge discontinuities. However, it is not possible to completely overcome these artifacts.

The Object Placement algorithm overcomes the block edge constraints by using a dictionary of objects (small shapes) and freely placing these objects to convey a specific ID. Figure 3 shows the steps used by the object placement algorithm. The examples in this paper only show the placement of binary objects, but the algorithm may be applied to grayscale objects as well.

Given a ‘dictionary’ of objects on the top left, we automatically segment the objects as shown on the bottom left. We also compute a ‘mask’ for the outer boundary of each ‘object’ (not shown in the figure). We correlate each object with the signal tile and obtain the correlation heatmap (middle, top). We then choose some number (design choice) of points of highest correlation and place the object at those locations. Here we can add an additional keepout constraint when we choose points to control the amount of overlap between successively placed objects. The more we allow objects to overlap, the stronger the signal, but the visual appearance of the pattern may be worse. After the object is placed, we null the signal tile at those locations using the object mask (middle, bottom). We loop over all the objects and could repeat the process once all the objects are placed.

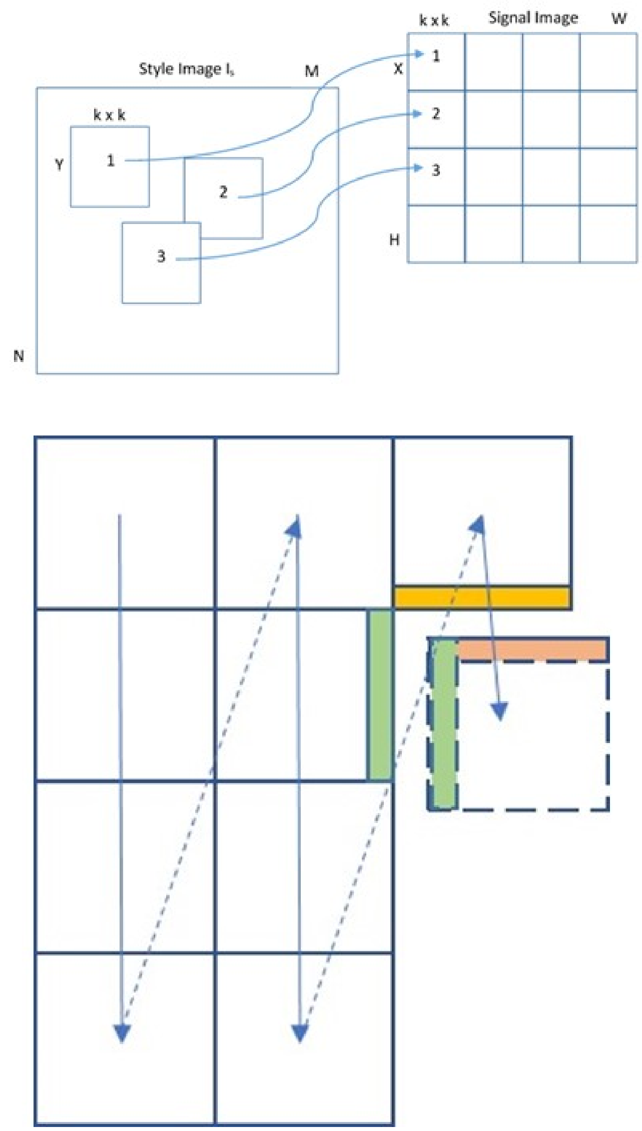

Figure 2 Correlation based style transfer algorithm. We correlate distinct subblocks of the signal image (top) with arbitrarily located subblocks in the style image. We place each subblock from the style image in the pattern shown at the bottom, with an additional edge continuity/smoothness constraint to reduce block edge artifacts.

In the subsequent iterations of the loop, we have a choice to transform each object (rotation, scale, etc.) to obtain a more diverse set of patterns. This may also help in improving the signal correlation. Figure 4 shows the pattern output by the process shown in Figure 3, with a small random rotation added to each object in the following iterations. Figure 5 shows an example of object placement where we place a single object, (the symbol ‘*’) but change the scale of the object in each iteration.

