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UV Watermarking of Images in Clustered Dot Scenarios

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Abstract

Digital Watermarking of printed images is an important capability for many applications. Visually detecting the watermark through, e.g. UV illumination, enables the watermark use in uncontrolled environments. In our previous work, UV watermarking was proposed for in dispersed dot scenarios (assuming the use of standard colorants). This talk describes the generalization of that concept to clustered dot scenarios thereby allowing the creation on standard printing equipment, such as offset or xerographic printing.

Introduction

Image watermarking or digital watermarking is an active area of research. It is commonly understood that in digital watermarking the watermark should not be visible to the unaided human eye and that a specific action or operation has to be performed to read or decode the watermark information from the printed image. For classification and description, one can coarsely distinguish two distinct approaches. In the first approach, the decoding of the watermark is done by pure digital means, i.e.: through scanning, processing and decoding. In a second approach, the watermark is decoded directly by the human user through some simple physical tools, as overlays [1,2], magnification [3], or illumination [4].

This talk will focus on watermarks that are directly decoded by a human observer with the aid of a standard UV or "blacklight" and is a further development of previous work limited to inkjet systems [4]. In this talk we describe the extension of the algorithm introduced in [4] to a clustered dot scenario, making the method applicable to a wider range of potential output devices.

Metameric Rendering

The basic principle that allows the watermark encoding for different illuminants, UV in our case, is the metameric effect created by the use of 4 or more colorants. In these scenarios, the mapping of the human visual 3-component color to the printing n-component color is generally underdetermined and we can use this to embed the thus hidden watermark information.

For the case of four color printing (c,m,y,k) this simply means that there are generally multiple (c,m,y,k) quadruplets that will yield the same color experience or triplet (L,a,b) to the user. If the quadruplets differ in their response to the illuminant – in our case UV – an additional signal can be encoded. It should be noted here that the spatial arrangement of the actual printed dot plays a large role and is essential to the method described here.

Halftoning

During the conversion of the (L,a,b) triplet – or any other triplet as R,G,B – to the (c,m,y,k) quadruplet we still assume that the values are continuous. In real world scenarios, however, only a small number of discrete levels exist at any location, and only the grouping of multiple locations followed by some averaging will result in an approximate continuous value. Mapping the continuous data to the discrete colorant set over a fixed or variable area is called halftoning. For our application this is an important aspect. We use the visual averaging to create "identical" – in a metameric sense – colors, while the actual physical colorants and colorant distributions are different.

Differential UV Response

So far, we only talked about the behavior of the created image in the visual spectrum. The colorants were designed for the visual spectrum, the application of creating a color image assumes the visual spectrum, thus it is reasonable to ignore effects outside of this range. For the described UV watermarking, however, the response to UV illumination is essential in the creation. We need two metameric combinations that have a differential UV response.

In the case of standard 4-color printing, we commonly find that all colorants strongly absorb UV illumination – at least in an idealized view. Standard paper, on the other hand, contains fluorescent whitening agents (FWAs) or optical brightening agents (OBAs) to create a "better" white impression for the user. This is generally reflected in the brightness number associated with paper, with a higher brightness indicating a higher FWA level.

For the above reason, it is the amount of paper visible that is actually controlling the strength of the UV response of a print. It is understood that the UV illumination might have a visible pollution, or that the colorants have a partial UV transmission. However, for our scenario we will consider these effects noise and use a first order approximation where only the white paper area is used to define the watermark.

UV Encoding

Bala et al [5, 6] have shown a simple system where a fixed palette of pre-computed metameric pairs was used. This was later expanded by Kitanovski et al. [4] dynamically calculating the required colorant for every individual pixel of an image, thereby making the system much more flexible and usable. For this purpose, the Color DBS (CDBS) algorithm [7] was modified to include a term representing the desired watermark and the allowed visual deviation. This deviation is describing the difference between the original continuous image and the perceived halftone ready-for-printing image.

UV Watermarking for Clustered Dots

CDBS is inherently an algorithm that creates dispersed dot print data, since the minimum difference between original and actual rendering does not include any spatial constraints for the dots distribution. The method of Ref. [4] also inherits this property. Several printing technologies, e.g.: xerography and offset, suffer in dispersed dots scenarios and in those cases, it is preferred to impose a superstructure of a clustered dot (Holladay dot [8]).