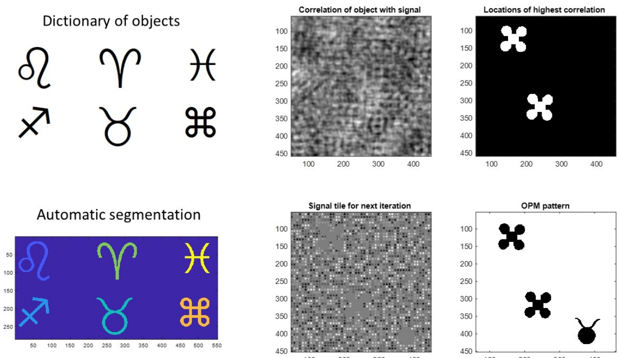

Figure 3 Steps in the object placement algorithm.

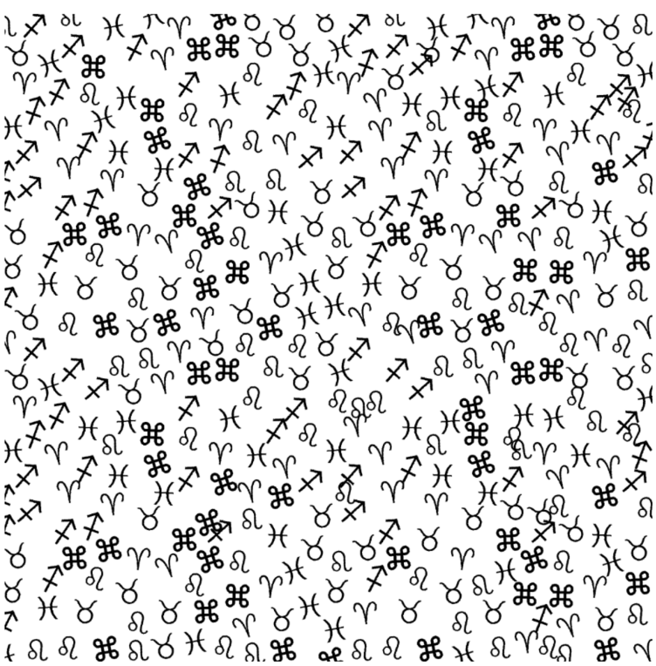

Figure 4 Signal carrying pattern output by the algorithm in Figure 3

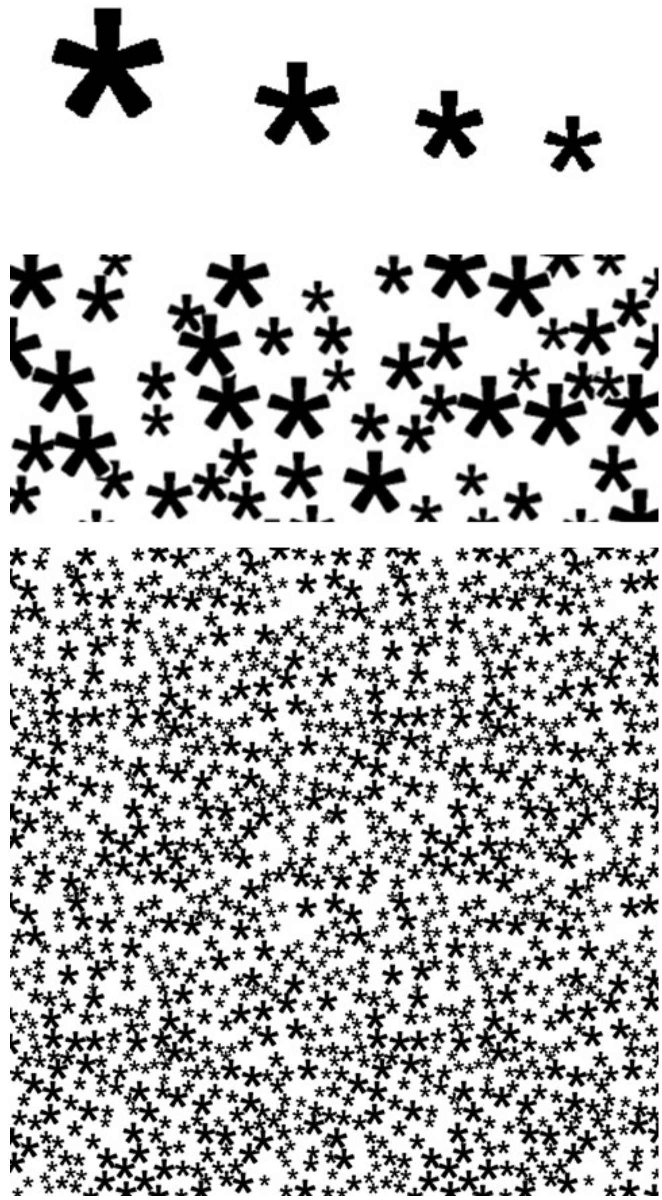

Figure 5 Object placement with a single object at multiple scales. The different scales of the '*' used as the object for placement is shown at the top, the middle shows the pattern detail and the signal carrying pattern is shown at the bottom.

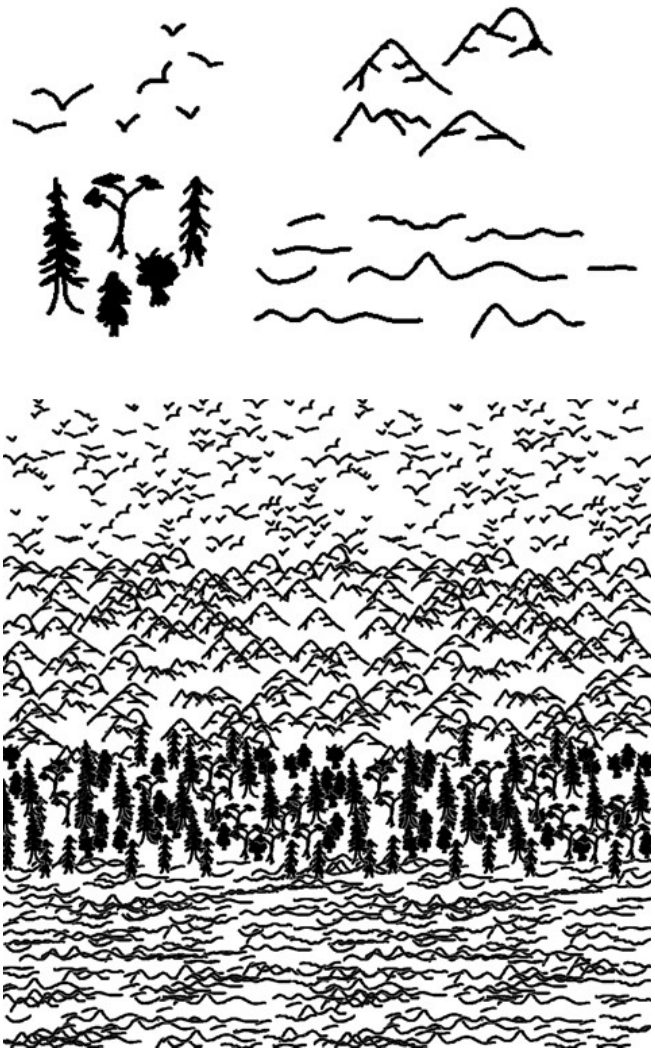

Figure 6 Example for the artistic possibilities with the OP algorithm. We divide the signal ‘canvas’ into four horizontal bands and place the objects from the four dictionaries shown at the top in each band respectively.

Figure 6 shows the artistic possibilities with the OP algorithm. We divide the signal ‘canvas’ into four horizontal bands and place the objects from the four dictionaries shown at the top in each band respectively. In general we may use regions with arbitrary boundaries and use a ‘pallete’ of signal carrying patterns to create artwork, much like the shaders used in CGI (computer generated imagery).

Object Position Modulation

We will next describe an alternative technique called Object Position Modulation (OPM) to embed patterned artwork specified in a vector file format. As the name suggests, in this case we are given a pattern with small shapes (we call these small shapes as objects) and we locally alter the positions of the objects - we call this modulation - to correlate with a signal carrying a particular ID.

In some applications, we may have less freedom in the placement of the objects in the pattern, i.e. the pattern may be more strongly constrained. For instance, a customer may want to embed a signal in a uniform pattern of circles as shown in Figure 8. We also assume that the pattern is available in a vector file format and that we can manipulate the objects individually.

If the pattern of objects is sufficiently dense (we will discuss what is sufficient below), and if we are permitted to perturb the positions of the objects slightly, we may still be able to embed an ID carrying signal in the pattern using the following approach.