In CDBS, the starting conditions for the iterations are a free parameter. One might postulate that a CDBS-like iteration will depend on the starting halftone and that a clustered starting point will lead to a clustered output look, albeit modified by DBS to minimize visual error. This is actually not correct, as can be seen in Figure 1. Here, the image on the left is the input, the image in the center is a rotated dot halftone used as the starting point for the DBS iteration and the image on the right is the resulting DBS image (all color pixels rendered as gray).

Figure 1. Using CDBS with a halftone starting distribution (center) results in a dispersed dot structure comparable to standard DBS.

The result of Figures 1 indicates that we have to take a different approach if we want to embed a UV watermark signal into our (c,m,y) output data.

The approach we have chosen is to add a step before the CDBS, which redefines the "ideal" input image. In this case, the minimization will try to re-create that new input with the available valid output states, in our case binary (c,m,y). The flowchart of the new layout is shown in Figure 2.

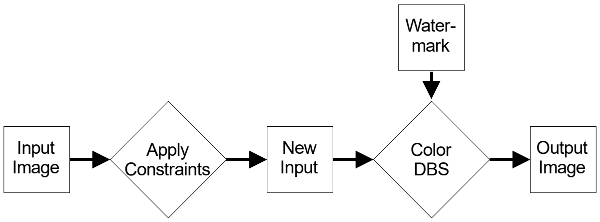

Figure 2. Introducing an intermediate step defining a new, modified input as the optimization image for DBS iterations.

By adding constraints before the actual CDBS iterations, we assure that the constraints are part of the "ideal" image that CDBS is trying to reproduce the constraints. This leads to some counterintuitive behavior. First, if we use as constraint that the input is halftoned the CDBS will almost exactly reproduce that halftoned image, since it has zero error to itself. There would be small differences between the input halftone and the output halftone image due to the DBS property that it converges (locally) once the (local) error becomes small enough (not necessarily zero) [9].

This situation changes in our watermark scenario. We had introduced an additional term into the error calculation that represents the desire to have the variable number of white pixels in the output. This also means that the actual minimum has changed and thus CDBS will – within strong limits given by the constraint input image – modify the pixel locations to add the watermark.

Conceptually, the CDBS algorithm will now give us the watermarked image that is – in the visual sense – closest to the original halftone.

Experimental Results

In order to show the feasibility, we ran two types of experiments. In the first set, we assumed an ideal printer and simulated both printing and UV illumination. For the printing simulation, we used a linear display as a placeholder, and for the UV illumination we set all pixels that had any colorant load to black, simply assuming that UV light is blocked by toner. It seems clear that we are overestimating the watermark strength in our simulation. Any transmission of UV by the toner - and the diffuse reflection from paper – is ignored and any overlap of common UV illuminators with the visible spectrum is also ignored. In this sense, the simulation can be considered the optimal case and the actual printed and decoded samples can be compared to this ideal case.

Simulated Results

We first halftone our input image using a standard rotated dot creating a (c,m,y) image. We did not use any optimized halftone structure for this step.

This image is used as "New Input" (see Figure 2) for the Color DBS iterations. This halftoned image was handed to the CDBS watermarking algorithm and the resultant halftone is shown in Figure 3. One can clearly see that the dot structure is maintained, and under first examination, no change seems to have been made to the original rotated halftone.

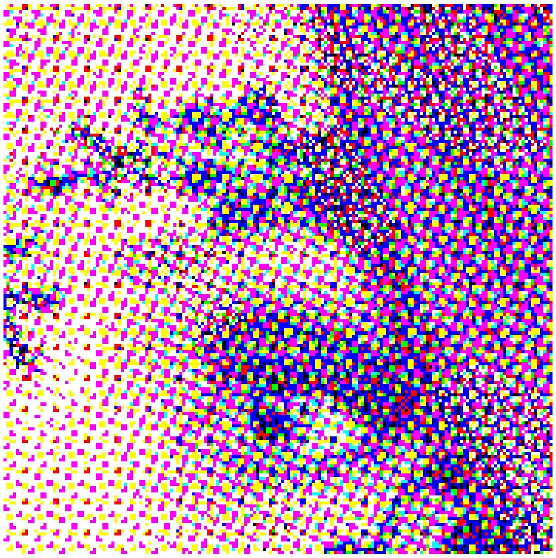

Figure 3. Using the method outlined in Figure 2 to "re-halftone" a halftoned image with the watermark constraints.

For this image, we know apply the UV illumination simulation namely turning all non-white pixels to black. At that moment, the watermark becomes visible as seen in Figure 4. This magnified view allows the identification of the watermark, while at the same time the original dot-structure is still visible. The complete image under simulated UV is shown in Figure 5.