To aid the discussion, we call each signal carrying pixel as a “waxel”, short for watermarking pixel. This terminology is necessary to fix the watermarking signal scale when we are talking about arbitrary image DPI resolutions. For instance, let us say our signal is embedded at a scale of 150 waxels per inch (WPI), which is the standard for the Digimarc Barcode signal used in consumer packaging applications. If we want to embed the signal in a pattern at a 600 DPI resolution, each waxel will now span 4 x 4 pixels, using the following math: 4 pixels per waxel = (600 DPI)/(150 WPI).

The signal we want to embed looks like a grayscale noise signal at the default 150 WPI resolution. However, at the target embedding resolution of say 600 DPI, we may use nearest neighbor upsampling and apply a “small” Gaussian filter (say 11 taps, with a standard deviation of 3) to smooth the waxel edge transitions. This has a minimal impact on the strength and readability of the signal, since it mostly filters out of band signal components. We may then compute a local gradient on this signal at the location of each waxel as shown in Figure 7.

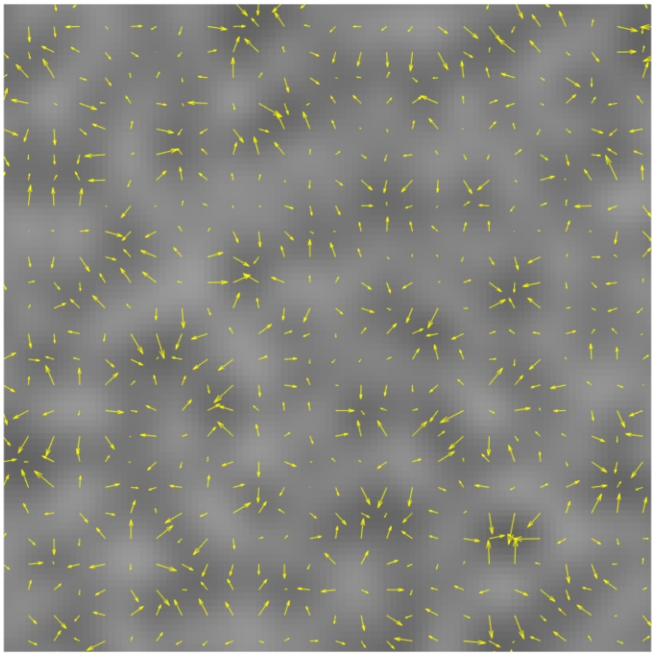

Figure 7 Zoomed in view of the local 2-D gradient quiver plot for a gaussian filtered watermark signal

Using the gradient computed at the 'center' of each object in a given pattern, we may 'push' each object in the direction of the minima (darker areas of the signal), thereby achieving the desired correlation with the signal. Hence, we call this embedding algorithm as object position modulation or OPM, for short. We may dial the amount we push each object, which allows us to control the signal embedding strength. However, the more we move each object, the larger the visual difference on the pattern.

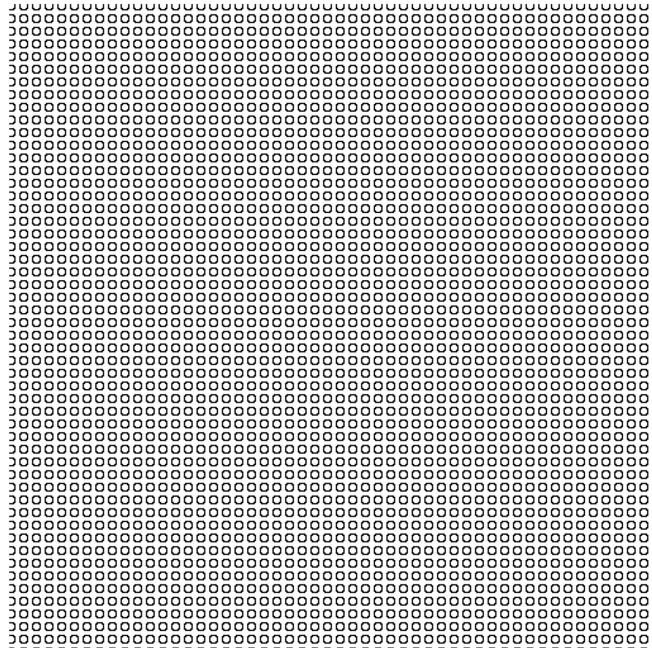

Figure 8 Uniform pattern of circles to embed

Figure 9 Signal carrying OPM pattern

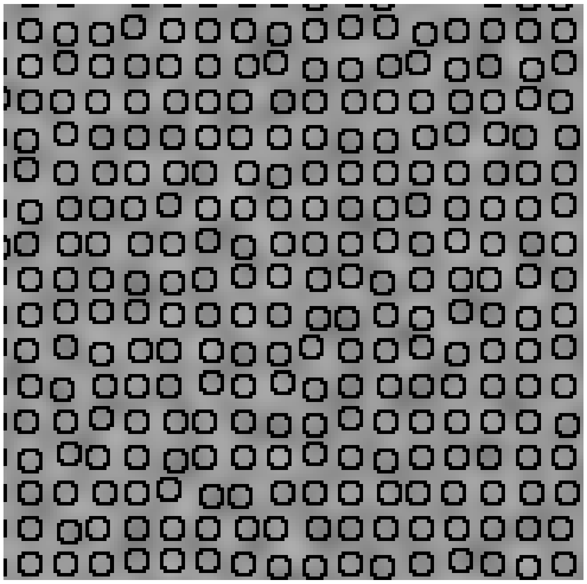

Figure 10 Signal carrying OPM pattern overlaid on the smoothed signal showing the clustering of the circles in the darker areas and gaps in the lighter signal areas

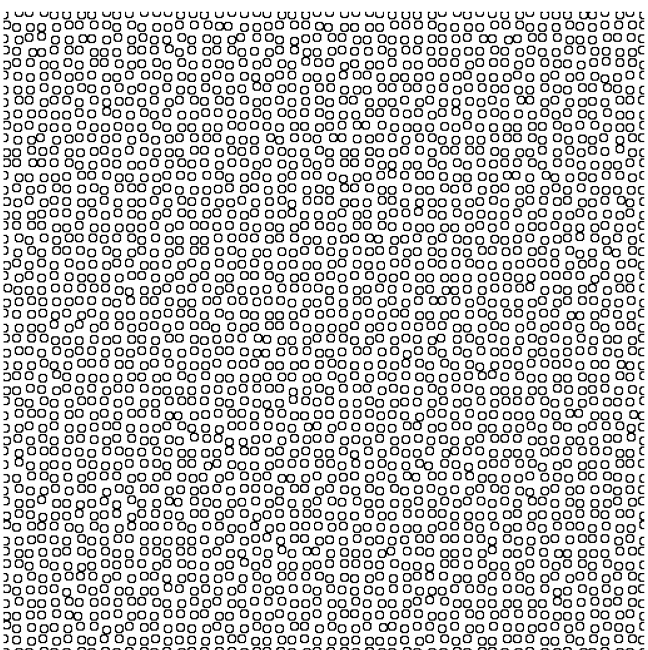

Figure 11 Signal carrying OPM pattern (moderate signal strength)

If the given pattern consists of a single object placed in a regular grid structure, the impact of the modulation will be obvious. However, if the given pattern consists of irregularly placed objects to start with, the modulation may be hard to perceive, thereby allowing us to embed a signal more strongly. Figure 12 shows an such an example. However, in this case, the pattern consists of overlapping objects, so this algorithm may only be applied if the input pattern is in a vector file format, so that we may modulate the positions of the individual objects.