Figure 5 shows one of the limitations of creating a UV watermark without using UV inks. In our case, we need to modulate the dot places in a metameric manner to change the number of white pixels, but the number of white pixels is itself a function of the input image. Assume - for simplicity - a part of an image that is solid black. In that part, no white pixels can be created. Or, assume an image area of solid magenta, here no metameric match can be found. In both cases, the UV signal strength drops to zero. In Figure 5, this can be seen by the varying watermark strength in the different image areas. The dark hair has low strength, since few white pixels exist, whereas the skin area has a sufficient number of white pixels as well as available metameric matches.

The drawback of image dependent watermark strength, however, is – in our view – compensated by the ability to create a UV watermark on a standard printer with standard materials.

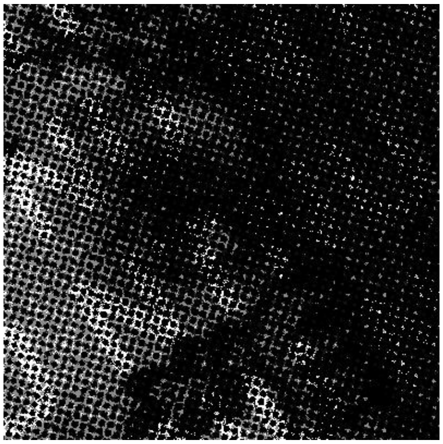

Figure 4. Simulated UV response of the data from Figure 3, by turning all non-white pixels to black.

Figure 5. Simulated UV for the entire image. Note the dependence of watermark strength on image content.

Printed Experiments

After the simulations, we also performed test on a standard office-type dry-ink printer (multi-function device). In this case, it is important to note, that in the initial printed experiments only RGB (or CMY) rotated dots were used and that the overall calibration was performed using the 2x2 method by Wang [10].

Figures 6 through 8 show examples of some results taken with a consumer point-and-shoot camera in a standard viewing booth under both UV (top) and D50 (bottom) illumination. It should be noted that in this preliminary test, no adaptation of the algorithm parameters to image content has been performed and thus not all images showed a UV watermark of sufficient strength. The images shown have at least some areas that show the watermark using our settings from previous work [4].

In Figure 6, the colored areas (of the original) show a good strength, whereas the more gray dark and bright areas do not. This is in agreement with the expectation, since dark and light areas should not have good signal strength.

Figure 7 shows the interplay of image detail with watermark detectability. Here, most of the image is of similar overall color, but the fine detail on the right interferes with detectability whereas the more constant area on the left shows good strength.

Figure 8 shows an example where most of the image is in the mid-tones and the object detail is coarse enough to not interfere with the additional watermark information.

Figure 6. Printed sample under UV (top) and D50 (bottom), photographed using a consumer point-and-shoot camera. Watermark visibility is best in the color midtones.

Summary

We have shown that it is possible to create a UV watermark inside a clustered-dot halftone. In order to achieve this, we redefined the function of DBS from a halftoning algorithm to a halftone-rearrangement algorithm. The results obtained show that it is possible to create secured image documents by embedding a UV watermark. No special inks are needed, as long as the image content allows a metameric rendering, which is the case for natural images, photos, portraits, etc.

In this initial work, we did not optimize the algorithm parameters as a function of the image content. For example, the UV watermark strength will in general be associated with artifacts/visibility under normal light. Since detailed regions mask these artifacts better than smooth regions, one can envision a variable watermark strength. In addition, the current halftones used were not adapted to the new application. Likely, running a DBS-like algorithm using a halftoned image as the "original" for optimization should have a strong dependency on that initial halftone.

The current set-up has shown adding UV watermarks into natural scene images without the addition of UV inks is possible and that this opens several new application scenarios.

Figure 7. Interplay of image detail and watermark detectability. As expected, fine detail obscures or even eliminates watermarks.

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Figure 8. Printed sample under UV (top) and D50 (bottom). The object detail is coarse enough to not interfere with the watermark.

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Author Biography

Vlado Kitanovski is a PhD candidate at the Colourlab, Department of Computer Science, NTNU. His research is focused on print-and-scan optimized data hiding.

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Jon Yngve Hardeberg is a Professor in Color Imaging at the Norwegian Colour and Visual Computing Laboratory, NTNU, Norway. He received his PhD from ENST in Paris, France in 1999. He has 20 years experience with industrial and academic color imaging research and development, and has co-authored over 150 research papers within the field. He is a member of IS&T, SPIE, and the Norwegian representative to CIE Division 8.