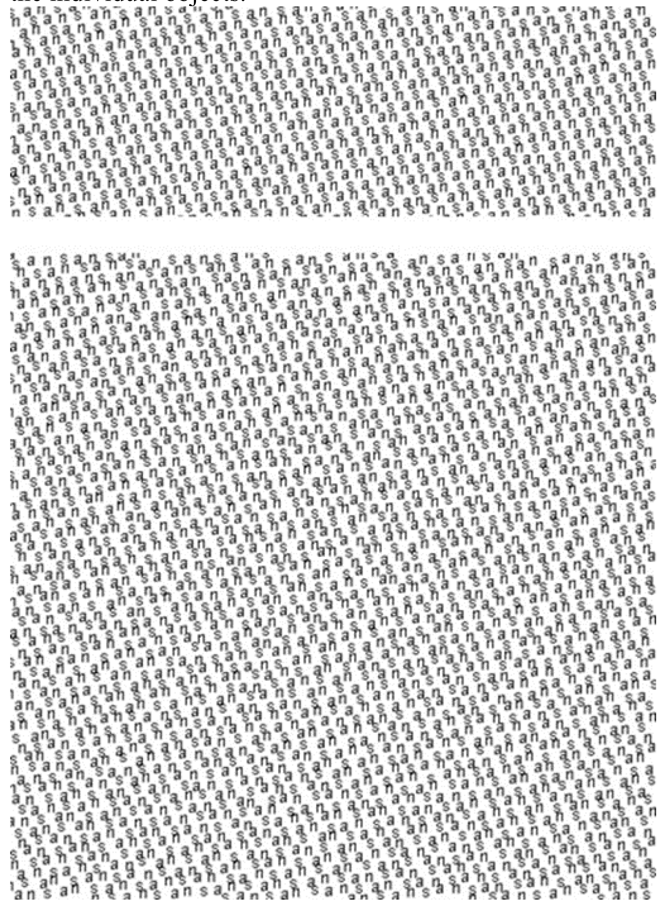

Figure 12 OPM pattern from a given pattern (crop shown above) consisting of the letters 'a, n, s'.

The OPM embedding method only works on patterns with a sufficient density of objects, as we mentioned earlier. At an embedding resolution of 150 WPI, we have $150^2 = 22500$ waxels per square inch. We have found that to achieve a reasonably good signal embedding strength, we need a pattern with an object density of at least 10% of that. For example, in the circle pattern, the density of the circles is about 14% of the waxel density. This density threshold limits the application of the OPM algorithm only to patterns carrying very small objects. In contrast, the object placement algorithm described in the previous section can embed the signal using objects an order of magnitude larger in size.

We may also use the following embedding approaches (not implemented in this paper) as an alternative to OPM when we are given a patten:

- Object scale modulation (OSM): we can modulate the size of each object to increase or decrease the local grayscale contrast when the image is downsampled. For example, given the circle pattern, we could increase the circle radius in areas where the signal is darker and decrease the radius where the signal is lighter. This is more suitable when the given pattern is in a vector file format.

- Warp modulation (WM): we could locally warp the image, i.e. stretch or shrink the image locally in a continuous manner as defined by the gradient map to increase the pattern correlation with the signal that we want to embed. This approach may be more suitable when the given pattern is in a raster file format.

Hybrid Halftone Patterns

In [4] we have described halftone SRA pattern generation using the Voronoi and Delaunay graphs. The Voronoi pattern is based on a sparse mark created from local signal maxima, whereas the Delauany pattern is created from local signal minima. Figure 13 shows that we can achieve a grayscale variation by either varying the sizes of the dots (AM) or the density of the dots (FM). This has analogues in the Delauany and Voronoi halftone patterns, corresponding to varying the line thickness or cell size, respectively. To create a signal carrying pattern however, we used a watermarked grayscale image as input, and thereby the output halftone pattern would also carry the signal.

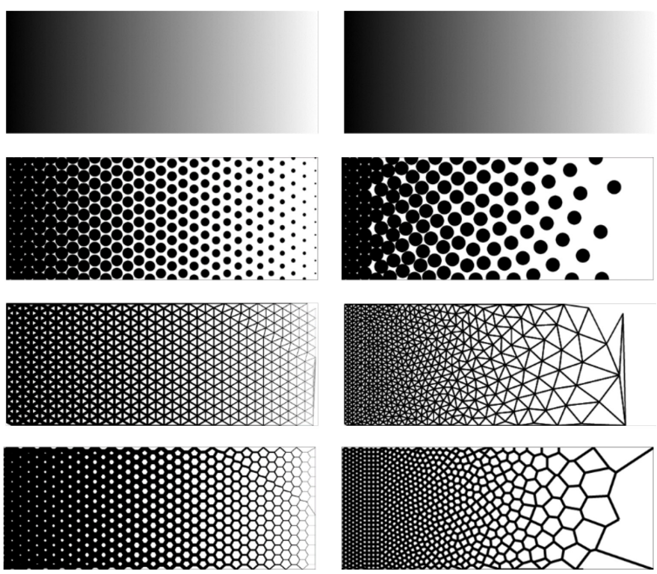

Figure 13 Grayscale ramp created using Delaunay and Voronoi cell based line patterns, in which the density of cells determines the grayscale level.

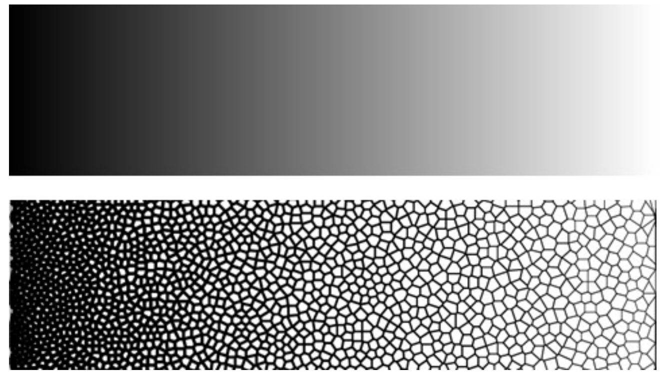

Figure 14 Hybrid Voronoi halftone pattern applied to a grayscale ramp.

However, for greater image fidelity, it helps to separate the signal embedding from the halftone image representation. At the darker grayscale levels, the Voronoi and Delaunay cells converge to a uniform plane tiling, which does not give us freedom to embed a signal. Figure 14 shows a hybrid Voronoi signal pattern in which we use a grayscale image to control the cell size and line thickness only, but the locations of the cell centers is determined purely by the signal maxima. Figure 15 shows an application of this hybrid Voronoi algorithm to create a signal carrying Lena image. The same approach may be used to create a Delaunay pattern by using the signal minima instead of the maxima. In an alternative hybrid approach, the signal may be used to modulate the line widths also, while the image only controls the cell size.

Figure 15 Hybrid Voronoi halftone pattern applied to a grayscale Lena test image to create a signal carrying halftone pattern

Conclusion

We introduced the concept of signal rich art in [3]. Here we have described a couple of new methods which we call object placement (OP) and object position modulation (OPM) of generating signal carrying patterns and improvements to previous Voronoi and Delaunay halftone signal carrying pattern techniques.

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Author Biography

Ajith Kamath received his BTech in Electrical Engineering from IIT Madras (2000) and PhD in Electrical Engineering from North Carolina State University(2005). He is currently working as an R&D Engineer at Digimarc Corporation since 2009. His work focuses on the development of embedding and detection algorithms, as well as novel applications of watermarking.

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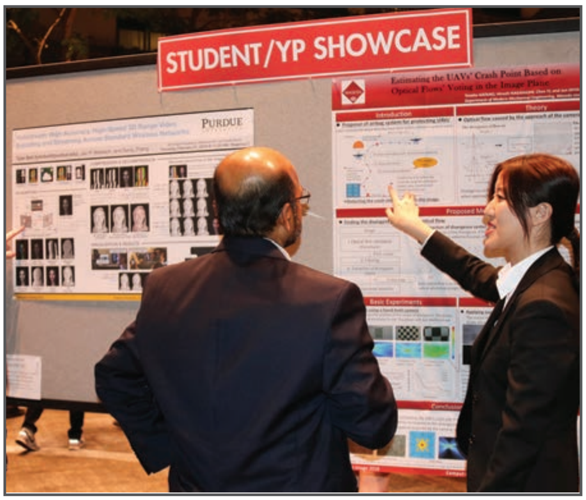

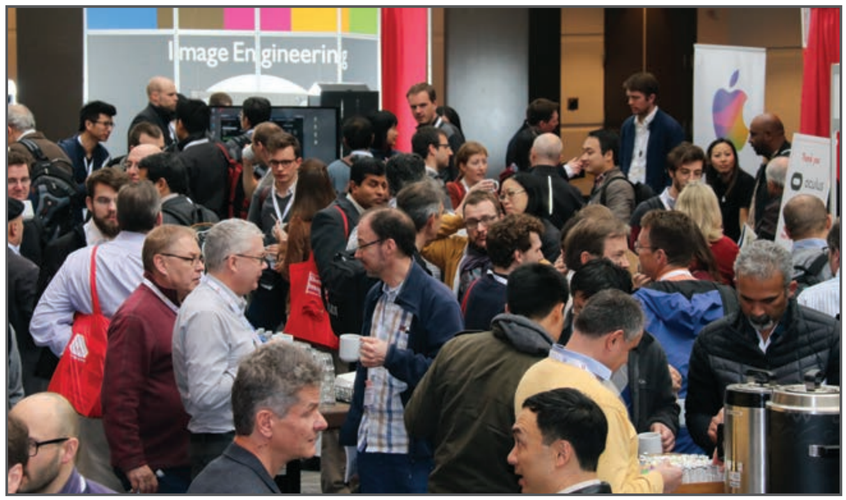

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